UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Tesis doctoral

Use Of Statistical Methods For The Analysis Of Educational Data: The Role Of ICTs In The Educational Context

Programa de Doctorado en Estadística y Optimización

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A Juan Fran; no podría haber encontrado mejor compañero de viaje y de vida.

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Abstract

In recent decades, the intensification of the use of information and communication technologies (ICT) has brought about major changes in our way of life. In this context of intense and increasing digitalization, this doctoral thesis studies the role of ICT as a determinant of the academic performance of secondary school students, as well as the factors that favour the use of ICT in the classroom by teachers. The thesis consists of three chapters: (1) in the first one, the relationship between different types of ICT use in the social and educational context and academic performance is analysed; (2) in chapter two, attention is focused on the impact on academic performance of the use of ICT in the classroom to carry out tasks and exercises; (3) and in chapter three, the factors that determine the frequency of ICT use in the classroom by teachers are analysed. In order to carry out these analyses, data from international and national educational assessments are studied by applying different statistical methods: multilevel models, instrumental variables method, propensity score matching method, quantile regressions and multivariate imputation technique by chained equations. The results achieved in the different investigations provide novel empirical evidence that allows us to elaborate recommendations for educational policy, as well as to open future lines of research that will allow us to complement the results of this doctoral thesis.

Resumen

En las últimas décadas, la intensificación del uso de las tecnologías de la información y la comunicación (TIC) ha supuesto grandes cambios en nuestra forma de vida. En este contexto de intensa y creciente digitalización, esta tesis doctoral estudia el papel que juegan las TIC como un factor determinante del rendimiento académico de los estudiantes de educación secundaria, así como los factores que propician el uso de las TIC en el aula por parte de los docentes. La tesis se compone de tres capítulos: (1) en el primero de ellos, se analiza la relación entre distintos tipos de uso de las TIC en el contexto social y educativo y el rendimiento académico; (2) en el capítulo dos, se centra la atención en el impacto que tiene sobre el rendimiento académico el uso de las TIC en el aula para realizar tareas y ejercicios; (3) y en el capítulo tres se analizan los factores que determinan la frecuencia de uso de las TIC en el aula por parte de los docentes. Para realizar estos análisis, se estudian datos procedentes de evaluaciones educativas internacionales y nacionales mediante la aplicación de distintos métodos estadísticos: modelos multinivel, método de variables instrumentales, método de emparejamiento por puntaje de propensión, regresiones cuantílicas y técnica de imputación multivariante por ecuaciones encadenadas. Los resultados alcanzados en las distintas investigaciones proporcionan evidencia empírica novedosa que permite elaborar recomendaciones en materia de política educativa, así como abrir futuras líneas de investigación que permitirán complementar los resultados de esta tesis doctoral.

Resum

En les últimes dècades, la intensificació de l'ús de les tecnologies de la informació i la comunicació (TIC) ha suposat grans canvis en la nostra forma de vida. En aquest context d'intensa i creixent digitalització, aquesta tesi doctoral estudia el paper que juguen les TIC com un factor determinant del rendiment acadèmic dels estudiants d'educació secundària, així com els factors que propicien l'ús de les TIC a l'aula per part dels docents. La tesi es compon de tres capítols: (1) en el primer d'ells, s'analitza la relació entre diferents tipus d'ús de les TIC en el context social i educatiu i el rendiment acadèmic; (2) en el capítol dos, se centra l'atenció en l'impacte que té sobre el rendiment acadèmic l'ús de les TIC a l'aula per a fer tasques i exercicis; (3) i en el capítol tres s'analitzen els factors que determinen la freqüència d'ús de les TIC a l'aula per part dels docents. Per a realitzar aquestes anàlisis, s'estudien dades procedents d'avaluacions educatives internacionals i nacionals mitjançant l'aplicació de diferents mètodes estadístics: models multinivell, mètode de variables instrumentals, mètode d'aparellament per puntuació de propensió, regressió quantílica i tècnica d'imputació multivariant per equacions encadenades. Els resultats aconseguits en les diferents investigacions proporcionen evidència empírica nova que permet elaborar recomanacions en matèria de política educativa, així com obrir futures línies d'investigació que permetran complementar els resultats d'aquesta tesi doctoral.

General Index

Index of Tables

CHAPTER 1

Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain

CHAPTER 2

Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain)

CHAPTER 3

Technology In The Classroom: Factors Influencing Teachers' Use Of ICT

Index of Figures

INTRODUCTION

Over the last decades, information and communication technologies (ICTs) have been a key factor in the major economic, social and technological changes experienced in society. Within this context, those born from the mid-1990s to the mid-2000s - the so-called Generation Z - have grown up in a period characterized by intense digitization and massive expansion of the internet and ICTs. While the predecessor generation - known as Generation Y or millennials - is associated with the beginning of digitalization, Generation Z has become the first generation to be born and grow up making frequent use of ICTs in their social, educational and work relationships. Undoubtedly, it is to be expected that growing up in such a technologically different context has had consequences on the cognitive, emotional and social development of the now young and adolescent members of this generation. Certainly, the Generation Alpha - the demographic cohort that succeeds Generation Z - is also characterized by frequent ICT use. Indeed, the great defining feature of the Generation Alpha is that they are considered to be the first digital natives. It is therefore evident that today's children, adolescents and young people have faced and are facing a reality in which ICTs are major players. Considering this intense and growing digitalization, this thesis uses statistical techniques to evaluate the role of ICT in the educational context.

In addition to this technological revolution of the last decades, which motivates the research topic of this thesis, the consequences of the health crisis caused by COVID-19 have recently been added. Focusing on the educational context, in line with the objective of this thesis, the closure of schools in March 2020 was a turning point in the use of ICT and opened an important debate on the role of technology in schools. The closure of schools forced teachers to use ICT to teach online and to familiarise themselves with the use of these tools. For most teachers, this situation resulted in a forced adaptation to a virtual environment and the use of ICT in the classroom. There is no doubt, therefore, that the COVID-19 crisis has led to substantial changes in education in terms of the use of ICT and that, as a result, it is to be expected that this has had important consequences for the way in which the relationship between education and ICT is understood.

In this context of technological revolution and intense use of ICT, this thesis has two general objectives related to the role of ICT in the educational context of Generation Z in Spain: (1) to analyse the relationship between ICT and the academic performance of secondary school students; and (2) to study which factors favor the use of ICT in the classroom - for educational purposes - by primary and secondary school teachers. Both objectives are achieved by obtaining empirical evidence through the application of various statistical techniques for the analysis of data from international and national educational evaluations.

The study of the effect of ICT use on academic performance is not new. As relevant literature reviews show (Cheung and Slavin, 2013; Fu, 2013), there are empirical studies that have evaluated this relationship since the popularization of ICT in the 1980s. In addition to this previous literature, there are also more recent studies that are detailed in the previous literature sections of the various chapters of this thesis (see for example Checchi et al., 2019; Muralidharan et al., 2019; Baert et al., 2020; Gorjón et al., 2021). However, a detailed analysis of the literature in this area - presented in the different chapters of this thesis - shows that there are still no clear scientific conclusions on the impact of ICT use on academic performance. In addition, in the specific case of Spain, the country that is the subject of the research in this doctoral thesis, there are few studies that have analysed this relationship and there is no consensus on the conclusions reached (Cabras and Tena, 2013; Choi and Calero, 2013; Cordero et al., 2015; Mediavilla and Escardíbul, 2015; Escardíbul and Mediavilla, 2016; Vilaplana, 2016; Gorjón et al., 2021). In other words, despite not being a new area of research, there is still an important scientific debate on the role of ICT in the educational context and its effects on academic performance.

This lack of scientific consensus and scarce empirical evidence for Spain is compounded by the dizzying pace at which new technologies are evolving. ICT are constantly changing and advancing technologically, which makes it necessary to continue researching and evaluating the relationship between ICT and academic performance in the current social context. These three reasons explain the fundamental motivation of this doctoral thesis which, through its three chapters, contributes new empirical evidence to the scientific debate.

The decision to focus the analysis on the Spanish case is based on the knowledge of the country's educational system and on the strong commitment to the use of ICT for educational purposes made by the Public Administrations in the last decade. For this last reason, it is relevant to know the impact that the use of these technologies has had so far on academic performance in the Spanish context, in order to be able to adequately guide public policies and measures aimed at promoting the use of ICT in the educational sphere. Nevertheless, the results presented in this thesis may be useful for other countries, in the absence of being corroborated with their own research. In this sense, it should be noted that ICT is a global phenomenon that is bursting into society and the educational system in all countries, so it is to be expected that the conclusions reached in this thesis can also be extrapolated to other geographical areas.

Specifically, this thesis contributes to the scientific literature with three chapters of empirical research that respond to the general research objectives previously stated:

- Chapter 1: Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain.
- Chapter 2: Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain).
- Chapter 3: Technology In The Classroom: Factors Influencing Teachers' Use Of ICT.

In Chapter 1, "Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain", I study the relationship between different ICT-related variables and the scores obtained by 15-year-old students (born in 1999) in schools located in Spain in the 2015 PISA (Programme for International Student Assessment) tests. Specifically, I analyse the relationship between academic performance (measured through the score achieved in the PISA tests measuring proficiency in science, mathematics and reading comprehension) and the following variables obtained from the PISA student and school questionnaire: (1) frequency of ICT use at home for homework; (2) frequency of ICT use at home for entertainment purposes; (3) frequency of ICT use at school; (4) ratio of students per computer at school; (5) degree of students' interest in ICT; (5) degree of importance of ICT in students' social interactions; and (6) age of starting to use ICT. To study the relationship between these variables and academic performance, I use multilevel regression models that consider the hierarchical structure of the PISA data. Additionally, considering that the PISA 2015 database for Spain presents high percentages of missing values in some of the control variables included in the multilevel regressions, I implement the multivariate imputation by chained equations (MICE) technique to impute missing values and increase the sample size. Finally, in order to complement the results derived from the multilevel regressions, I use the quantile regression methodology to study whether the results obtained differ according to the quantile of academic performance in which the student is placed.

In Chapter 2, "Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain)", I analyse the impact of the use of ICT in the classroom (for projects and exercises) on the scores obtained by students in the fourth year of secondary education in the Community of Madrid (mostly born in 2001) in the census tests of the Final Assessment of Secondary Education carried out at the end of the 2016-2017 academic year. I estimate this impact separately for the different competencies assessed in these tests (linguistic communication in Spanish and English, mathematical competence, and social and civic competence) using information from the context questionnaires completed by students, families, teachers and school principals. To estimate the impact, I use quasi-experimental methodologies that allow me to identify causal effects in the absence of an experimental design. Specifically, I estimate the main model of this research using the instrumental variables technique and, additionally, as a robustness test, I use the propensity score matching technique. Although the database I use in this chapter has a high percentage of missing values, I justify that implementing imputation techniques is unfeasible and show that, despite the loss of information, the sample finally used in the estimations is representative of the set of students, teachers and school principals who participate in the evaluations. In line with Chapter 1, I complement the results using quantile regressions - with instrumental variables - that allow me to identify whether the impact of ICT use in the classroom on academic performance differs according to the quantile of student performance.

In Chapter 3, "Technology In The Classroom: Factors Influencing Teachers' Use Of ICT", I study the factors that influence primary and secondary school teachers' decisions to use ICT resources in their classrooms. To do so, I use information from the context questionnaires of students, families, teachers and principals in the Community of Madrid who participated in the Primary and Secondary Education Final Assessment census tests carried out at the end of the 2018-2019 academic year. Specifically, I analyse the decision to use ICT in the classroom of teachers who teach at the three levels assessed in these tests: third year of primary education (students mostly born in 2010); sixth year of primary education (students mostly born in 2007); and fourth year of secondary education (students mostly born in 2003). To perform this analysis, I use multilevel logistic regressions that consider that the dependent variable (ICT use in the classroom) answered by the different teachers is predicted using information from the higher level (characteristics common to the whole school) and from the lower level (individual characteristics of the students). To facilitate the interpretation and comparison of the results, I express the coefficients obtained in the regressions using the odds ratio measure. Additionally, given that the database with which I work in this chapter presents a significant percentage of missing values in some of the variables included in the regressions, I implement the MICE technique to carry out the imputation of missing values and increase the sample size.

The results obtained in the different chapters confirm that ICT are related to academic performance and that certain factors are key to explaining teachers' decisions to implement ICT in the classroom. At the end of the presentation of the three chapters, there is a section of conclusions and reflections which details the main results obtained in the three chapters, reflects on their implications, draws up recommendations for policy makers, school principals and teachers, and points out future lines of research.

INTRODUCCIÓN

Durante las últimas décadas, las tecnologías de la información y el conocimiento (TICs) han sido un factor clave en los principales cambios económicos, sociales y tecnológicos experimentados en la sociedad. Dentro de este contexto, aquellos nacidos desde la mitad de la década de 1990 a mediados de la década de 2000 – la conocida como generación Z – han crecido en una etapa caracterizada por una intensa digitalización y una expansión masiva de internet y las TIC. Si bien la generación predecesora – la conocida como generación Y o milénica – es asociada con el inicio de la digitalización, la generación Z se ha convertido en la primera generación que ha nacido y crecido haciendo un uso frecuente de las TIC en sus relaciones sociales, educativas y laborales. Indudablemente, cabe esperar que haber vivido en un contexto tecnológicamente tan distinto haya tenido consecuencias en el desarrollo cognitivo, emocional y social de los ahora jóvenes y adolescentes pertenecientes a esta generación. Ciertamente, la generación alfa - la cohorte demográfica que sucede a la generación Z - también se caracteriza por un uso frecuente de las TIC. De hecho, el gran rasgo definitorio de la generación alfa es que son considerados como los primeros nativos digitales. Es evidente por tanto que los niños, adolescentes y jóvenes actuales se han enfrentado y se enfrentan a una realidad en la que las TIC son grandes protagonistas. Teniendo en cuenta esta intensa y creciente digitalización, esta tesis utiliza técnicas estadísticas para evaluar el papel de las TIC en el contexto educativo.

A esta revolución tecnológica de las últimas décadas que motiva la temática de investigación de esta tesis, se suman recientemente las consecuencias derivadas de la crisis sanitaria ocasionada por la COVID-19. Poniendo el foco en el contexto educativo, en línea con el objetivo de esta tesis, el cierre de las escuelas en marzo de 2020 supuso un punto de inflexión en el uso de las TIC y abrió un importante debate sobre el papel de la tecnología en las escuelas. El cierre de los centros educativos obligó a los docentes a utilizar las TIC para impartir la docencia de forma online y a familiarizarse con el uso de estas herramientas. Para la mayoría de los docentes, esta situación se tradujo en una adaptación forzada a un entorno virtual y al uso de las TIC en las aulas. Es indudable por tanto que la crisis de la COVID-19 ha conllevado cambios sustanciales en educación en cuanto al uso de las TIC se refiere y que, como resultado, cabe esperar que esto haya tenido consecuencias importantes en la forma de entender la relación entre la educación y las TIC.

En este contexto de revolución tecnológica e intensa utilización de las TIC, esta tesis se plantea dos objetivos generales relacionados con el papel de las TIC en el contexto educativo de la generación Z en España: (1) analizar la relación entre las TIC y el rendimiento académico de estudiantes de educación secundaria; y (2) estudiar qué factores propician el uso de las TIC en las aulas - con fines educativos - por parte de los docentes de educación primaria y educación secundaria. Ambos objetivos son alcanzados mediante la obtención de evidencia empírica a través de la aplicación de diversas técnicas estadísticas para el análisis de datos procedentes de evaluaciones educativas internacionales y nacionales.

El estudio del efecto del uso de las TIC sobre el rendimiento académico no es nuevo. Tal y como muestran relevantes revisiones bibliográficas (Cheung y Slavin, 2013; Fu, 2013), existen estudios empíricos que han evaluado esta relación desde la popularización de las TIC en la década de 1980. A esta literatura previa se suman también estudios más recientes que son detallados en las secciones de literatura previa de los distintos capítulos de esta tesis (ver por ejemplo Checchi et al., 2019; Muralidharan et al., 2019; Baert et al., 2020; Gorjón et al., 2021). No obstante, cuando se realiza un análisis pormenorizado de la literatura en esta área – presentado en los distintos capítulos de esta tesis – se observa que no existen todavía a día de hoy conclusiones científicas claras sobre el impacto del uso de las TIC en el rendimiento académico. A ello se suma que para el caso concreto de España, país objeto de las investigaciones de esta tesis doctoral, existen exiguos estudios que hayan analizado esta relación y tampoco se observa en ellos un consenso sobre las conclusiones alcanzadas (Cabras y Tena, 2013; Choi y Calero, 2013; Cordero et al., 2015; Mediavilla y Escardíbul, 2015; Escardíbul y Mediavilla, 2016; Vilaplana, 2016; Gorjón et al., 2021). Es decir, pese a no ser un área de investigación nueva, todavía existe un importante debate científico sobre el papel de las TIC en el contexto educativo y sus efectos sobre el rendimiento académico.

A esta falta de consenso científico y escasa evidencia empírica para España, se suma el vertiginoso ritmo al que evolucionan las nuevas tecnologías. Las TIC están en continuo cambio y avance tecnológico, lo que hace necesario continuar investigando y evaluando la relación entre TIC y rendimiento académico en el contexto social actual. Estos tres motivos explican la motivación fundamental de esta tesis doctoral que, a través de los tres capítulos que la componen, aporta nueva evidencia empírica al debate científico.

La decisión de centrar el análisis en el caso español se fundamenta en el conocimiento del sistema educativo del país y en la fuerte apuesta por el uso de las TIC con fines educativos realizada desde las Administraciones Públicas en la última década. Por este último motivo, resulta pertinente conocer el impacto que hasta el momento el uso de estas tecnologías ha tenido sobre el rendimiento académico en el contexto español, al objeto de poder guiar adecuadamente las políticas públicas y medidas orientadas a fomentar el uso de las TIC en el ámbito educativo. No obstante, los resultados presentados en esta tesis pueden ser útiles para otros países, a falta de ser corroborados con investigaciones propias. En este sentido, cabe destacar que las TIC son un fenómeno global que está irrumpiendo en la sociedad y sistema educativo en todos los países, por lo que cabe esperar que las conclusiones alcanzadas en esta tesis también sean extrapolables a otras áreas geográficas.

Concretamente, esta tesis contribuye a la literatura científica con tres capítulos de investigación empírica que dan respuesta a los objetivos generales de investigación previamente expuestos:

- Capítulo 1: Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain.
- Capítulo 2: Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain).
- Capítulo 3: Technology In The Classroom: Factors Influencing Teachers' Use Of ICT.

En el Capítulo 1, "Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain", se estudia la relación entre distintas variables relacionadas con las TIC y la puntuación obtenida por estudiantes de 15 años (nacidos en 1999) de centros educativos ubicados en España en las pruebas PISA (Programme for International Student Assessment) del año 2015. Concretamente, se analiza la relación que guardan con el rendimiento académico (medido a través de la puntuación alcanzada en los tests de PISA que miden la competencia en ciencias, matemáticas y comprensión lectora) las siguientes variables obtenidas del cuestionario de estudiantes y de centros educativos de PISA: (1) frecuencia de uso de las TIC en el hogar para realizar tareas escolares; (2) frecuencia de uso de las TIC en el hogar con fines de entretenimiento; (3) frecuencia de uso de las TIC en la escuela; (4) ratio de alumnos por ordenador en el centro educativo; (5) grado de interés de los estudiantes por las TIC; (5) grado de importancia de las TIC en las interacciones sociales de los estudiantes; y (6) edad de inicio en el uso de las TIC. Para estudiar la relación entre estas variables y el rendimiento académico, se utilizan modelos de regresión multinivel que tienen en cuenta la estructura jerárquica de los datos de PISA. Adicionalmente, considerando que la base de datos de PISA 2015 para España presenta porcentajes elevados de valores perdidos en algunas de las variables de control incluidas en las regresiones multinivel, se implementa la técnica de imputación multivariante por ecuaciones encadenadas (MICE) para imputar valores perdidos e incrementar el tamaño muestral. Finalmente, al objeto de complementar los resultados derivados de las regresiones multinivel, se utiliza la metodología de regresión cuantílica para estudiar si los resultados obtenidos difieren según el cuantil de rendimiento académico en el que se sitúa el estudiante.

En el Capítulo 2, "Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain)", se analiza el impacto que tiene el uso de las TIC en el aula (para realizar trabajos y ejercicios) en la puntuación obtenida por los estudiantes de cuarto curso de educación secundaria en la Comunidad de Madrid (nacidos mayoritariamente en el año 2001) en las pruebas censales de

Evaluación Final de Educación Secundaria realizadas a finales del curso 2016-2017. Este impacto se estima separadamente para las distintas competencias evaluadas en estas pruebas (comunicación lingüística en español y en inglés, competencia matemática, y competencia social y cívica) utilizando la información procedente de los cuestionarios de contexto cumplimentados por estudiantes, familias, profesores y directores de los centros educativos. Para la estimación del impacto, se emplean metodologías cuasiexperimentales que permiten identificar efectos causales en ausencia de un diseño experimental. Concretamente, el modelo principal de esta investigación se estima usando la técnica de variables instrumentales y, adicionalmente, como prueba de robustez, se utiliza la técnica de emparejamiento por puntajes de propensión. A pesar de que la base de datos que se emplea en este capítulo presenta un porcentaje elevado de valores perdidos, se justifica que implementar técnicas de imputación resulta inviable y se demuestra que, a pesar de la pérdida de información, la muestra finalmente usada en las estimaciones es representativa del conjunto de estudiantes, docentes y directores de centro que participan en las evaluaciones. En línea con el capítulo 1, se complementan los resultados utilizando regresiones cuantílicas – con variables instrumentales – que permiten identificar si el impacto del uso de las TIC en el aula sobre el rendimiento académico difiere según el cuartil de rendimiento del estudiante.

En el Capítulo 3, "Technology In The Classroom: Factors Influencing Teachers' Use Of ICT", se estudia cuáles son los factores que influyen en la decisión de los docentes de educación primaria y secundaria a la hora de utilizar recursos TIC en sus clases. Para ello, se utiliza información procedente de los cuestionarios de contexto de estudiantes, familias, profesores y directores de la Comunidad de Madrid que participaron en las pruebas censales de Evaluación Final de Educación Primaria y Secundaria realizadas a finales del curso 2018-2019. Concretamente ,se analiza la decisión de uso de las TIC en el aula de los docentes que imparten clases en los tres niveles evaluados en estas pruebas: tercer curso de educación primaria (estudiantes nacidos mayoritariamente en el año 2010); sexto curso de educación primaria (estudiantes nacidos mayoritariamente en el año 2007); y cuarto curso de educación secundaria (estudiantes nacidos mayoritariamente en el año 2003). Para realizar este análisis, se utilizan regresiones logísticas multinivel que tienen en cuenta que la variable dependiente (uso de las TIC en el aula) contestada por los distintos profesores se predice empleando información del nivel superior (características comunes a todo el centro educativo) y del nivel inferior (características individuales de los estudiantes). Para facilitar la interpretación y comparación de los resultados, expreso los coeficientes obtenidos en las regresiones utilizando la medida de razón de momios. Adicionalmente, dado que la base de datos con la que se trabaja en este capítulo presenta un porcentaje significativo de valores perdidos en algunas de las variables incluidas en las regresiones, se implementa la técnica MICE para llevar a cabo la imputación de valores perdidos e incrementar el tamaño muestral.

Los resultados obtenidos en los distintos capítulos confirman que las TIC guardan relación con el rendimiento académico y que determinados factores son claves para explicar la decisión de implementar las TIC en las aulas por parte de los docentes. Al concluir la presentación de los tres capítulos, se presenta una sección de conclusiones y reflexiones donde se detallan los principales resultados obtenidos en los tres capítulos, se reflexiona sobre sus implicaciones, se elaboran recomendaciones para responsables políticos, directores de centros educativos y docentes, y se señalan futuras líneas de investigación.

INTRODUCCIÓ

Durant les últimes dècades, les tecnologies de la informació i el coneixement (TICs) han sigut un factor clau en els principals canvis econòmics, socials i tecnològics experimentats en la societat. Dins d'aquest context, aquells nascuts des de la meitat de la dècada de 1990 a mitjan dècada de 2000 – la coneguda com a Generació Z – han crescut en una etapa caracteritzada per una intensa digitalització i una expansió massiva d'internet i les TIC. Si bé la generació predecessora – la coneguda com a Generació Y o milénica – és associada amb l'inici de la digitalització, la Generació Z s'ha convertit en la primera generació que ha nascut i crescut fent un ús freqüent de les TIC en les seues relacions socials, educatives i laborals. Indubtablement, cal esperar que haver viscut en un context tecnològicament tan diferent haja tingut conseqüències en el desenvolupament cognitiu, emocional i social dels ara joves i adolescents pertanyents a aquesta generació. Certament, la Generació alfa - la cohort demogràfica que succeeix a la Generació Z - també es caracteritza per un ús freqüent de les TIC. De fet, el gran tret definitori de la Generació alfa és que són considerats com els primers nadius digitals. És evident per tant que els xiquets, adolescents i joves actuals s'han enfrontat i s'enfronten a una realitat en la qual les TIC són grans protagonistes. Tenint en compte aquesta intensa i creixent digitalització, aquesta tesi utilitza tècniques estadístiques per a avaluar el paper de les TIC en el context educatiu.

A aquesta revolució tecnològica de les últimes dècades que motiva la temàtica d'investigació d'aquesta tesi, se sumen recentment les conseqüències derivades de la crisi sanitària ocasionada per la COVID-19. Posant el focus en el context educatiu, en línia amb l'objectiu d'aquesta tesi, el tancament de les escoles al març de 2020 va suposar un punt d'inflexió en l'ús de les TIC i va obrir un important debat sobre el paper de la tecnologia a les escoles. El tancament dels centres educatius va obligar els docents a utilitzar les TIC per a impartir la docència en línia i a familiaritzar-se amb l'ús d'aquestes eines. Per a la majoria dels docents, aquesta situació es va traduir en una adaptació forçada a un entorn virtual i a l'ús de les TIC a les aules. És indubtable per tant que la crisi de la COVID-19 ha comportat canvis substancials en educació quant a l'ús de les TIC es refereix i que, com a resultat, cal esperar que això haja tingut conseqüències importants en la manera d'entendre la relació entre l'educació i les TIC.

En aquest context de revolució tecnològica i intensa utilització de les TIC, aquesta tesi es planteja dos objectius generals relacionats amb el paper de les TIC en el context educatiu de la Generació Z a Espanya : (1) analitzar la relació entre les TIC i el rendiment acadèmic d'estudiants d'educació secundària; i (2) estudiar quins factors propicien l'ús de les TIC a les aules - amb finalitats educatius - per part dels docents d'educació primària i educació secundària. Tots dos objectius són aconseguits mitjançant l'obtenció d'evidència empírica a través de l'aplicació de diverses tècniques estadístiques per a l'anàlisi de dades procedents d'avaluacions educatives internacionals i nacionals.

L'estudi de l'efecte de l'ús de les TIC sobre el rendiment acadèmic no és nou. Tal com mostren rellevants revisions bibliogràfiques (Cheung i Slavin, 2013; Fu, 2013), existeixen estudis empírics que han avaluat aquesta relació des de la popularització de les TIC en la dècada de 1980. A aquesta literatura prèvia se sumen també estudis més recents que són detallats en les seccions de literatura prèvia dels diferents capítols d'aquesta tesi (veure per exemple Checchi et al., 2019; Muralidharan et al., 2019; Baert et al., 2020; Gorjón et al., 2021). No obstant això, quan es realitza una anàlisi detallada de la literatura en aquesta àrea – presentat en els diferents capítols d'aquesta tesi – s'observa que no existeixen encara hui dia conclusions científiques clares sobre l'impacte de l'ús de les TIC en el rendiment acadèmic. A això se suma que per al cas concret d'Espanya, país objecte de les investigacions d'aquesta tesi doctoral, existeixen minsos estudis que hagen analitzat aquesta relació i tampoc s'observa en ells un consens sobre les conclusions aconseguides (Cabras i Tena, 2013; Choi i Calero, 2013; Cordero et al., 2015; Mediavilla i Escardíbul, 2015; Escardíbul i Mediavilla, 2016; Vilaplana, 2016; Gorjón et al., 2021). És a dir, malgrat no ser una àrea d'investigació nova, encara existeix un important debat científic sobre el paper de les TIC en el context educatiu i els seus efectes sobre el rendiment acadèmic.

A aquesta falta de consens científic i escassa evidència empírica per a Espanya, se suma el vertiginós ritme al qual evolucionen les noves tecnologies. Les TIC estan en continu canvi i avanç tecnològic, la qual cosa fa necessari continuar investigant i avaluant la relació entre TIC i rendiment acadèmic en el context social actual. Aquests tres motius expliquen la motivació fonamental d'aquesta tesi doctoral que, a través dels tres capítols que la componen, aporta nova evidència empírica al debat científic.

La decisió de centrar l'anàlisi en el cas espanyol es fonamenta en el coneixement del sistema educatiu del país i en la forta aposta per l'ús de les TIC amb finalitats educatius realitzada des de les Administracions Públiques en l'última dècada. Per aquest últim motiu, resulta pertinent conèixer l'impacte que fins al moment l'ús d'aquestes tecnologies ha tingut sobre el rendiment acadèmic en el context espanyol, a fi de poder guiar adequadament les polítiques públiques i mesures orientades a fomentar l'ús de les TIC en l'àmbit educatiu. No obstant això, els resultats presentats en aquesta tesi poden ser útils per a altres països, mancant ser corroborats amb investigacions pròpies. En aquest sentit, cal destacar que les TIC són un fenomen global que està irrompent en la societat i sistema educatiu en tots els països, per la qual cosa cal esperar que les conclusions aconseguides en aquesta tesi també siguen extrapolables a altres àrees geogràfiques.

Concretament, aquesta tesi contribueix a la literatura científica amb tres capítols d'investigació empírica que donen resposta als objectius generals d'investigació prèviament exposats:

- Capítol 1: Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain.
- Capítol 2: Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain).
- Capítol 3: Technology In The Classroom: Factors Influencing Teachers' Use Of ICT.

En el Capítol 1, "Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain", s'estudia la relació entre diferents variables relacionades amb les TIC i la puntuació obtinguda per estudiants de 15 anys (nascuts en 1999) de centres educatius situats a Espanya en les proves PISA (Programme for International Student Assessment) de l'any 2015. Concretament, s'analitza la relació que guarden amb el rendiment acadèmic (mesurat a través de la puntuació aconseguida en els tests de PISA que mesuren la competència en ciències, matemàtiques i comprensió lectora) les següents variables obtingudes del qüestionari d'estudiants i de centres educatius de PISA: (1) freqüència d'ús de les TIC en la llar per a fer tasques escolars; (2) freqüència d'ús de les TIC en la llar amb finalitats d'entreteniment; (3) freqüència d'ús de les TIC a l'escola; (4) ràtio d'alumnes per ordinador en el centre educatiu; (5) grau d'interés dels estudiants per les TIC; (5) grau d'importància de les TIC en les interaccions socials dels estudiants; i (6) edat d'inici en l'ús de les TIC. Per a estudiar la relació entre aquestes variables i el rendiment acadèmic, s'utilitzen models de regressió multinivell que tenen en compte l'estructura jeràrquica de les dades de PISA. Addicionalment, considerant que la base de dades de PISA 2015 per a Espanya presenta percentatges elevats de valors perduts en algunes de les variables de control incloses en les regressions multinivell, s'implementa la tècnica d'imputació multivariant per equacions encadenades (MICE) per a imputar valors perduts i incrementar la grandària mostral. Finalment, a fi de complementar els resultats derivats de les regressions multinivell, s'utilitza la metodologia de regressió quantílica per a estudiar si els resultats obtinguts difereixen segons el quantil de rendiment acadèmic en el qual se situa l'estudiant.

En el Capítol 2, "Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain)", s'analitza l'impacte que té l'ús de les TIC a l'aula (per a fer treballs i exercicis) en la puntuació obtinguda pels estudiants de quart curs d'educació secundària en la Comunitat de Madrid (nascuts majoritàriament l'any 2001) en les proves censals d'Avaluació Final d'Educació Secundària realitzades a la fi del curs 2016-2017. Aquest impacte s'estima separadament per a les diferents competències avaluades en aquestes proves (comunicació lingüística en espanyol i en anglés, competència matemàtica, i competència social i cívica) utilitzant la informació procedent dels qüestionaris de context emplenats per estudiants, famílies, professors i directors dels centres educatius. Per a l'estimació de l'impacte, s'empren metodologies quasi experimentals que permeten identificar efectes causals en absència d'un disseny experimental. Concretament, el model principal d'aquesta investigació s'estima usant la tècnica de variables instrumentals i, addicionalment, com a prova de robustesa, s'utilitza la tècnica d'aparellament per puntuació de propensió. A pesar que la base de dades que s'empra en aquest capítol presenta un percentatge elevat de valors perduts, es justifica que implementar tècniques d'imputació resulta inviable i es demostra que, malgrat la pèrdua d'informació, la mostra finalment usada en les estimacions és representativa del conjunt d'estudiants, docents i directors que participen en les avaluacions. En línia amb el capítol 1, es complementen els resultats utilitzant regressions quantíliques – amb variables instrumentals – que permeten identificar si l'impacte de l'ús de les TIC a l'aula sobre el rendiment difereix segons el quartil de rendiment de l'estudiant.

En el Capítol 3, "Technology In The Classroom: Factors Influencing Teachers' Use Of ICT", s'estudia quins són els factors que influeixen en la decisió dels docents d'educació primària i secundària a l'hora d'utilitzar recursos TIC en les seues classes. Per a això, s'utilitza informació procedent dels qüestionaris de context d'estudiants, famílies, professors i directors de la Comunitat de Madrid que van participar en les proves censals d'Avaluació Final d'Educació Primària i Secundària realitzades a la fi del curs 2018-2019. Concretament, s'analitza la decisió d'ús de les TIC a l'aula dels docents que imparteixen classes en els tres nivells avaluats en aquestes proves: tercer curs d'educació primària (estudiants nascuts majoritàriament l'any 2010); sisé curs d'educació primària (estudiants nascuts majoritàriament l'any 2007); i quart curs d'educació secundària (estudiants nascuts majoritàriament l'any 2003). Per a realitzar aquesta anàlisi, s'utilitzen regressions logístiques multinivell que tenen en compte que la variable dependent (ús de les TIC a l'aula) contestada pels diferents professors es prediu emprant informació del nivell superior (característiques comunes a tot el centre educatiu) i del nivell inferior (característiques individuals dels estudiants). Per a facilitar la interpretació i comparació dels resultats, els coeficients obtinguts en les regressions s'expressen utilitzant la mesura de raó de momios . Addicionalment, atés que la base de dades amb la qual es treballa en aquest capítol presenta un percentatge significatiu de valors perduts en algunes de les variables incloses en les regressions, s'implementa la tècnica MICE per a dur a terme la imputació de valors perduts i incrementar la grandària mostral.

Els resultats obtinguts en els diferents capítols confirmen que les TIC guarden relació amb el rendiment acadèmic i que determinats factors són claus per a explicar la decisió d'implementar les TIC a les aules per part dels docents. En concloure la presentació dels tres capítols, es presenta una secció de conclusions i reflexions on es detallen els principals resultats obtinguts en els tres capítols, es reflexiona sobre les seues implicacions, s'elaboren recomanacions per a responsables polítics, directors de centres educatius i docents, i s'assenyalen futures línies d'investigació.

CHAPTER 1

Exploring The Relationship Between Information And Communication Technologies (ICT) And Academic Performance: A Multilevel Analysis For Spain*.

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1.1 Introduction

The intense digitalization that current society is experiencing calls for analysis of the role of Information and Communication Technologies (ICT) in the educational context in order to offer appropriate guidance in educational policy decision making.

The incorporation of ICT into the educational process offers numerous advantages that have been extolled in the literature (Fu, 2013). The use of ICT is associated with greater student motivation thanks to the use of more attractive, entertaining and fun tools (Bullock, 2001; Tüzün et al., 2009). Likewise, ICT allow a greater interactivity in learning, greater possibilities for cooperation and an improvement in communication between teachers and students (Schulz et al., 2002; Koç, 2005). The ICT also stimulates initiative and creativity (Allegra et al., 2001; Wheeler et al., 2002; Chai et al., 2010), enables individualization and flexibilization of education (Abell, 2006) and makes knowledge acquisition more accessible (Brush et al., 2008). Moreover, based on a constructive learning approach, ICT helps students focus on higher-level concepts rather than less meaningful tasks (Levin and Wadmany, 2006). All these advantages, among others, should lead to an improvement in academic performance and the acquisition of competences by the students.

However, the use of ICT by students is also frequently associated with problems. The possible distraction of students when consulting resources that do not contribute to learning (Lee et al., 2014) and addiction to ICT (Carbonell et al., 2012; Türel and Toraman, 2015) are examples of potential disadvantages. In addition, the excess of information on the internet can lead to significant losses of time and use of resources of poor reliability. All these disadvantages can have negative consequences on the personal and social development of students as well as on their academic performance and acquisition of skills.

The coexistence of potential advantages and disadvantages has led to an important debate about how ICT should be implemented to enable an improvement in the learning process. The previous literature has evaluated the effects of various ICT modalities on academic performance, but the results obtained are not conclusive, that is, there is no consensus about the incidence (positive, negative or neutral) of ICT in the acquisition of competences. Some of the more prominent studies to date are analysed in detail in the next section of this article.

The objective of this study is to explore the relationship between different types of ICT use at home and at school, as well as students' attitudes towards ICT (interest, importance in social interaction and the age at which they started using them), and the academic performance of Spanish students based on the results of the Program for International Student Assessment (PISA) in 2015. The approach of this analysis lies in the use of PISA 2015 microdata and the inclusion of new variables not explored in the previous literature (students' interest in ICT and importance of ICT as a topic in Social Interaction). The analysis of a number of variables related to the use of ICT of students and schools allows analysis and evaluation of the effectiveness of factors that potentially affect the quality of education. This will help to identify potential successful educational policies and interventions for Spain.

The analysis of the 2015 data is especially relevant as it coincides with a period characterized by the intensification of the use of ICT in homes and in Spanish schools. In 2013, the Digital School Culture Plan (Ministry of Education, Culture and Sports) was launched, and, at the same time, the different Autonomous Communities carried out their own programs.[1] The final goal of all these measures is to improve the connectivity between schools and the quality of educational ICTs. The Digital School Culture Plan in Spain can be considered the most important programme introduced in Spain to promote the use of ICTs among schools, teachers and students. It was launched in early 2013 and from this plan, many Autonomous Communities refined their plans focused on promoting the use of ICT in the educational field. Therefore, we considered it appropriate to focus on the PISA 2015 data, since in that year ICT was already established in Spanish classrooms thanks to the aforementioned programmes, whereas before that date we considered that ICT was not widely used either in schools or at home for educational purposes. In addition to the interest of analysing data from Spain in 2015 after the implementation of the previously mentioned measures, the analysis of Spain in particular is also relevant given that our research provides novelties that have not been explored in the previous literature for this country, such as the application of quantile regressions and the analysis of new ICT variables.

The results of this research show that the use of ICT at home is associated with better academic performance in science and reading, but only if the use is for leisure activities. On the contrary, the use of ICT at home for schoolwork seems to be negatively associated with academic performance in mathematics, science and reading. Regarding the use of ICT in schools, the results suggest that higher use of these tools is associated with lower levels of academic performance in mathematics, science and reading. However, results show that higher availability of computers per student is associated with higher levels of academic performance in mathematics and science.

[1]In addition to the Digital School Culture Plan (2013), the Common Framework for Digital Teaching Competence (2013) and other measures such as the Framework Agreement for School Connectivity (2015) were developed on the initiative of the Ministry of Education, Culture and Sport and with the agreement of the Autonomous Communities. In addition, several programs implemented in autonomous communities carried out important measures following the approval of this plan: the Averroes and Educastur portals in Andalusia and Asturias; the Medusa and Siega projects in the Canary Islands and Galicia; the Althia and Xtec programs in Castilla-La Mancha and Catalonia; and the Educamadrid plan in the Community of Madrid (Mediavilla, 2018).

In addition, we find that higher levels of student interest in ICT are associated with higher levels of performance in mathematics, science and reading. We also find that students' earlier initiation of ICT use is associated with better performance in these three competences. Conversely, the degree of importance students attach to ICT in their social interactions is negatively associated with reading performance. Finally, our quantile regressions by percentiles of performance show that ICT seem to be particularly associated with the academic performance of students in the lowest percentiles of performance.

The paper is structured as follows. Section 1.2 presents a review of previous studies that have investigated the relationship between ICT and academic performance. Then, section 1.3 describes the data and variables used in the analysis and the methodological approach. Section 1.4 presents the results of the empirical analysis and, lastly, section 1.5 concludes with the final considerations.

1.2 Literature Review

The report by Coleman et al. (1966) was the first analysis of the determinants of educational performance and initiated a line of research in the area of the Economics of Education focused on the study of personal, school and family factors that affect educational quality. The subsequent emergence of ICT in schools and homes led to the need to include this quality factor in the analysis of the determinants of academic performance, as evidenced in the literature review carried out by Cox et al. (2004), Condie and Munro (2006) and Claro (2010).

The empirical evidence on the effect of ICT on learning and academic performance is not conclusive. Articles that show a positive association between ICT and academic performance coexist alongside other research that clarifies the absence of significant associations or that affirms a negative association. One of the factors that may explain this lack of consensus is the use of very varied analysis methodologies and models. In addition, the inconsistency of results can be attributed to variations in the object of study (subjects, countries), which only allow extraction of limited information on the effect of ICT on academic performance. In addition, the ICTs themselves have been developed at a considerable rate, which also significantly alters the results between years.

Next, we present the main results achieved by some of the most relevant studies carried out so far. These investigations can be divided into two groups. On the one hand, there are studies focused on the analysis of the availability and use of ICT at school. Additionally, there are articles that study the effects of ICT availability and use at home by students. Finally, in this review we focus on specific studies for Spain.

Availability and use of ICT at school

The use of computer programs for educational purposes in schools has been widely evaluated in the literature. Barrow et al. (2009) evaluate the impact of the introduction of a computer program for the teaching of algebra in schools in the United States. Their results indicate that the students who used the computer program reached higher scores than those who were exposed to the traditional teaching method. These results are in line with those obtained by Banerjee et al. (2007) for India, who study the effects of a computer-assisted learning program for the reinforcement of mathematics instruction. The case of India is also analysed by Linden (2008), who finds that the effects on performance in mathematics are positive when the computer is a complement to traditional teaching methods. However, when the computer replaces traditional teaching, negative effects are observed. More recently, Muralidharan et al. (2019) study the impact of a computer-assisted after-school instruction program in urban areas of India. Specifically, they evaluate the effects of the random provision of a voucher to cover program expenses and observe an increase in the marks obtained in the evaluation tests of the mathematics and Hindi subjects, with the higher gain for students with lower starting scores.

Furthermore, there are studies that suggest the lack of a relevant impact of educational software on the academic performance of schoolchildren. Rouse and Krueger (2004) evaluate the impact of the "Fast for World" computer program, implemented in schools in the United States to improve reading and linguistic skills, and observe a limited improvement in the language skills of students, with no clear impact on academic performance.

Another group of authors has focused on the analysis of investment in ICT, especially in the availability of computers in schools. In this line, Machin et al. (2010) find in England a positive effect on academic performance because of the greater investment in ICT, especially in the subjects of English and Science. More recently, Tan and Hew (2017) analyse data for secondary school students in 22 developed economies participating in PISA 2012 and find that ICT resource shortages in school had a detrimental impact on student achievement.

However, numerous studies indicate the absence of significant effects of the installation of computers in schools on academic performance. In Israel, Angrist and Lavy (2002) conclude that the greater availability of computers does not have a positive effect on the scores of the standardized tests. This result is also in line with that obtained by Goolsbee and Guryan (2006) when analysing the effect of the "E-Rate" subsidy promulgated by the United States government to facilitate investment in ICT in schools. In Peru, Barrera-Osorio and Linden (2009) and Cristia et al. (2014) also evaluate the introduction of computers in schools and conclude that it had a zero impact on academic performance in mathematics and language. In this line, Checchi et al. (2019) evaluate the effect of ICT resources at school on student achievements conducted in Italy after 156 classes at 6th grade were endowed with additional resources earmarked for purchasing ICT equipment. The authors find that the intervention was far from being cost effective since the average improvement in test results are very small.

Some previous studies that have evaluated specific policies have also found negative effects of the investment in ICT on academic performance. This is the case in Leuven et al. (2007), who evaluate the implementation of a subsidy to finance computers and software for disadvantaged students in the Netherlands. Similarly, Belo et al. (2016) investigate whether the installation of broadband in schools in Portugal affects academic performance. The results suggest negative effects of significant magnitude in the grades obtained. The introduction of broadband allows new resources for learning, but it is also a distraction opportunity for students, showing that schools that restrict access to pages of distraction obtain better results than those that do not.

Several studies specifically analyse the implementation of the 1:1 computer model in schools using experimental designs. This model consists of delivering to the educational institutions individual electronic devices for each student. The implementation of the Plan Ceibal in Uruguay – which provides a portable computer to each child of school age and to each teacher at the public school - is noteworthy. De Melo et al. (2013) suggest that Plan Ceibal would not have had an impact on mathematics and reading. In the same line of research, Grimes and Warschauer (2008) evaluate the effect of the 1:1 computer model in three schools in California. The results show improvements in academic performance in the subjects of English and Mathematics from the second year of use of the device. Suhr et al. (2010) also evaluate the program in the United States and find that students who participate in the program obtain higher scores in the subject of English at the end of two years of their participation. Similarly, Lai et al. (2015) study the effects of the establishment of the model in certain schools for immigrants from Beijing and find evidence of improvements in academic performance in the subject of Mathematics. More recently, Mora et al. (2018) analyse the impact of a One Laptop per Child program introduced by the Catalan government in Spain. Their results indicate that the program had a negative impact on student performance in Catalan, Spanish, English, and Mathematics, being this effect stronger among boys than girls.

Based on the analysis of the PISA database, several authors find positive effects in the scores achieved in the tests due to the use of ICT in the learning process. Fuchs and Woessman (2005) analyse the data of all the countries participating in PISA 2000 and show positive effects of the use of a computer in the educational process. Similarly, Kubiatko and Vlckova (2010) evaluate PISA 2006 data for the Czech Republic and find that students who use ICT in the educational process obtain higher scores than students whose use of ICT is not linked to the educational process. Similarly, the recent study by Alderete and

Formichella (2016) analyses the effects of the "Connect Equality" Program implemented in Argentina that consists of the delivery of three and a half million laptops for students and teachers of public high schools. Using PISA data, the authors find that students who participate in the program show a higher academic performance as a result of the use of laptops. Güzeller and Ayça (2014) also find positive effects in Turkey but of very little significance, suggesting the existence of a lack of adequate integration of ICT in schools.

However, other studies do not find clear evidence that there is a relationship between ICT and academic performance in PISA in certain subjects. Aypay (2010) analyses the PISA 2006 data for Turkish students. The author suggests that there is no significant relationship between the use of computers and academic performance in mathematics, science and reading.

In the previous literature, there are also works related to the kind of use of ICT. Biagi and Loi (2013) determine that the extent of use of computers - as opposed to the intensity of use of an activity - has positive effects on the results of the PISA exams. Specifically, the authors determine that the use of computers for gaming activities increases scores, while the intensity of use for activities related to the study plan decreases performance. More recently, Falck et al. (2018) using international database Trends in International Mathematics and Science Study (TIMSS) for basic education conclude that using computers to look up information has a positive effect on students' results, while using computers to practise skills has negative effects. Authors suggest that these two effects compensate, resulting in overall null effects of classroom computers on student achievement.

Availability and use of ICT at home

There are studies that evaluate the effects of computer availability and use at home on academic performance. Fairlie and Robinson (2013) analyse the measures implemented in California schools for the free provision of computers at home. The results suggest the absence of effects of computer use at home in the educational process. In Peru, Beuermann et al. (2015) evaluate an experiment in the provision of portable computers for the home and do not find evidence of improvements in academic performance. However, Malamud and Pop-Eleches (2010) study the government bonds offered in Romania in 2008 for the purchase of a personal computer and find that the children of households that benefited from a computer improve their skills test computer scores but get lower results in Mathematics, English and Romanian tests. More recently, Fairlie (2016) investigates the effects by gender of the provision of free personal computers for the home for low-income students in US schools. The author concludes that boys are more likely than girls to use computers for games rather than for schoolwork. Based on this evidence, Fairlie (2016) analyses the effect of the free provision of computers on academic performance by gender. There is no evidence of negative effects of the use of the computer at home on academic performance for boys compared to girls.

Using PISA, a series of investigations have focused on analysing the effects of the use of the computer at home, several studies showing a positive correlation between the possession of a computer at home and the educational result in PISA (Schmitt and Wadsworth, 2006; Fairlie, et al., 2010; Notten and Kraaykamp, 2009). Similarly, Spiezia (2010) shows that the positive effect is greater when the computer is used at home than when it is used in school. However, Agasisti et al. (2020) carry out a more detailed analysis of the use of ICT at home and show that in most OECD countries there is an association between using computers intensely at home for homework and achieving lower test scores across all subjects.

Recently, a novel study by Baert et al. (2020) analyses the use of smartphones and finds that one-standard-deviation increase in daily smartphone use yields a decrease in average exam scores of about one point and suggest that policymakers should at least invest in information and awareness campaigns of teachers and parents to highlight this trade-off between smartphone use and academic performance.

The familiarization of students with the use of ICT also seems to be a key factor for the effects on educational performance. Kubiatko and Vlckova (2010) conclude that students more familiar with the use of ICT obtain better academic results in science, especially if the use is related to the educational process. The analysis of international tests also allows the study of the so-called "knowledge gap" (Donohue at al., 1975) between social strata in the educational area. Gui et al. (2014) analyse the case of Italy and find evidence that the use of the internet for completing homework does not have different impacts on learning according to their social background.

Spanish Case

In the case of Spain, the previous literature does not provide clear evidence of the impact of ICT on educational performance.

Choi and Calero (2013) find evidence that having a computer at home reduces the chances of obtaining results lower than level two of PISA. The authors also clarify that those students who most frequently use a computer at home are more likely to reach level two of PISA. With respect to the computer in the classroom, the proportion of computers with internet connection and the number of computers does not show statistically significant effects on academic performance. Contrary to these results, Cabras and Tena (2013) and Cordero et al. (2015) show a positive effect of having computers in schools for educational purposes. However, the authors emphasize the need to equip the centres with computers, but only with the accompaniment of a strategy that encourages use for teaching purposes. Cordero et al. (2015) also find a significant positive relationship between owning a home computer and performance for students with the lowest scores.

More recently, Mediavilla and Escardíbul (2015) conclude that a longer time of use of ICT to perform school tasks has negative effects on the academic performance of the subjects evaluated in PISA, while the greater use of computers as entertainment and the earlier use of ICT leads to improvements in the acquisition of skills. Escardíbul and Mediavilla (2016) also find a positive impact of attitudinal variables towards computers and the starting age for using ICT, but a negative impact of ICT´s excessive use.

On the other hand, Vilaplana (2016) analyses the specific impact of the Escuela 2.0 program implemented in Spanish schools with the aim of favouring the introduction of new technologies. The author finds a positive net effect of the provision of ICT, albeit minor, deferring the effects between repeating and non-repeating students. With regard to computer use at home on completion of homework, a positive effect on reading comprehension scores is observed. This last result contradicts that obtained by Mediavilla and Escardíbul (2015), calling for further research on the possible causes of this discrepancy. One of the explanations by the authors of the negative effect of the use of ICT on the performance of school tasks could be the reverse causality, that is, students with lower performance require more frequent use of ICT for the completion of tasks. Likewise, less familiarity with ICTs can lead to a greater dedication of time to learning to work with the tool, to the detriment of the time dedicated to learning itself. On the other hand, the positive impact obtained by Vilaplana (2016) can be explained by the disappearance of this last cause, thanks to the effects of familiarization and mastery of ICT that entails the introduction of a 1: 1 computer program such as Escuela 2.0.

1.3 Data and Methodological Approach

1.3.1 Data: PISA 2015

The Program for International Student Assessment (PISA) is a study carried out by the Organization for Economic Cooperation and Development (OECD) every three years. The objective is to evaluate educational systems by assessing the skills and knowledge of 15-year-old students, regardless of their academic year. The first application of the PISA study was carried out in the year 2000 and it was subsequently edited in 2003, 2006, 2009, 2012, 2015 and 2018. Throughout this research, we work with the data available from December 2016, corresponding to the study conducted in 2015.[2] The purpose of the report is to enable the comparison of data between countries and thus improve educational policies and student outcomes.

[2]We do not use the data from PISA 2018 because in this last round of PISA for Spain anomalies were detected in the responses of the students and the OECD decided not to publish the reading results. We considered these anomalies were large enough to not be able to ensure a reliable comparison in any of the competences.

More than half a million students participated in PISA 2015, with 72 countries represented. The selection technique of the sample consists of a two-stage sampling: (1) selection of educational centres with a minimum of 150 per country, and (2) election of approximately 35 students of 15 years in each centre. The total number of students evaluated in each country must exceed 4,500. In the case of Spain in PISA 2015, 980 schools and 32,330 students participated.

While as previously explained the students included in the final PISA sample were chosen randomly, the selection probabilities of the students vary. Thus, survey weights must be incorporated into the analysis to ensure that each sampled student properly represents the right number of students in the full PISA population. The final student weights (W_FSTUWT) and final school weights (W_SCHGRNRABWT) were extracted from PISA datasets and incorporated into the analysis to reduce sampling bias.

The test carried out by the students lasts two hours and includes standardized tests for all the countries that evaluate the areas of science, mathematics and reading comprehension. In addition to the test, students must complete a questionnaire of approximately one hour in which they are asked information about their background, study habits, perception of their learning environment and their commitment and motivation. Likewise, PISA also conducts a questionnaire for schools. In this survey, information is requested on aspects such as demographic characteristics or the evaluation of the quality of learning. The questionnaire for schools includes specific questions about ICTs that are used in this paper. Finally, there is a specific ICT Familiarity questionnaire in which the participating countries in PISA can voluntarily decide to participate. In this questionnaire, the students gives more details about the availability of ICT, what they use it for, how familiar they are with ICT and their general attitude towards the use of computers. This questionnaire provides very specific information. In the case of Spain, it was decided to participate in this questionnaire, so all surveyed students in the country were asked about questions related to their level of use and familiarity with ICT. In this paper we have merged the microdata bases for Spain of the student test, the questionnaire for schools and the specific questionnaire on ICT.

Working with the PISA database requires making a series of adjustments prior to the econometric analysis specified in the PISA manual (see OECD, 2009). The use of PISA microdata requires working with plausible values from the results of the evaluations. The plausible values refer to random values that are calculated based on the distributions of the scores obtained by the students. This happens because, in PISA, not all students respond to the complete test and it is necessary to estimate how they would have answered the total number of items. In fact, PISA 2015 includes ten plausible values instead of only five as in its previous versions. The OECD (2009) explains that the population statistics and the parameters of the regression models have to be estimated using the plausible values separately, while the value of the population statistic must be calculated as the average of the statistics obtained with each of these. All these considerations have been taken into account in our analysis.

Additionally, as evidenced, PISA has a complex survey design that violates the assumption of independence of observations since schools are selected as the primary sampling unit and students are 'clustered' within schools. This characteristic can lead to underestimated standard errors unless this clustering is considered. There are different methods for handling this complex survey design, such as Huber-White adjustments, multi-level models or replication methods using the 80 weights provided by OECD. In this research, we have chosen to carry out a multilevel analysis in order to accurately estimate standard errors.

1.3.2 Descriptive Analysis

Based on the PISA 2015 database, the variables that have been considered for the econometric analysis are detailed in this section. Specifically, a multilevel model has been developed at two levels (school and student) to investigate the relationship between the use of ICT by students and academic performance in the case of Spain. Three separate models have been developed for each of the dependent variables: the score in mathematics, the score in science and the score in reading comprehension.

These dependent variables are defined by the three competences that are evaluated in PISA-2015. Mathematical competence analyses the student's ability to identify and understand the role of mathematics in the world, to make informed judgments and to use and be involved in mathematics in a way that satisfies vital needs as a citizen. The competence in reading comprehension assesses the student's ability to understand, use and analyse critical texts in order to achieve their own goals, develop their possibilities and knowledge and participate in society. Finally, the competence in science reflects the degree of scientific knowledge of the student and how it is used for the identification of questions, acquisition of new knowledge, explanation of scientific phenomena and extraction of conclusions based on evidence of topics related to science. Table 1 shows the main descriptive statistics of the dependent and ICT explanatory variables of our analysis.[3]

[3]The correlation between all the variables used in our estimates has been tested so as not to incur problems of inclusion of correlated variables. It has been confirmed that there are no correlation coefficients greater than 0.3 between the variables included. Results available upon request.

Table 1: Descriptive statistics of the ICT variables and dependent variables

Variable	*N*	*% Missing Values*	*Mean*	*Std. Dev.*	*Min*	*Max*
ICT use outside of school for schoolwork	30,724	4.97	-0.090	0.870	-2.691	3.604
ICT use outside of school for leisure	31,259	3.31	-0.086	0.834	-3.710	4.848
Use of ICT at school in general	30,888	4.46	-0.043	0.868	-1.668	3.629
Students' ICT interest	30,688	5.08	0.173	0.981	-2.995	2.720
Students' ICT as a topic in Social interaction	30,177	6.67	0.103	0.943	-2.136	2.428
Starting age for using ICT	31,699	1.95	1.896	0.852	1.000	5.000
Computer / Students ratio	29,181	9.74	0.798	0.726	0.000	8.654
Mean Mathematics	32,330	0.00	492.979	76.128	221.876	736.249
Mean Reading	32,330	0.00	501.576	80.336	204.008	755.130
Mean Science	32,330	0.00	499.347	83.086	198.269	745.844

Source: compiled by the authors based on microdata from PISA 2015

In relation to the use of ICT, we have selected the following six variables from the ICT questionnaire: ICT use outside of school for schoolwork, ICT use outside of school for leisure, use of ICT at school, students' ICT Interest, the degree to which ICT is a part of their daily social life and starting age for using ICT. ICT in the school has also been measured with the index of availability of computers obtained from the school questionnaire, which represents the ratio of computers available to 15-year-olds for educational purposes to the total number of students in the modal grade for 15-year olds. Table A.1 of the appendix presents the exact definition of each of the ICT variables and indexes.

Regarding the interpretation of the variables' values, the ICT variables at student level that we have chosen – except for the starting age for using ICT - were scaled using the Item Response Theory (IRT) model. Weighted likelihood Estimates (WLE) for the latent dimensions were transformed to scales with a mean of zero and a standard deviation of one across OECD countries. Therefore, the scores of these indices must be interpreted by comparing them to the OECD mean. Negative values on the index indicate that students responded less positively than the average student did across OECD countries. Likewise, students with positive scores are those who responded more positively than the average student in OECD countries.

The variables regarding students' ICT Interest and students' ICT as a topic in Social Interaction have been introduced for the first time in PISA 2015, so its analysis becomes novel and especially relevant. The variables "Index of perceived competence in ICT" and "Index of autonomy in ICT" are also new in PISA 2015. Nevertheless, we have decided not to include these two variables in our analysis since we consider that they present a bias of subjectivity. Students may overestimate or underestimate their competence or autonomy in the use of ICT and therefore, if these variables were used, it may lead us to extract wrong conclusions.

As control variables at student level, we consider the gender, the index of immigration status, the age of arrival of immigrant students in the country, the repetition of grade at ISCED 1 and ISCED 2, school truancy and the start age of ISCED 0. At family level, we consider the language at home, the highest occupational status of parents (HISEI), the *index* of highest educational level of parents (HISCED) and the total number of books in the home. These three last variables (HISEI, HISCED and number of books at home) have been included to approximate the socioeconomic level of the students, given that in the data for Spain by Autonomous Community in PISA 2015 we do not have information on the social, cultural and economic status index (ESCS) directly provided by PISA. Regarding the Index of highest occupational status of parents (HISEI), note that this indicator can take values from 11 to 89 and higher HISEI indicates higher levels of occupational status.

According to the information provided by the school directors, we have used control variables related to the characteristics of schools. The school factors included in the analysis as control variables are: school ownership (private independent, private government-dependent or public), location (number of inhabitants), index of school autonomy, number of students per classroom, school size (total enrolment at school), number of students per teacher (total number of enrolled students divided by total number of teachers) and the index proportion of all teachers fully certified (fully certified teachers divided by the total number of teachers). Regarding the index of school autonomy, this reflects the responsibility of the school for allocating resources to schools (appointing and dismissing teachers; determining teachers' starting salaries and salary increases; formulating school budgets and allocating them within the school; establishing student-assessment policies; choosing textbooks; and determining which courses are offered and the content of those courses). The index of autonomy takes value from zero to one and higher scores indicate a higher degree of autonomy.

In addition to the school questionnaire, PISA 2015 also includes a teachers' questionnaire. However, we should point out as a limitation of this research that the database we use for Spain subdivided into Autonomous Communities does not contain information about the teachers' training in ICT. Therefore, in this research we are not able to include in our analysis the relation between teachers' ICT training, use of ICT in schools and the academic performance of students. Nevertheless, as suggested by Lei and Zhao (2007) and Comi et al. (2017), the effect of the use of ICT in the class on academic performance may depend on its proper integration into the teaching process, which in turn depends mainly on the level of training of teachers in the use of ICTs in education. In this sense, these authors indicate that what is really important is how ICTs are used in the class and emphasise the need to have teachers who are properly trained in the use of these tools. As we are not able to distinguish by levels of ICT training of the teachers who implement ICT in their classes, we cannot discern whether the level of ICT training might actually affect the ability to properly integrate ICT into the teaching process and therefore the association we find between ICT use in schools and academic performance or whether on the contrary the association remains the same regardless of the teacher's level of ICT training.

We have also used as control variables seventeen dummies created from the string variable SUBNATIO and that represent the different Autonomous Communities of Spain. The reference category is “Comunidad Valenciana”. Including these variables enables potential regional variations to be considered and included in our regressions. Table A.2 of the appendix specifies the definition of the categorical control variables and table A.3 presents the most relevant descriptive statistics of all the control variables.

1.3.3 Missing- data Imputation

Regarding the missing values, table A.3 of the appendix shows that there are six control variables with a percentage of missing values higher than 5% and whose imputation enables the sample of the final estimates to be increased. The initial sample for the three models estimated in this research - prior to the imputation - is of 20,438 students, this being the total of observations of 32,330 students from the original PISA database for Spain and thus indicating that we lose around a 36% of the sample. That is, 36% of PISA participants have no data (non-response) for at least one of the variables included in our research described in section 3.2.

The large drop in the number of observations could lead to problems related to the selection of the sample through non-response. To test this potential sample non-response bias, we compare characteristics of students who answered all the questions included in our models (after the imputation process is carried out) and students who did not answer at least one of these questions. Using a difference in means test [4], we find that there are variables with differences in means that are statistically different from zero. However, if we look at the absolute value of these differences and consider the scale of the different variables, we conclude that no relevant differences are observed and that the characteristics of the student who answers all the questions are similar to that of the student who does not answer at least one of them. This result is relevant, since it suggests that despite the loss of observations as a consequence of the non-response of a high percentage of students, the sample used in our main models continues to be representative of the set of students participating in PISA 2015 in Spain.

Missing data are a common problem in databases in education and there are various methods of handling it. Simple and commonly used methods include complete or available case analysis, that is, only including participants for which we have no missing data on the variables of interest. However, this method could have possible consequences,

[4] Results available upon request.

such as (1) the loss of information and possible loss of relative efficiency in the estimation (increase in variance and standard deviations) and an increase in the probability of reaching a poor specification of the model; and (2) the decrease in the degree of representativeness of the sample. Previous literature has shown that complete-case analysis to address missing data can lead to inefficient analyses and generate biased estimates (Nissen et al., 2019). Contrary, more sophisticated imputation techniques to handle missing data, such as multiple imputation, have proven to give much better results (Lall, 2016; Pampaka et al., 2016; Nissen et al., 2019). To ensure that we are not incurring any of these potential problems and taking into account that in our case we are facing a partial lack of information (respondents do not answer some of the questions, but they do answer the rest), we consider it appropriate to employ multiple imputation methodologies. With these techniques, missing data for a student are imputed by a value that is predicted using the rest of the questions answered by the student.

In order to impute the missing values, we first explore the pattern of the missing values. It should be noted that in our database there are no observations with missing values in the dependent variables (student scores), and we have not imputed values for the ICT variables directly of interest in our research. The analysis of the pattern confirms the suitability of the imputation of the six control variables with values of missing values higher than 5%: (1) age at start of ISCED 0 (7%); (2) highest occupational status of parents (HISEI) (5.64%); (3) school ownership (5.91%); (4) school size (8.80%); (5) student-teacher ratio (9.89%); and (6) index proportion of all teachers fully certified (15.21%).

Once the imputation of these six variables has been decided, the dichotomous correlation test is carried out between the variables to be imputed - with zero value for the missing values and value one for the valid values - and the rest of the original variables, as recommended by Carpenter et al. (2007). The results confirm the randomness (MAR - Missing at Random -, Rubin, 1976). Based on this, it is appropriate to proceed with the imputation.

In line with the previous literature, the imputation is carried out using an iterative imputation method that imputes multiple variables by using chained equations (van Buuren et al., 1999).[5] The imputation through this technique involves a sequence of univariate imputation methods with fully conditional specifications of prediction equations (Royston and White, 2011). Specifically, in our case, we follow the recommendations of Rubin (1996) and Acock (2005) and we use all the variables available in the models. After considering the characteristics of each variable, we estimate the missing values from three different empirical approaches: ordered logistic regression for ordinal variables, multinomial logistic regression for nominal variables and linear regression for continuous variables. For each missing value, 16 imputed observations have

[5] The correlation between all the variables used in our estimates has been tested so as not to incur problems of inclusion of correlated variables. It has been confirmed that there are no correlation coefficients greater than 0.3 between the variables included. Results available upon request.

been generated (m = 16), considering that the variable "index proportion of all teachers fully certified" presents a maximum percentage of missing values of 15.21%.

After the variables are imputed, a post-estimation analysis is carried out. The differences in means between the original and the imputed variables are tested, finding a non-significant difference in all cases. A graphical analysis is also carried out to analyse the differences in the kernel density distribution function of the imputed variables and the original ones.[6] It is shown that the distribution of the imputed variables replicates that of the original ones. Therefore, it can be concluded that the imputation does not affect the distribution of the variables.

The result of the imputation of the missing values is a gain of 3,983 observations on average, which implies an increase of the sample of around a 20%. That is, thanks to the imputation of the missing values, the total number of observations in the estimates has increased from 20,438 to a mean of 24,421 observations. The final multilevel models presented in this research have been estimated with the imputed values. However, the conclusions achieved regarding the association between ICT and academic performance do not differ from those obtained if the imputation process is not carried out.[7]

1.3.4 Methodological Approach

Multilevel regression model

As explained in the data section, in the PISA test, the population is selected in stages. First, the participating schools are chosen and subsequently students are selected within each school. There is therefore a hierarchical multilevel structure (i.e., the participating students were nested in schools) that implies dependence on observations within each set (Hox, 1995). Due to this structure, traditional statistical approaches are not appropriate and it is convenient to examine PISA data using multilevel regression models (Thorpe, 2006, Calero et al., 2009, Formichella, 2011, Song and Kang, 2012, Mediavilla and Escardíbul, 2015).

The use of linear hierarchical regression models has made it possible to overcome the limitations of methodologies traditionally applied in research on academic performance. Since the principle of independence is not met in PISA - the observations of students from the same school have similar characteristics - it is not appropriate to make Ordinary Least Squares (OLS) estimates. Employing OLS means forgetting the context of the students, producing what is called in the literature an atomistic fallacy (Alker, 1969). The atomization makes reference to the fact that the variance-covariance matrix of the results does not consider the homogeneity within each group (schools). OECD (2009) states that using a multilevel analysis implies incorporating the consideration of the dependence of the observations inside each group, since the fact that the observations of the students are grouped into larger units - the schools- is taken into account.

[6] See figure A.1 in the Appendix.
[7] These results are available in table A.4 in the Appendix.

The multilevel models in this research consider the clustering of students (level 1) within schools (level 2) and thus variations in student academic achievement are partitioned between and within schools. Specifically, three different models are developed, one for each dependent variable: mathematics score, reading comprehension score and science score.

Once the previous considerations are applied, the multilevel analysis model presented in equations (1) to (3) is estimated following Snijders (2011):

Level 1 equation

$$\mathrm{Y_{ij}} = \beta_{0j} + \sum_{k=1}^{K} \beta_{kj}\mathrm{X_{kij}} + \mathrm{r_{ij}} \qquad r_{ij} \sim N(0, \sigma^2) \qquad (1)$$

Level 2 equation

$$\beta_{kj} = \gamma_{k0} + \sum_{q=1}^{Q} \gamma_{kq}\mathrm{W_{qj}} + \mathrm{u_{kj}} \qquad \mathrm{u_{kj}} \sim N(0, \tau_1) \qquad (2)$$

Where $\mathrm{Y_{ij}}$refers to the score obtained by student "i" at school "j"; X is a set of "k" characteristics of student "i" in school "j" (variables of level 1); β_{0j} and β_{kj} are level 1 estimated coefficients and $\mathrm{r_{ij}}$ are the level 1 random effects. Each of the level 1 coefficients turns into a dependent variable in the level 2 equation. $\mathrm{W_{qj}}$ is a vector of "q" characteristics of school "j"; γ_{k0} and γ_{kq} are level 2 coefficients and $\mathrm{u_{kj}}$ are the random effects at level 2.

Equation (3) has been obtained by substituting in equation 1 (student level) the coefficients by equations 2 and 3 (school level). In this way, a series of effects can be distinguished fixed ($\gamma_{00} + \sum_{q=1}^{Q} \gamma_{0q}\mathrm{W_{qj}} + \sum_{k=1}^{n} \beta_{kj}\mathrm{X_{kij}}$) of the random effects ($u_{0j} + \mathrm{r_{ij}}$).

$$Y_{ij} = \gamma_{00} + \sum_{q=1}^{Q} \gamma_{0q}\mathrm{W_{qj}} + \sum_{k=1}^{n} \beta_{kj}\mathrm{X_{kij}} + \mathrm{r_{ij}} + u_{0j} \qquad (3)$$

The models were estimated using maximum likelihood estimation with robust standard errors by software Stata 14 and the *meglm* command, which also allows the application of weights at both levels simultaneously.

Quantile regression models

We are also interested in the possibility that the use of ICT may differentially affect students of different ability levels. In order to assess this, we estimate the previous models but using quantile regression techniques. The basic quantile regression model specifies the conditional quantile as a linear function of covariates. Following Buchinsky (1998) for the θ^{th} quantile, the model can be written as:

$$Y_i = x_i'\beta_\theta + u_{\theta i}, \quad Quant_\theta(y_i|x_i) = x_i'\beta_\theta \;\; \theta\epsilon(0,1) \qquad (4)$$

where Y_i refers to the score obtained by student "i" and x_i' is a vector of explanatory variables (the same ones included in the multilevel models) regarding students, family, location (Autonomous Communities) and school characteristics; $u_{\theta i}$ is a mean zero error term. $Quant_\theta(y_i|x_i) = x_i'\beta_\theta$ denotes the conditional quantile of Y_i, conditional on the vector of explanatory variables x_i' and $\theta\epsilon(0,1)$. The distribution of the error term is left unspecified. It is assumed only that $u_{\theta i}$ satisfies the quantile restriction $Quant_\theta(u_{\theta i}|x_i)$ = 0. The essential element of this framework is that the marginal effects of the covariates, given by β_θ , might vary over quantiles. Additionally, we implement the Wald tests for equality of coefficients across quantiles to test whether the differences in the coefficients of the quantile regressions (β_θ) are statistically significant. The Wald test works by testing the null hypothesis that the coefficients of a particular covariate across quantiles are equal.

The models were estimated with the original number of observations (since it has been confirmed that the imputation process does not alter the results in the multilevel models) and taking into account the hierarchical structure of our data by clustering the standard errors by school. The estimates were made with the software Stata 14 and the *qreg2* command.

1.4 Results

Multilevel regression models

The results of the incidence of the variables related to ICT in the acquisition of the three competences evaluated at PISA 2015 are presented in table 2 and the full results of the estimates can be found in the table A.5 in the Appendix.[8]

[8] In addition to the estimates for Spain as a whole, the main models have been estimated for each of the Autonomous Communities, in order to identify whether there were differences in results depending on the Community analyzed. Although small differences are observed in some variables, the main conclusions of the research remain the same. These results are available on request.

Table 2: Results of the multilevel regression models

VARIABLES	(1) Mathematics	(2) Science	(3) Reading
ICT use outside of school for schoolwork	-11.494***	-13.649***	-14.109***
	(1.145)	(1.340)	(1.312)
ICT use outside of school for leisure	1.431*	5.698***	5.469***
	(1.314)	(1.480)	(1.458)
Use of ICT at school in general	-2.703***	-5.318***	-5.214***
	(1.124)	(1.179)	(1.033)
Students' ICT interest	1.812**	2.897***	4.162***
	(0.831)	(0.966)	(1.023)
Students' ICT as a topic in Social interaction	1.696*	0.465	-2.427**
	(0.942)	(1.056)	(0.967)
Starting age for using ICT	-10.462***	-13.051***	-9.901***
	(0.963)	(1.099)	(1.053)
Computer / Students ratio	1.820**	3.049**	2.346*
	(1.240)	(1.350)	(1.152)
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes
Constant	460.386***	492.572***	477.393***
	(22.65)	(31.40)	(34.49)
Observations (min-max) [α]	24,370-24,472	24,370-24,472	24,370-24,472
Number of schools	864	864	864

Robust standard errors in parentheses

**** p<0.01, ** p<0.05, * p<0.1*

[β] The coefficients and the standard errors are the result of calculating the average of the 16 estimates made for the different 16 values of each imputed variable.

[α] Total number of observations varies according to the estimate as a consequence of the manual elimination of outliers presented by some imputed variables.

As for the use of ICT at home, the use of ICT at home for schoolwork shows in the three models a negative relation with academic performance. Moreover, the coefficients for this variable are the largest of all the estimates thus indicating that the use of ICT for schoolwork at home seems to play a key role and needs to be further analysed. Nevertheless, the use of ICT at home for leisure is associated with higher values of scores in science and reading. These two results are in line with that obtained in previous studies (Biagi and Loi, 2013, Mediavilla and Escardíbul, 2015, Agasisti et al., 2020).

Results for the use of ICT at school indicate a negative association with academic performance, independently of the competence evaluated. These negative effects should also be analysed in depth to identify their causes and be able to put in place educational policies to overcome these problems. However, regarding the number of computers per students at school, results show that higher availability of computers per student is associated with higher levels of academic performance in mathematics and science.

Regarding the related ICT personal variables one result that stands out is the magnitude of the coefficient for the starting age for using ICT and its negative association with the scores in mathematics, science and reading. The higher the age, the lower the score achieved, as also suggested by Mediavilla and Escardíbul (2015) and Escardíbul and Mediavilla (2016). Moreover, it is important to highlight the result obtained for the variables introduced for the first time in PISA 2015: "interest in use by ICT of the students "and "ICT as a topic in social interaction". Students' interest in ICT is positively related with the scores achieved in our three models, while the importance of ICT as a topic in social interaction shows a negative association, but only for reading comprehension.

As a robustness check, in order to check that the inclusion of all the ICT variables in the same regression does not lead to any bias in the results because some of the variables may be potentially correlated with each other, we have run separately regressions for each relevant explanatory variable. The results confirm that the direction of the estimates for each independent variable is the same as when including all together (table A.6 in Appendix).

Additionally, in order to consider the possible interaction that may exist between the scores achieved in the different competences (see Coco et al. 2020), an additional model with a composite index of the results in the three competences has been estimated as proof of robustness (table A.7 in Appendix). The composite index for each student has been calculated by averaging the values obtained by the student on the mathematics, reading and science tests. The results of this model are mostly in line with the results of the models estimated for the various competences separately. It is confirmed that the use of ICT at home for schoolwork, the use of ICT at school and the starting age for using ICT, are negatively associated with academic performance. Contrary, the use of ICT at home for leisure, students' interest in ICT and the number of computers per students at school, are positively associated with academic performance. However, the coefficient for the variable "Students' ICT as a topic in Social interaction" is not statistically significant in the model with a composite index.

Quantile regression models

As explained in the methodology section, we have run separately quantile regressions with robust and clustered standard errors in order to study if there are significant variations on the relation between ICT and academic performance depending on the percentile of performance of the students. For this purpose, we focus on the differences in the marginal effects of the covariates related to ICT over quantiles. Specifically, we focus on the 25th, 50th, 75th and 90th percentile. Table A.8 in the Appendix shows the mean value of the score achieved by students in each of these percentiles for the different competences. Table 3 shows the main results of the quantile regressions for the three competences [9] and

[9] The complete estimates of quantile regressions are available upon request.

table A.9 in the Appendix shows the results of the Wald Tests carried out to test the equality of the coefficients across and between quantiles.

Table 3: Results of the quantile regression models

VARIABLES	(1) Mathematics			
	0.25 coef.	0.50 coef.	0.75 coef.	0.9 coef.
ICT use outside of school for schoolwork	-8.189***	-9.464***	-9.639***	-10.44***
	(0.687)	(0.675)	(0.710)	(1.041)
ICT use outside of school for leisure	1.672**	1.492*	1.238	1.936
	(0.687)	(0.784)	(1.049)	(1.179)
Use of ICT at school in general	-2.894***	-1.886***	-1.724***	-1.809*
	(0.795)	(0.713)	(0.608)	(1.025)
Students' ICT interest	4.084***	3.962***	3.242***	2.836***
	(0.516)	(0.584)	(0.681)	(0.952)
Students' ICT as a topic in Social interaction	-1.215**	-1.618***	-1.079*	-1.056
	(0.601)	(0.545)	(0.554)	(0.738)
Starting Age for using ICT	-10.06***	-11.25***	-11.28***	-11.41***
	(0.636)	(0.600)	(0.595)	(0.803)
Computer / Students ratio	0.597	0.248	1.041	0.769
	(1.081)	(0.806)	(1.104)	(1.538)
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes	Yes
Observations	20,438	20,438	20,438	20,438
Number of schools	756	756	756	756

VARIABLES	(2) Science			
	0.25 coef.	0.50 coef.	0.75 coef.	0.9 coef.
ICT use outside of school for schoolwork	-10.19***	-12.20***	-13.41***	-11.98***
	(0.996)	(0.811)	(1.090)	(0.952)
ICT use outside of school for leisure	3.488***	3.701***	2.864***	2.059*
	(1.013)	(0.996)	(0.983)	(1.075)
Use of ICT at school in general	-5.068***	-3.592***	-2.938***	-2.411***
	(0.956)	(0.900)	(0.782)	(0.930)
Students' ICT interest	5.589***	4.447***	4.317***	3.275***
	(0.709)	(0.727)	(0.803)	(0.956)
Students' ICT as a topic in Social interaction	-1.784**	-1.263**	-0.632	-2.072***
	(0.746)	(0.635)	(0.730)	(0.794)
Starting Age for using ICT	-11.87***	-13.46***	-12.85***	-12.47***
	(0.802)	(0.692)	(0.820)	(0.931)
Computer / Students ratio	-0.0917	0.644	1.077	1.344
	(1.404)	(1.247)	(1.230)	(1.019)
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes	Yes
Observations	20,438	20,438	20,438	20,438
Number of schools	756	756	756	756

Table 3: Results of the quantile regression models (*continuation*)

VARIABLES	(1) Reading			
	0.25 coef.	0.50 coef.	0.75 coef.	0.9 coef.
ICT use outside of school for schoolwork	-11.88***	-13.23***	-13.77***	-12.87***
	(0.845)	(0.785)	(0.678)	(1.166)
ICT use outside of school for leisure	4.197***	3.551***	3.351***	4.287***
	(0.948)	(0.933)	(1.028)	(1.199)
Use of ICT at school in general	-4.452***	-4.061***	-1.935***	-2.358**
	(0.788)	(0.697)	(0.668)	(0.990)
Students' ICT interest	6.346***	5.513***	5.163***	3.588***
	(0.587)	(0.713)	(0.694)	(1.021)
Students' ICT as a topic in Social interaction	-4.339***	-3.412***	-3.580***	-3.742***
	(0.706)	(0.630)	(0.727)	(0.973)
Starting Age for using ICT	-10.57***	-10.50***	-8.794***	-9.056***
	(0.808)	(0.651)	(0.651)	(0.830)
Computer / Students ratio	0.173	0.978	0.579	-0.194
	(0.954)	(1.180)	(1.070)	(1.232)
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes	Yes
Observations	20,438	20,438	20,438	20,438
Number of schools	756	756	756	756

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

The results by percentiles show that in some variables the association between ICT and academic performance varies according to the level of ability of the student. In others, however, there are no differences by performance level. The latter is the case of the use of ICT at home to carry out schoolwork in all the competences, the age of beginning of the use of ICT in mathematics and science, ICT use at home for leisure in science and reading, the importance of ICT as a topic in social interaction in science and reading, and the ratio of computers per students in schools in all the competences. In the rest of the variables or competences, the results, and therefore the final considerations, are affected according to the percentile we analyse.

In the case of the use of ICT at home for schoolwork, the quantile regressions show that the result obtained in the main multilevel models is maintained for all parts of the distribution. That is, regardless of the student's performance level, the association between using ICT at home for homework and academic performance remains negative. Moreover, Wald's tests confirm that there are no significant differences between the coefficients obtained for the different quantiles. These results suggest that the association between the use of ICT in the homework and the performance is negative and of similar magnitude regardless of the student's performance level.

With regard to the age of beginning of the use of ICT, the quantile regressions show that the negative association with academic performance is maintained regardless of the performance percentile. If we look at the magnitude of the coefficients and take into consideration the results of the Wald tests, we can conclude that there are no statistically significant differences between them in mathematics and science, so that in these competences no differences are detected in the magnitude of the association found between the age of beginning of the use of ICT and academic performance according to the level of student performance. However, in reading, the results of the Wald test do show differences between the coefficients of the 25th percentile and the 75th and 90th percentiles, indicating that the negative association between the age of beginning of the use of ICT and academic performance in this competence seems to be of greater magnitude for students in the lower part of the distribution.

In the case of ICT use at home for leisure, in the multilevel regressions we found a positive impact on science and reading, while there was no statistically significant relationship in mathematics. When analysing the quantile regressions, it is observed that in mathematics there is a positive association between the level of ICT use at home for leisure and the academic performance of students at the 25th percentile, the lower part of the distribution. In science, the results show that the positive association is maintained in the 25th, 50th and 75th percentiles, but Wald's test results indicate that the differences between quantiles are not statistically significant. In the case of reading, the positive association continues to be statistically significant in the four percentiles, but Wald's tests also indicate that there are no statistically significant differences between the coefficients across quantiles. Therefore, the results suggest that in mathematics the positive association between the use of ICT at home for leisure purposes and academic performance seems to affect students at the lower end of the distribution to a greater extent, while in science and reading no differential effects by performance level are observed.

As regards the use of ICT in schools, the results are particularly interesting. In the multilevel models we found a negative association between increased use of ICT in schools and academic performance in all competences, this being one of the main results obtained. In the quantile regressions, it is observed that although the negative association is maintained for most of the percentiles -with the exception of the 90th percentile in mathematics-, the magnitude of the coefficients is always higher at the lower part of the distribution (25th and 50th percentile). Wald's tests also confirm that the coefficients at the 25th percentile in mathematics, science and reading are significantly different from those at the 75th and 90th percentile. These results suggest that ICT in schools seems to be associated with negative effects on academic performance, especially for the worst performing students. A very similar result is observed for Students' ICT interest. In the multilevel regressions we found a positive association in all competences, an association that is maintained in the quantile models independently of the level of performance. However, it is also evident that the coefficients are of greater magnitude in the lower percentiles of the distribution and are losing magnitude as we move towards the best performing students. Wald's tests confirm that there are statistically significant differences in the magnitude of the coefficients obtained for the 25th and 90th percentiles in all the competences, and between the 25th and 75th percentiles in science and reading. These results confirm that the positive association between Students' ICT interest and academic performance is greatest in the case of the worst performing students in all the competences.

In the case of the variable “students' ICT as a topic in social interaction”, the multilevel results indicated a negative association with academic performance only in reading. The results of the quantile regressions show instead that this negative association is also observed at the 25th and 50th percentiles in mathematics; at the 25th, 50th and 90th percentiles in science, and at all percentiles analysed in reading. However, Wald's tests confirm that there are no statistically significant differences between the coefficients obtained for the different percentiles in science and reading, which leads us to indicate that in the case of the variable "students' ICT as a topic in social interaction" we only find differences by performance level in mathematics. More specifically, the results suggest that in mathematics the negative association between the importance of ICT as a topic in Social interaction and academic performance is only maintained for the worst performing students, while in all other competences it is maintained in similar magnitude for all quantiles.

Finally, in relation to the ratio of computers per students in schools, while in the main regressions a positive association was found in mathematics and science, in the quantile regressions the coefficients are not statistically significant in any of the competences and percentiles and Wald's tests indicate that there are no statistically significant differences by percentiles.

According to these results, we consider that certain uses of ICT seem to have differential effects according to the level of performance of the students. In particular, as has been shown, it seems that ICT use at the school and Students' ICT interest, are factors associated with the academic performance in mathematics, science and reading especially for the worst performing students. Moreover, in mathematics, the importance of ICT as a topic in Social interaction and the use of ICT outside of school for leisure also appear to be factors associated with poorer academic performance especially in students in the lower percentiles, while in reading the negative association between the age of beginning of the use of ICT and academic performance seems to be of greater magnitude for students in the lower part of the distribution.

We consider these results to be very novel and have substantial implications for public policy recommendations, as they suggest that certain types of ICT use seem to be more related to the academic performance of the students with the worse results. Therefore, correctly implemented, ICT can be an important tool to improve the academic performance of the students with the worse results, as also advocated by Muralidharan et al. (2019).

1.5 Final Considerations

The analysis of PISA 2015 microdata through a two-level linear hierarchical model reveals an association between the use of ICT at the personal and school level and the academic performance of Spanish students in mathematics, science and reading comprehension. Below, we would like to suggest some explanations that we believe could explain the results obtained in this research. These are hypotheses that would need to be validated or refuted through future research, preferably of a qualitative nature and methods of direct observation. The data from our research only allows us to study the associations observed between ICT and academic performance, but in order to explain the cause of these associations our data are insufficient. Nevertheless, we consider this study to be an important starting point for opening up the debate on ICT and their relationship with the educational field.

We have obtained several results that deserve special attention. The sign of the association with academic performance differs between the diverse ICT variables used. This fact shows the importance of properly implementing ICT in the learning process, with the aim of making the most of the advantages of ICT. In this regard, it is striking that the positive association between academic achievement and the use of ICT at home is related with the use of ICT for entertainment purposes and not for homework (negative association). This result is in line with that obtained in previous studies (Biagi and Loi, 2013, Mediavilla and Escardíbul, 2015, Agasisti et al., 2020).

We consider this negative association of using ICT at home for schoolwork and academic performance could be explained by two reasons: (1) existence of inverse causality (the worst performers use computers more for these types of tasks because they require more time for homework and study); and (2) the incorrect integration of ICT by teachers when assigning homework. In this last regard, we consider it necessary to emphasize the importance of implementing ICT training programs for teachers to encourage greater and better use of ICT to take advantage of the potential benefits of these tools.

As for the positive association between the use of ICT for entertainment and the academic performance, we consider it can be explained by the fact that, thanks to playing with ICT, students become more motivated and more familiar with using these tools and they can incorporate their knowledge of ICT into all aspects of life, such as using technology for educational purposes in an appropriate way that allows them to take advantage of the benefits of ICT and improve their academic performance.

On the other hand, it is also noteworthy that the index of general use of ICT in schools by students is associated with negative effects. This result indicates an inadequate use of ICT at schools and thus should be analysed in depth in order to identify its causes and overcome them. As noted above in explaining a possible cause of the negative association between the use of ICT for homework and academic performance, one reason for the negative association between the use of ICT in schools and students' scores could be the inadequate use of resources or the lack of familiarization of the teaching staff, as found by Cruz el al. (2018). The lack of familiarization of teachers with devices such as digital whiteboards or computers can lead to limitations when using ICT in the teaching process that negatively affect the content of the subject taught and therefore academic performance, since strong teacher skills seem to have positive effects on student achievement (Meroni et al., 2015). Therefore, as suggested by Mediavilla (2018), we should ask ourselves whether we have our teachers adequately trained to develop new pedagogical methodologies that allow the effective use of ICT. In other words, the resources must be adapted in order to adequately complement the traditional teaching method.

At the student level, one significant result is the magnitude of the coefficient for the relation between the starting age for using ICT on the scores in mathematics, science and reading. The higher the age, the lower the score achieved, in line with Mediavilla and Escardíbul (2015) and Escardíbul and Mediavilla (2016). This result seems to be in line with that found for the use of ICT for entertainment. As mentioned previously, this could be explained by the fact that students are more familiar with digital devices and use them as an additional resource in the educational process in an adequate and advantageous way for their performance.

Moreover, it is important to highlight the result obtained for the variables introduced for the first time in PISA 2015: "interest in use by ICT of the students" and "ICT as a topic in social interaction". Students' interest in ICT is positively related with the scores achieved in our three models while the importance of ICT as a topic in social interaction shows a negative association with academic performance in reading. These two results are very novel since they had not been studied in the previous literature. The outcome for the interest in ICT continues to be in line with the conclusions drawn previously on the importance of familiarising students with ICTs in order to be able to use them in the educational process to improve their academic performance. However, the negative association between the importance of ICT as a topic in social interaction and academic performance could be explained because higher values of this variable imply a greater presence of ICT in the social life of students (being for example the statement "I like to meet friends and play computer and video games with them" one of those that compose this variable) and those social uses, rather than improving students' familiarity with ICTs, leave less time for students to engage in learning activities focused on improving their competences.

The results obtained highlight the need to include ICT as an *input* into the educational production function and have substantial implications for educational policies in Spain. According to our results, we consider that it would be advisable to explore the use of ICT in schools. New technologies must adapt to the curriculum of the subjects and be conveniently applied in the learning process. At the same time, teachers must receive sufficient training to be competent in digital uses and be able to take advantage of ICT in the classroom. Likewise, considering our results, the interest in ICT of students should be strengthened but in an appropriate way and encouraging the use for learning purposes, since as evidenced the importance in social interaction of these tools is associated with negative effects on performance. Additionally, as observed in the quantile regressions, ICT can also play an important role in improving the academic performance of those students with the worse results and thus should be considered as an additional element in the fight against school failure. Considering this result, we consider public policies in the future should take into account this interaction between ICT and the educational performance of underperforming students.

Given the novelty and relevance of our results, we believe that the associations obtained open the door to future research. In this sense, we consider it would be interesting to make comparisons of the results of Spain with other countries. These comparative analyses would allow the contextualization of the results and would make it possible to compare the ICT policies implemented in the different countries, in order to identify the most successful policies. In addition, as we have also previously pointed out, we believe that it is necessary to carry out studies of a qualitative nature that allow the causes of the associations obtained in this research to be clarified. Moreover, we also consider it important to point out that in order to make correct ICT policy recommendations it would be necessary to carry out an efficiency analysis, something that the data used in our research does not allow, and which must necessarily be pointed out as a limitation of our study. Therefore, we consider that it would be very interesting to carry out efficiency analysis in future research in this area.

Considering our results, we find that the structure of the education system must be reorganized and adapted to the new needs of an intensely digitized world in order to convert ICT into a quality factor that leads to an improvement in the learning process of students, translating into higher levels of competences and therefore a better preparation to face real-life challenges.

1.6 Appendix

Table A.1: Definition of ICT variables used in the empirical analysis

Variable	*Definition*
ICT use outside of school for schoolwork (WLE)	Frequency of use of digital devices (never or hardly ever, once or twice a month, once or twice a week, almost every day, every day) to perform the following activities at school: use email or Social Networks for communication with other students or teachers about schoolwork; browse the internet to complete school assignments or follow up lessons; download/upload/browsing school materials from the school's intranet; check the schools website for announcements; do homework on computer or on a mobile device; download learning apps on a mobile device.
ICT use outside of school for leisure (WLE)	Frequency of use of digital devices (never or hardly ever, once or twice a month, once or twice a week, almost every day, every day) to perform the following activities at home: games (one-player or collaborative); email; chat; social networks; online games; fun videos; read the news; get practical information; download music, films, games or software from the Internet; upload own created content for sharing; download new applications on a mobile device.
Use of ICT at school in general (WLE)	Frequency of use of digital devices (never or hardly ever, once or twice a month, once or twice a week, almost every day, every day) to perform the following activities at school: chat online; use e-mail; browse the Internet for schoolwork; download/upload/browse school webs; post the work on the schools website; play simulations at school; practice and drill, foreign language learning or math; do homework on a school computer; use school computers for group work and communication with other students.
Students' ICT interest (WLE)	Degree of agreement (strongly disagree, disagree, agree, strongly agree) with the following statements: "I forget about time when I'm using digital devices"; "The Internet is a great resource for obtaining information I am interested in"; "It is very useful to have Social Networks on the Internet"; "I am really excited discovering new digital devices or applications"; "I really feel bad if no Internet Connection is possible"; "I like using digital devices".
Students' ICT as a topic in Social interaction (WLE)	Degree of agreement (strongly disagree, disagree, agree, strongly agree) with the following statements: "To learn something new about digital devices, I like to talk about them with my friends"; "I like to exchange solutions to problems with digital devices with others on the Internet"; "I like to meet friends and play computer and video games with them"; "I like to share information about digital devices with my friends"; "I learn a lot about digital media by discussing with my friends and relatives".
Starting age for using ICT (Categorical)	1 = 6 years old or younger 2 = 7-9 years old 3 = 10-12 years old 4 = 12 years old or older 5 = I have never used a digital device until today
Computer / Students ratio	Ratio of computers available to 15-year olds for educational purposes to the total number of students in the modal grade for 15-year olds.

Source: compiled by the authors based on OECD codebook for microdata from PISA 2015.

Table A.2: Definition of categorical control variables

Student Level	
Female	0 = Male 1 = Female
Index Immigration Status (IMMIG)	0= Native 1 = Second-generation 2 = First-generation
Age of Arrival of Immigrant Students	0 = Native 1 = age 0-2 2 = age 3-5 3 = age 6-7 4 = age 8-9 5 = age 10-11 6 = 12 years or older
Repetition of grade	0 = Did not repeat a grade 1 = Repeated a grade
School truancy (number of whole school days skipped in the last two full weeks prior to the test)	1= None 2 = One or two times 3 = Three or four times 4 = Five or more times
Starting age of ISCED 0	1 = 2 years or younger 2 = 3 years 3 = 4 years or older 4 = Did not attend ISCED 0
Family Level	
Language at home	0 = Language of test 1 = Other language
Highest educational level of parents (HISCED)	1 = None or ISCED 1 2 = ISCED 2 3= ISCED 3B, 3C, 3A, 4 4 = ISCED 5B, 5A, 6
Number of books at home	1.= 0-10 books 2 = 11-25 books 3 = 26-100 books 4 = 101-200 books 5 = 201-500 books 6 = More than 500 books

Source: compiled by the authors based on microdata from PISA 2015.

Table A.2: Definition of categorical control variables *(continuation)*

School Level	
School Ownership	1 = Private Independent 2 = Private Government-Dependent 3 = Public
Location (Community in which the school is located)	1 = A village, hamlet, or rural area (fewer than 3,000 people) 2 = A small town (3,000 to about 15,000 people) 3 = A town (15,000 to about 100,000 people) 4 = A city (100,000 to about 1,000,000 people) 5 = A large city (with over 1,000,000 people)
Class Size (Average size of classes in the national modal grade for 15-year-olds in the school)	1 = 15 students or fewer 2 = 16-20 students 3 = 21-25 students 4 = 26-30 students 5 = 31-35 students 6 = 36-40 students 7 = 41-45 students 8 = 46-50 students 9 = More than 50 students

Source: compiled by the authors based on microdata from PISA 2015

Table A.3: Descriptive statistics control variables

Variable	***N***	***% Missing Values***	***Mean***	***Std. Dev.***	***Min***	***Max***
	Student Level					
Female	32,330	0.00	0.494	0.500	0	1
Index Immigration Status (Immig)	31,640	2.13	0.201	0.588	0	2
Age of Arrival of Immigrant Students	32,309	0.00	0.318	1.060	0	6
Repetition of Grande	32,130	0.00	0.285	0.451	0	1
School Truancy	31,840	1.51	1.277	0.585	1	4
Starting age of ISCED 0	30,065	7.00	1.827	0.610	1	4
Family Level						
Language at home	32,119	0.00	0.171	0.376	0	1
Highest occupational status of parents (HISEI)	30,507	5.64	48.519	23.166	11	89
Highest educational level of parents (HISCED)	31,698	1.95	3.289	0.950	1	4
Number of books at home	32,038	0.00	3.493	1.374	1	6

Source: compiled by the authors based on microdata from PISA 2015.

Table A.3: Descriptive statistics control variables *(continuation)*

School Level						
School Ownership	30,418	5.91	2.609	0.587	1	3
Location	31,140	3.68	3.019	1.002	1	5
School Autonomy	31,228	3.40	0.562	0.186	0	1
Class Size	30,971	4.20	3.826	1.809	1	9
School Size	29,484	8.80	744.506	435.693	23	4,034
Student-Teacher ratio	29,133	9.89	12.527	4.420	1	50.476
Index proportion of all teachers fully certified	27,410	15.21	0.887	0.280	0	1

Source: compiled by the authors based on microdata from PISA 2015.

Figure A.1: Kernel Density Estimates (original vs imputed variables)

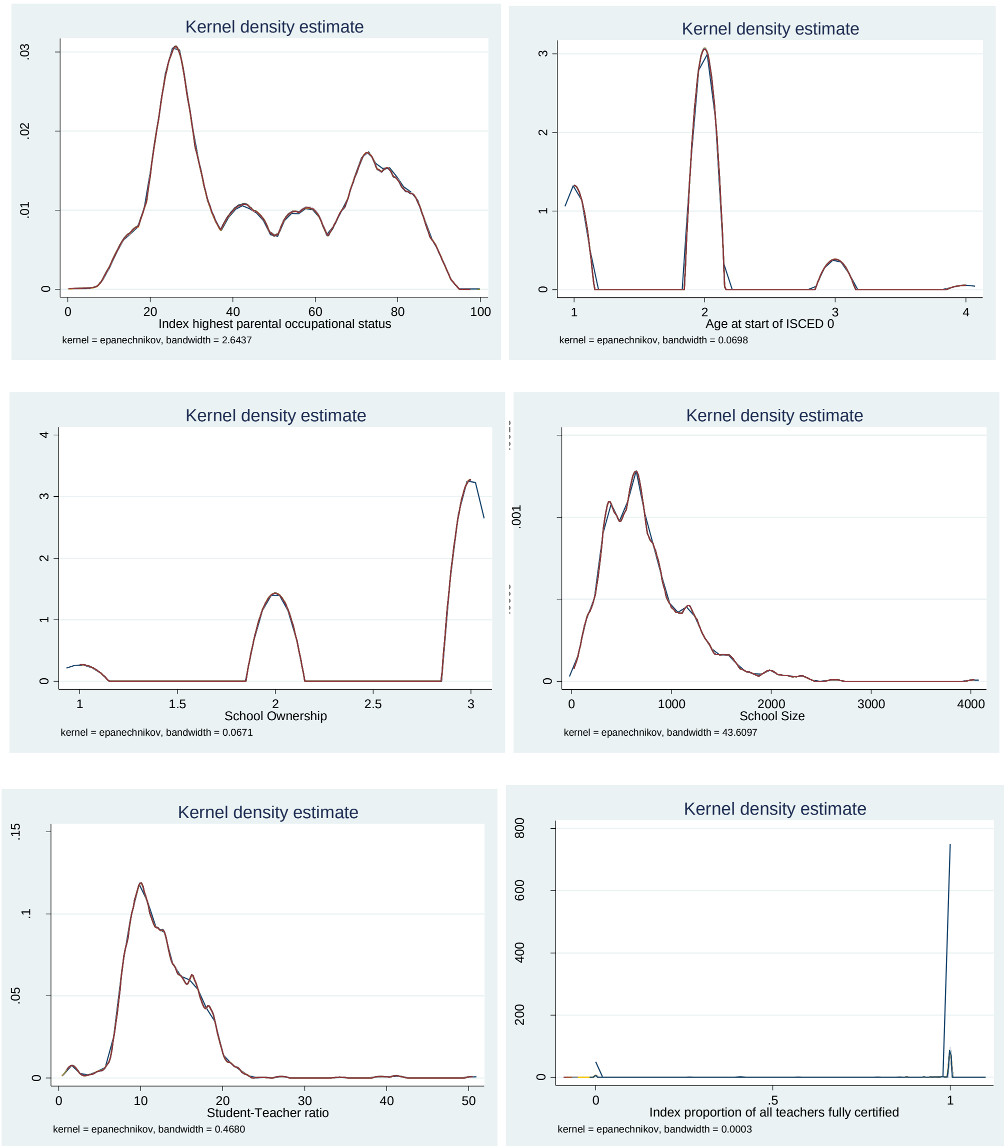


Table A.4: Full results of the multilevel models (without imputed missing values)

VARIABLES	(1) Mathematics	(2) Science	(3) Reading
ICT use outside of school for schoolwork	-10.18***	-12.90***	-13.39***
	(1.173)	(1.452)	(1.411)
ICT use outside of school for leisure	1.461	4.636***	4.745***
	(1.439)	(1.617)	(1.675)
Use of ICT at school in general	-2.988***	-4.603***	-4.218***
	(1.049)	(1.268)	(1.090)
Students' ICT interest	2.557***	3.578***	4.971***
	(0.893)	(0.995)	(1.051)
Students' ICT as a topic in Social interaction	1.464	0.611	-2.463**
	(0.903)	(1.090)	(1.038)
Starting age for using ICT	-11.84***	-13.50***	-9.750***
	(1.019)	(1.123)	(1.083)
Computer / Students ratio	2.206**	2.855**	2.086*
	(1.140)	(1.328)	(1.109)
Female	-19.56***	-15.05***	8.942***
	(1.704)	(2.184)	(1.985)
Index Immigration Status	5.367**	10.13***	12.08***
	(2.516)	(3.390)	(2.873)
Age of arrival of immigrant students	-6.511***	-8.287***	-7.932***
	(1.381)	(1.534)	(1.478)
Repetition of grade	-69.85***	-71.92***	-74.25***
	(1.990)	(2.533)	(2.330)
School truancy	-8.305***	-8.386***	-7.465***
	(1.288)	(1.403)	(1.536)
Starting age of ISCED 0	-2.260*	-0.548	1.515
	(1.339)	(1.523)	(1.443)
Language at home	1.648	-4.813*	-4.325
	(2.467)	(2.916)	(2.764)
Highest occupational status of parents (HISEI)	0.284***	0.300***	0.231***
	(0.0492)	(0.0515)	(0.0434)
Highest educational level of parents (HISCED)	0.229	-0.0676	0.778
	(0.927)	(1.159)	(1.087)
Number of books at home	10.10***	11.25***	11.08***
	(0.737)	(0.875)	(0.861)
School ownership	2.147	2.763	-0.477
	(2.371)	(2.802)	(2.445)
Location	-2.022**	-1.180	0.0900
	(1.008)	(1.189)	(1.022)
School autonomy	12.78*	10.54	12.83*
	(6.613)	(7.886)	(7.154)
Class size	0.681	0.581	0.612
	(0.672)	(0.830)	(0.746)
School size	0.00531**	0.00411	0.00188
	(0.00226)	(0.00264)	(0.00226)
Student-Teacher ratio	-0.115	-0.0834	0.100
	(0.220)	(0.220)	(0.179)
Index proportion all teachers fully certified	-3.423	-3.353	-0.970
	(3.271)	(4.283)	(3.924)
Andalucía	-10.30***	-12.31***	-12.76***
	(3.493)	(3.743)	(3.274)

Table A.4: Full results of the multilevel models (*continuation*)

VARIABLES	(1) Mathematics	(2) Science	(3) Reading
Aragón	13.36***	9.970**	2.531
	(4.035)	(4.275)	(3.900)
Asturias	0.0212	-0.0197	-10.74***
	(3.541)	(3.684)	(3.508)
Baleares	1.539	4.174	-2.699
	(3.756)	(3.858)	(3.211)
Canarias	-14.62***	2.179	2.184
	(3.734)	(4.041)	(3.596)
Cantabria	7.445**	-1.653	-2.601
	(3.729)	(3.926)	(3.647)
Castilla León	17.16***	17.12***	12.89***
	(4.349)	(4.520)	(4.171)
Castilla La Mancha	6.575*	7.423*	2.703
	(3.809)	(4.104)	(3.584)
Cataluña	10.73***	9.513**	-1.984
	(4.160)	(4.720)	(4.025)
Extremadura	-3.132	-12.05***	-15.32***
	(3.415)	(3.635)	(3.457)
Galicia	4.302	15.38***	5.448
	(4.179)	(4.376)	(3.891)
La Rioja	21.71***	3.847	-10.62***
	(3.633)	(4.054)	(3.576)
Madrid	12.93***	12.26***	8.828***
	(3.348)	(3.595)	(3.420)
Murcia	-5.533*	-2.154	-4.585
	(3.255)	(3.577)	(2.865)
Navarra	22.29***	8.271**	2.656
	(3.655)	(3.925)	(3.811)
País Vasco	-1.465	-15.79***	-12.92***
	(3.826)	(4.262)	(4.180)
Comunidad Valenciana	-	-	-
Constant	498.6***	500.7***	486.6***
	(12.90)	(15.01)	(14.28)
Observations	20,438	20,438	20,438
Number of schools	756	756	756

Robust standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Table A.5: Full results of the multilevel models (with imputed values)

VARIABLES	(1) Mathematics	(2) Science	(3) Reading
ICT use outside of school for schoolwork	-11.494***	-13.649***	-14.109***
	(1.145)	(1.340)	(1.312)
ICT use outside of school for leisure	1.431*	5.698***	5.469***
	(1.314)	(1.480)	(1.458)
Use of ICT at school in general	-2.703***	-5.318***	-5.214***
	(1.124)	(1.179)	(1.033)
Students’ ICT interest	1.812**	2.897***	4.162***
	(0.831)	(0.966)	(1.023)
Students’ ICT as a topic in Social interaction	1.696*	0.465	-2.427**
	(0.942)	(1.056)	(0.967)
Starting age for using ICT	-10.462***	-13.051***	-9.901***
	(0.963)	(1.099)	(1.053)
Computer / Students ratio	1.820**	3.049**	2.346*
	(1.240)	(1.350)	(1.152)
Female	-17.465***	-15.152***	8.949***
	(1.668)	(2.070)	(1.845)
Index Immigration Status	1.977	9.163**	12.047***
	(2.837)	(3.554)	(3.321)
Age of arrival of immigrant students	-2.605	-6.705***	-7.312***
	(2.441)	(1.634)	(1.410)
Repetition of grade	-66.605***	-72.297***	-74.421***
	(2.014)	(2.418)	(2.185)
School truancy	-13.535***	-9.059***	-8.094***
	(1.152)	(1.272)	(1.386)
Starting age of ISCED 0	-2.922*	-0.482	1.538
	(1.438)	(1.479)	(1.358)
Language at home	2.837	-4.796*	-4.789*
	(3.035)	(2.744)	(2.715)
Highest occupational status of parents (HISEI)	0.466***	0.306***	0.225***
	(0.0542)	(0.0493)	(0.0407)
Highest educational level of parents (HISCED)	-0.660	-0.778	0.120
	(0.896)	(1.084)	(0.982)
Number of books at home	9.736***	11.522***	11.425***
	(0.712)	(0.792)	(0.816)
School ownership	3.879	4.056	1.653
	(4.802)	(6.500)	(6.963)
Location	-0.596**	-0.277	0.550
	(1.139)	(1.352)	(1.213)
School autonomy	12.062	11.402	14.700
	(10.29)	(14.08)	(14.81)
Class size	2.267	0.458	0.546
	(0.657)	(0.831)	(0.745)
School size	0.044**	0.003*	0.002
	(0.00270)	(0.00305)	(0.00278)
Student-Teacher ratio	0.095	0.046	0.255
	(0.315)	(0.347)	(0.342)
Index proportion all teachers fully certified	-2.059	-0.495	0.449
	(13.05)	(9.883)	(11.22)
Andalucía	-8.696***	-12.557***	-12.607***
	(3.301)	(3.791)	(3.567)
Aragón	10.374***	8.527*	2.516
	(4.003)	(4.191)	(4.015)

Table A.5: Full results of the multilevel models (*continuation*)

VARIABLES	(1) Mathematics	(2) Science	(3) Reading
Asturias	0.586	-0.856	-10.243***
	(3.962)	(4.190)	(4.034)
Baleares	1.323	3.864	-2.048
	(3.712)	(3.799)	(3.349)
Canarias	-14.157***	0.483	1.267
	(3.719)	(4.123)	(3.839)
Cantabria	7.339*	-0.606	-1.083
	(4.060)	(4.487)	(4.434)
Castilla León	16.668***	16.935***	13.498***
	(4.307)	(4.641)	(4.381)
Castilla La Mancha	6.364	6.536	1.573
	(3.693)	(4.022)	(3.506)
Cataluña	9.180**	9.039*	-1.752
	(3.948)	(4.568)	(3.906)
Extremadura	-1.711	-11.343***	-14.837***
	(3.328)	(3.604)	(3.500)
Galicia	1.385	12.059***	3.209
	(4.024)	(4.457)	(3.956)
La Rioja	19.421***	2.829	-10.981***
	(3.739)	(4.239)	(4.011)
Madrid	11.700***	10.579***	7.823***
	(3.334)	(3.628)	(3.505)
Murcia	-5.055*	-3.082	-5.590*
	(2.995)	(3.409)	(3.061)
Navarra	19.688***	7.778**	2.885
	(3.561)	(3.657)	(3.605)
País Vasco	-2.315	-17.805***	-14.774***
	(3.611)	(4.046)	(4.085)
Comunidad Valenciana	-	-	-
Constant	460.386***	492.572***	477.393***
	(22.65)	(31.40)	(34.49)
Observations (min-max) [α]	24,370-24,472	24,370-24,472	24,370-24,472
Number of schools	864	864	864

Robust standard errors in parentheses

**** p<0.01, ** p<0.05, * p<0.1*

[β] The coefficients and the standard errors are the result of calculating the average of the 16 estimates made for the different 16 values of each imputed variable.

[α] Total number of observations varies according to the estimate as a consequence of the manual elimination of outliers presented by some imputed variables.

Table A.6: Results of the separate multilevel models for each explanatory ICT variable

VARIABLES	Mathematics	Science	Reading
ICT use outside of school for schoolwork	-10.634***	-12.775***	-13.907***
	(1.001)	(1.201)	(1.206)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations (min-max) $^{\alpha}$	25,276-25,738	25,276-25,738	25,276-25,738
Number of schools	879	879	879

VARIABLES	Mathematics	Science	Reading
ICT use outside of school for leisure	0.200	2.272**	1.221**
	(1.212)	(1.316)	(1.255)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations (min-max) $^{\alpha}$	25,598-25,650	25,598-25,650	25,598-25,650
Number of schools	879	879	879

VARIABLES	Mathematics	Science	Reading
Use of ICT at school in general	-5.559*** -5.559*** -5.559*** -5.559***	-7.718***	-7.735*** -7.735*** -7.735***
	(1.101) (1.101) (1.101) (1.101)	(1.315)	(1.122) (1.122) (1.122)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations (min-max) $^{\alpha}$	25,391-25,467	25,391-25,467	25,391-25,467
Number of schools	879	879	879

VARIABLES	Mathematics	Science	Reading
Students' ICT interest	3.746***	5.292***	5.431***
	(0.917)	(0.886)	(0.886)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations	25,237-25,339	25,237-25,339	25,237-25,339
Number of schools	879	879	879

VARIABLES	Mathematics	Science	Reading
Students' ICT as a topic in Social interaction	0.539	0.0302	-2.723***
	(0.827)	(1.014)	(0.915)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations	24,936-25,339	24,936-25,339	24,936-25,339
Number of schools	879	879	879

Table A.6: Results of the separate multilevel models for each explanatory ICT variable (*continuation)*

VARIABLES	Mathematics	Science	Reading
Starting Age for using ICT	-11.52***	-13.49***	-10.52***
	(0.924)	(1.059)	(1.025)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations	25,803-25,905	25,803-25,905	25,803-25,905
Number of schools	879	879	879

VARIABLES	Mathematics	Science	Reading
Computer / Students ratio	2.140**	2.761**	2.172*
	(1.225)	(1.414)	(1.239)
Constant and student, family, school, and location (Autonomous Communities) control variables	yes	yes	yes
Observations	25,863-25,941	25,863-25,941	25,863-25,941
Number of schools	879	879	879

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1*

β The coefficients and the standard errors are the result of calculating the average of the 16 estimates made for the different 16 values of each imputed variable.

α Total number of observations varies according to the estimate as a consequence of the manual elimination of outliers presented by some imputed variables.

Table A.7: Results of the multilevel model with a composite index

VARIABLES	(1) Composite Index
ICT use outside of school for schoolwork	-13.086***
	(1.172)
ICT use outside of school for leisure	4.292***
	(1.355)
Use of ICT at school in general	-4.528***
	(1.040)
Students’ ICT interest	3.063***
	(0.862)
Students’ ICT as a topic in Social interaction	-0.099
	(0.925)
Starting age for using ICT	-11.406***
	(0.983)
Computer / Students ratio	2.700**
	(1.208)
Female	-8.342***
	(1.749)
Index Immigration Status	8.156***
	(3.108)
Age of arrival of immigrant students	-5.639***
	(1.562)
Repetition of grade	-72.32***
	(2.111)
School truancy	-9.011***
	(1.146)
Starting age of ISCED 0	-0.446
	(1.282)
Language at home	-2.668
	(2.551)
Highest occupational status of parents (HISEI)	0.288***
	(0.0434)
Highest educational level of parents (HISCED)	-0.565
	(0.950)
Number of books at home	11.01***
	(0.713)
School ownership	-1.130
	(1.413)
Location	-0.708
	(1.065)
School autonomy	4.276
	(5.049)
Class size	0.480
	(0.701)
School size	0.00519**
	(0.00221)
Student-Teacher ratio	-0.0634
	(0.225)
Index proportion all teachers fully certified	-5.201
	(9.079)
Andalucía	-11.86***
	(3.094)

Table A.7: Results of the multilevel model with a composite index (*continuation*)

VARIABLES	(1) Composite Index
Aragón	7.765**
	(3.649)
Asturias	-4.730
	(3.225)
Baleares	0.752
	(3.328)
Canarias	-3.734
	(3.499)
Cantabria	2.029
	(3.943)
Castilla León	15.30***
	(3.901)
Castilla La Mancha	3.994
	(3.475)
Cataluña	5.363
	(3.785)
Extremadura	-9.825***
	(3.070)
Galicia	6.116
	(3.983)
La Rioja	3.383
	(3.577)
Madrid	10.08***
	(3.194)
Murcia	-5.935**
	(2.839)
Navarra	10.35***
	(3.246)
País Vasco	-12.55***
	(3.480)
Comunidad Valenciana	-
Constant	509.6***
	(11.68)
Observations (min-max) $^{\alpha}$	24,370-24,472
Number of schools	864

Robust standard errors in parentheses

**** p<0.01, ** p<0.05, * p<0.1*

$^{\beta}$ The coefficients and the standard errors are the result of calculating the average of the 16 estimates made for the different 16 values of each imputed variable.

$^{\alpha}$ Total number of observations varies according to the estimate as a consequence of the manual elimination of outliers presented by some imputed variables.

Table A.8: Mean of the dependent variable by competences and percentiles of performance

Percentiles	Mathematics	Science	Reading
	Mean	**Mean**	**Mean**
25^{th} percentile	440.274	440.320	448.826
50^{th} percentile	496.196	503.598	508.384
75^{th} percentile	548.157	560.322	560.391
90^{th} percentile	589.432	605.696	600.496

Source: compiled by the authors based on microdata from PISA 2015

Table A.9: Tests of coefficient equality across and between quantiles

VARIABLES	(1) Mathematics			
	25^{TH} quantile	50^{TH} quantile	75^{TH} quantile	90^{TH} quantile
ICT use outside of school for schoolwork				
F-test for equality coefficient across all quantiles		2.42*		
F-test for equality coefficient between quantiles				
25^{TH} quantile		3.08*	3.12*	5.33*
50^{TH} quantile			0.06	0.77
75^{TH} quantile				0.81
ICT use outside of school for leisure				
F-test for equality coefficient across all quantiles		0.16		
F-test for equality coefficient between quantiles				
25^{TH} quantile		0.08	0.23	0.06
50^{TH} quantile			0.07	0.14
75^{TH} quantile				0.38
Use of ICT at school in general				
F-test for equality coefficient across all quantiles		2.05**		
F-test for equality coefficient between quantiles				
25^{TH} quantile		2.52	5.57***	0.85***
50^{TH} quantile			0.07	0.00
75^{TH} quantile				0.01
Students' ICT interest				
F-test for equality coefficient across all quantiles		2.89**		
F-test for equality coefficient between quantiles				
25^{TH} quantile		0.05	1.76*	3.18**
50^{TH} quantile			2.73*	5.20**
75^{TH} quantile				0.38
Students' ICT as a topic in Social interaction				-
F-test for equality coefficient across all quantiles		0.31		
F-test for equality coefficient between quantiles				
25^{TH} quantile		0.37	0.04	0.04
50^{TH} quantile			0.85	0.00
75^{TH} quantile				0.47
Starting Age for using ICT				
F-test for equality coefficient across all quantiles		0.62		
F-test for equality coefficient between quantiles				
25^{TH} quantile		1.76	1.23	1.19
50^{TH} quantile			0.00	0.03
75^{TH} quantile				0.02

Table A.9: Tests of coefficient equality across and between quantiles (*continuation)*

VARIABLES	(1) Mathematics			
	25TH quantile	50TH quantile	75TH quantile	90TH quantile
Computer / Students ratio				
F-test for equality coefficient across all quantiles		0.53		
F-test for equality coefficient between quantiles				
25TH quantile		0.31	0.34	0.03
50TH quantile			1.54	0.28
75TH quantile				0.09
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes	Yes
Observations	20,438	20,438	20,438	20,438
Number of schools	756	756	756	756

VARIABLES	(1) Science			
	25TH quantile	50TH quantile	75TH quantile	90TH quantile
ICT use outside of school for schoolwork				
F-test for equality coefficient across all quantiles		3.45*		
F-test for equality coefficient between quantiles				
25TH quantile		5.84**	8.95*	1.97
50TH quantile			1.65	0.03
75TH quantile				1.91
ICT use outside of school for leisure				
F-test for equality coefficient across all quantiles		0.85		
F-test for equality coefficient between quantiles				
25TH quantile		0.07	0.47	1.86
50TH quantile			1.26	1.33
75TH quantile				0.37
Use of ICT at school in general				
F-test for equality coefficient across all quantiles		3.09**		
F-test for equality coefficient between quantiles				
25TH quantile		2.89*	5.86**	8.65***
50TH quantile			0.76	1.62**
75TH quantile				0.45
Students' ICT interest				
F-test for equality coefficient across all quantiles		1.91**		
F-test for equality coefficient between quantiles				
25TH quantile		3.22	2.29**	4.65**
50TH quantile			0.02	1.36**
75TH quantile				2.36
Students' ICT as a topic in Social interaction				
F-test for equality coefficient across all quantiles		1.15		
F-test for equality coefficient between quantiles				
25TH quantile		0.31	1.92	0.05
50TH quantile			0.88	1.89
75TH quantile				0.84

Table A.9: Tests of coefficient equality across and between quantiles (*continuation)*

VARIABLES	(1) Science			
	25TH quantile	50TH quantile	75TH quantile	90TH quantile
Starting Age for using ICT				
F-test for equality coefficient across all quantiles		2.06		
F-test for equality coefficient between quantiles				
25TH quantile		5.09*	0.86	0.36
50TH quantile			0.66	1.38
75TH quantile				0.20
Computer / Students ratio				
F-test for equality coefficient across all quantiles		0.66		
F-test for equality coefficient between quantiles				
25TH quantile		0.55	1.76	1.45
50TH quantile			0.26	0.35
75TH quantile				0.08
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes	Yes
Observations	20,438	20,438	20,438	20,438
Number of schools	756	756	756	756

VARIABLES	(1) Reading			
	25TH quantile	50TH quantile	75TH quantile	90TH quantile
ICT use outside of school for schoolwork				
F-test for equality coefficient across all quantiles		1.17		
F-test for equality coefficient between quantiles				
25TH quantile		2.17	3.41*	0.72
50TH quantile			0.63	0.18
75TH quantile				0.77
ICT use outside of school for leisure				
F-test for equality coefficient across all quantiles		0.42		
F-test for equality coefficient between quantiles				
25TH quantile		0.44	0.66*	0.00
50TH quantile			0.06	0.36
75TH quantile				0.61
Use of ICT at school in general				
F-test for equality coefficient across all quantiles		6.50***		
F-test for equality coefficient between quantiles				
25TH quantile		0.23	7.61***	3.37**
50TH quantile			18.31***	1.97
75TH quantile				0.16
Students' ICT interest				
F-test for equality coefficient across all quantiles		5.19***		
F-test for equality coefficient between quantiles				
25TH quantile		2.19	5.66**	13.28***
50TH quantile			0.78	7.80***
75TH quantile				5.00**

Table A.9: Tests of coefficient equality across and between quantiles (*continuation)*

VARIABLES	(1) Reading			
	25^{TH} quantile	50^{TH} quantile	75^{TH} quantile	90^{TH} quantile
Students' ICT as a topic in Social interaction				
F-test for equality coefficient across all quantiles		0.55		
F-test for equality coefficient between quantiles				
25^{TH} quantile		1.55	1.03	0.24
50^{TH} quantile			0.07	0.02
75^{TH} quantile				0.08
Starting Age for using ICT				
F-test for equality coefficient across all quantiles		3.43**		
F-test for equality coefficient between quantiles				
25^{TH} quantile		0.02	7.99***	3.01**
50^{TH} quantile			7.35***	4.22**
75^{TH} quantile				0.12
Computer / Students ratio				
F-test for equality coefficient across all quantiles		0.83		
F-test for equality coefficient between quantiles				
25^{TH} quantile		1.10	0.16	0.07
50^{TH} quantile			0.20	1.15
75^{TH} quantile				0.47
Constant and student, family, school, and location (Autonomous Communities) control variables	Yes	Yes	Yes	Yes
Observations	20,438	20,438	20,438	20,438
Number of schools	756	756	756	756

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

F statistics are reported for the test of equality of the coefficients across quantiles (i.e., Coefficient(0.25)=coefficient(0.50)= Coefficient(0.75)=coefficient(0.90)) and between quantiles (Coefficient(Q_i)=coefficient(Q_j), i,j=0.25,0.50,0.75,0.90).

CHAPTER 2

Can ICT Help Us To Improve Education? Causal Effects Of The Use Of ICT At Schools On Academic Performance In Madrid (Spain)*.

* I thank comments and suggestions from participants at the 32nd SASE Annual Conference (University of Amsterdam, July 2020), IEB internal seminar (Institut d'Economia de Barcelona, February 2021) and 23rd Annual International Conference on Education (Athens Institute for Education and Research, May 2021). I thank Dr. Luis Pires Jiménez for providing me with the data from the individualized evaluations in Madrid for this research.

2.1 Introduction

Information and communication technologies (ICT) have been and are a fundamental part of economic, social, and technological changes in society. Obviously, educational institutions have not been left out and have been affected by the arrival of ICT, which has meant and still means a major challenge for all the agents involved in the educational process.

It should be remembered that the term ICT encompasses different categories, such as (1) networks (users, software and hardware); (2) terminals (people's access points to information, such as computers or smartphones); and (3) services (e-mail, e-learning, etc.). Therefore, when we talk about ICT in education, we should not only think about the use of a computer by students to read course material or search for information, but also about the use of e.g., educational software or tools such as email that allow for fast communication between teacher and student.

In this sense, the need to teach classes online as a result of the health crisis resulting from the COVID-19, has highlighted the substantial differences between the different territories in terms of the use of ICT in the educational sphere. Those countries with a better previous implementation of ICT have had less difficulty in adapting their teaching to an online context, as they already had powerful educational software and had a teaching staff and students familiar with the use of these tools. In this sense, the 2018 PISA report shows that there are significant differences between OECD countries in terms of the use of technologies in teaching. By way of example, in the case of Spain, country to which the region we are analyzing in this research belongs, only 11.5% of the school principals indicated that they give incentives to teachers in their school to integrate digital devices in their teaching (see table V.B1.5.15 in OECD (2020)). This places Spain 50 points below the OECD average (56.7%) and makes it the OECD country with the lowest percentage, which seems to indicate that there is not a strong culture of integration of ICTs in the educational process.

Considering the fact that Spain seems to be behind the OECD in the importance of ICTs in the teaching process, this research aims to investigate empirically what effect the use of ICT resources to carry out projects or do exercises in class has on academic performance in this country. Specifically, we focus on analyzing the case of the Community of Madrid. We consider that the analysis of a region in Spain is particularly relevant, given that as the previously mentioned data show, in Spain as a whole there is still room to expand the use of ICTs in schools given that the majority of principals still do not consider them an important factor in the teaching process. Furthermore, in Spain the competence in education is delegated to the autonomous communities, so it is appropriate to focus on the concrete analysis of a region. Precisely because in Spain ICTs do not play the same role as in other countries, it is interesting to compare what students' results are depending on whether or not ICTs are used in the learning process. Only in this way is it possible to assess whether ICT is being adequately implemented in schools and having positive effects on academic performance and thus be in a position to make policy recommendations.

In this sense, the previous literature has pointed out various potential advantages of the use of ICT that would allow for the improvement of the academic performance of students (Fu, 2013), among which are: (1) greater student motivation (Bullock, 2001; Tüzün et al., 2009); (2) greater possibilities for cooperation and communication between teachers and students (Schulz et al., 2002; Koç, 2005); (3) stimulation of initiative and creativity (Allegra et al., 2001; Wheeler et al., 2002; Chai et al., 2010); (4) and greater individualization and flexibilization of education (Abell, 2006). In practice, as detailed in section 2.2 of this paper, many studies have been carried out at international level to try to evaluate the impact of the use of ICT on the process of acquisition of competences by students (Cox et al., 2004; Condie and Munro, 2006; and Claro, 2010). However, the conclusions are not clear, and studies can be found that show opposite results (see section 2.2), which seems to indicate that the potential benefits of the use of ICTs at schools depend on their proper implementation. Therefore, it is especially necessary to continue research in this field in order to try to determine what the real effects of the use of ICT are and to see if they are being applied successfully in the schools.

In order to achieve our objective of evaluating the impact of the use of ICT in schools on academic performance, in this research we are working with data from the individualized evaluations carried out at the end of the 2016-2017 school year in the fourth year of secondary education in all the schools in the Autonomous Community of Madrid. With these census data we estimate different models using an instrumental variables (IV) approach that allow us to establish causality between the use of ICT and the academic performance of students, as well as to distinguish whether these effects differ between students according to the quantile of performance in which each student is placed. In addition, as a robustness test, we also estimate the effect of ICT use in the classroom on academic performance using the propensity score matching (PSM) methodology. Our research is novel with respect to previous literature mainly for two reasons: (1) the analysis of data from individualized evaluations (census nature) by competences in Spain that allows us to identify which teacher teaches which student (see section 2.3.1); and (2) the application of quasi-experimental techniques (instrumental variables, quantile instrumental variables and propensity score matching) that consider the potential endogeneity that the use of ICT at schools presents.

The results of the main models show a positive impact of the use of ICT in the classroom on academic performance in English, social and civic competence and academic mathematics. The estimates obtained with the technique of quantile instrumental variable regression give more detailed results and show that there exist disparities in the impact of

ICT use on academic performance at the 5th through the 95th quantiles. Specifically, the results suggest that the positive effect of the use of ICT is particularly beneficial for students at the bottom part of the scores distribution in English. On the contrary, in Spanish, social and civic competence and academic mathematics this positive effect is especially relevant for students in the middle and upper percentiles of academic achievement. Based on these results we point out in our conclusions hypotheses on possible explanations and emphasize the need for further research on the basis of our findings.

The remainder of the chapter is structured as follows: Section 2.2 is a review of relevant literature; Section 2.3 provides details about the dataset; Section 2.4 outlines the methodology employed in this paper; Section 2.5 presents the main results; and Section 2.6 concludes with the final considerations.

2.2 Literature Review

The question of the effect that the introduction of ICT in the classroom has on the academic performance of students has been a subject of interest in recent years to researchers in different branches related to the educational field. Educators, education economists, pedagogues and psychologists, among others, have focused on analyzing this highly topical issue from different perspectives. However, as we will review in this section, the conclusions are still not clear and that is why this research aims to provide new empirical evidence that continues to help discern what effects the use of ICT in the schools is having in practice.

As mentioned in the previous section, several studies have found that the use of ICT in education could positively affect the students' academic performance because of the many potential advantages of using these tools in the classroom (Fu, 2013): (1) greater student motivation (Bullock, 2001; Tüzün et al., 2009); (2) greater possibilities for cooperation and communication between teachers and students (Schulz et al., 2002; Koç, 2005); (3) stimulation of initiative and creativity (Allegra et al., 2001; Wheeler et al., 2002; Chai et al., 2010); (4) and greater individualization and flexibilization of education (Abell, 2006). However, despite all these potential advantages of ICT use, the empirical evidence reviewed below shows that there is not a generalized conclusion on the impact of ICT use at school on academic achievement (Cox et al., 2004; Condie and Munro, 2006; and Claro, 2010). In this sense, one of the explanations for this lack of consensus may have to do with the variety of contexts evaluated. In our opinion, context makes an important contribution to understanding the relationship between ICT and students' academic performance and it is therefore advisable to carry out focused analyses in specific contexts that allow us to develop educational policy recommendations adapted to the particular context. In this sense, it could be that despite all the potential advantages previously mentioned, the use of ICT at schools has a negative impact on performance in specific contexts because for example teachers are not sufficiently trained in their use and misuse them (Cruz et al., 2018). Our research aims to provide new empirical evidence by focusing our analysis on a Spanish autonomous community, as well as overcoming some of the methodological limitations that studies in this area show and that merely allow us to talk about associations instead of about causal effects.

The following is a brief description of previous studies that have analyzed this relationship between the use of ICTs in schools and academic achievement. We focus on those studies that have focused on analyzing this relationship in secondary education in recent years.[10] We would like to point out that - taking into account the object of our research - we analyze only those studies that focus on the use of ICT in schools, but we exclude from our review those that have focused on analyzing the effect on academic performance of the mere availability of ICT resources in schools (Machin et al., 2010; Cristia et al., 2014; Belo et al., 2016; Tan Hew, 2017; Checchi et al., 2019). When reviewing the previous studies, we also indicate the methodology used in each one of them. We consider it important to know the methodologies used, given that most studies have applied regression techniques that only allow us to speak of associations, but not of causality. In this sense, our research goes a step further and provides new empirical evidence by applying quasi-experimental techniques. The following is a brief description of the most recent studies divided according to the sign of the association or causal effect they find.

Negative relationship between using ICT in schools and academic performance.

We find a majority group of studies that find a negative relationship between the use of ICT in schools and academic performance in secondary education. In this line, Gumus and Atalmis (2011), using data from PISA 2006 in Turkey and a Structural Equation Modeling, find that the use of computers at school for educational purposes affects students' reading scores negatively. Biagi and Loi (2013) analyze the data of PISA 2009 through OLS models and find that the use of ICT in the school curriculum is negatively correlated with students' PISA test scores in mathematics, reading and scientific literacy. In this same line, Skryabin et al. (2015) use a hierarchical linear modelling to analyze three international large-scale student assessment (TIMSS 2011; PIRLS 2011 and PISA 2012) and also find that ICT use at school is negatively associated with students' scores in reading, mathematics, and science in 8th grade students (13-14 years). In this line, Mediavilla and Escardíbul (2015) and Escardíbul and Mediavilla (2016), using PISA 2012 data and estimating a multilevel model, find that in Spain the use of ICT at school is negatively associated with academic performance in mathematics and in reading. Zhang et al. (2016) examine the trends of the relationship between ICT use and students' math and science achievements using PISA data from 2000 to 2012. Specifically, the authors

[10] Considering the pace at which ICTs are developing we focus on analyzing studies published in the last decade (from 2010 to the present).

estimate a three-level hierarchical linear modelling and find that internet use for education purposes at school has a negative influence on student academic performance. A similar result is obtained by Petko et al. (2017) who analyze PISA 2012 data estimating a weighted linear regression model and also find that school ICT use is negatively related with students' test scores in mathematics, reading and science. Hu et al. (2018) analyze data from the PISA 2015 using a multilevel model and find that ICT academic use is negatively correlated with student performance in mathematics, reading, and scientific literacy. In Spain, Mora et al. (2018) analyze the impact of a One Laptop per Child program introduced by the Catalan government employing a propensity score matching procedure. Their results indicate that the program had a negative impact on student performance in Catalan, Spanish, English, and Mathematics. More recently, Gómez-Fernández and Mediavilla (2021) estimate a multilevel regression model using PISA 2015 data and also find that a greater use of ICT in schools is associated with lower academic performance in reading, science and mathematics. In this line, Gorjón et al. (2021) use the Inverse Probability Weighting method to analyze PISA 2018 data in mathematics and find that students who make a very intensive use of ICT at schools perform worse in this competence.

Positive relationship between using ICT and academic performance.

In Beijing, Lai et al. (2015) study through a randomized field experiment the effects of a computer-assisted learning program and find evidence of improvements in the student standardized math scores. In Italy, Ferraro et al. (2018) applying a Bayesian Additive Regression Tree with PISA 2012 data, find that the use of ICT at school has a positive and strong impact on mathematic test scores. More recently, Fernández-Gutiérrez et al. (2020) estimate a multilevel model using PISA data in three different years (2009, 2012, 2015) and find that a higher frequency of use of ICT at school in Spain has a positive effect on scores in science.

Non-statistically significant relationship between using ICT and academic performance.

Some previous studies do not find evidence that there is a relationship between ICT and academic performance. In this line, Aypay (2010) estimating an OLS model analyze the PISA 2006 data for Turkey and find a non-statistically significant relationship between the use of computers at schools and academic performance in mathematics, science and reading. More recently, the previously mentioned research by Fernández-Gutiérrez et al. (2020) finds that a higher frequency of use of ICT at school in a Spanish Autonomous Community has non-significant effects in mathematics and reading.

In summary, the existing literature shows mixed evidence on the impact of the use of ICT at school for educational purposes on academic performance. However, we find important to note that most of the aforementioned studies have been based on statistical analyses that make it possible to establish associations but do not control for endogeneity problems and therefore do not allow us to speak of causal effects. In this sense, as shown, very few recent studies have applied experimental or quasi-experimental techniques that consider the potential endogeneity that ICT use at school variables present (Lai et al., 2015; Ferraro et al., 2018; Mora et al., 2018; Gorjón et al., 2021). However, it is striking that although based on the literature review carried out, most studies seem to indicate a negative association between ICT use at school and academic performance, if we look exclusively at the studies that use experimental or quasi-experimental methodologies, we find that two of them suggest a positive impact and two of them a negative impact. It seems, therefore, that the predominance of studies suggesting that ICTs have negative effects on performance disappears if we look at the studies that actually allow us to interpret the results in terms of causal effects. In this sense, the lack of empirical evidence on the impact of ICT use at schools on academic performance using experimental or quasi-experimental designs for causal inference is a major weakness of the existing literature in this area. In our study, we apply quasi-experimental techniques to overcome this limitation and provide new empirical evidence that can be interpreted in terms of causality.

2.3 Data and Variables

2.3.1 Institutional Background

The Spanish Education System (Ley Orgánica 3/2020) divides general education into the following stages: pre-primary education, primary education, compulsory secondary education, Bachillerato, vocational training and university education.

Pre-primary education is non-compulsory and is divided into two cycles. The first cycle covers up to 3 years of age and the second from 3 to 6 years of age, the latter being free of charge. At age 6, children enter compulsory education beginning with primary education. This stage comprises six academic years (from age 6 to 12). Following the Act on the Improvement of the Quality of Education, students carry out individualized evaluations at the end of the 3rd and 6th years of this educational stage. Subsequently, from the age of 12 to 16, children enter compulsory secondary education, which is the second and final compulsory educational stage and consists of four academic years. At the end of the 4th year of this educational stage, the students also carry out an individualized evaluation, these being the data we are working with in this research for the Autonomous Community of Madrid.

Once the compulsory education is finished, the students can accede to the Bachillerato, the basic vocational training or the intermediate vocational training. The Bachillerato lasts for two academic years (between 16 and 18 years of age) and allows access to higher education (advanced vocational training and university studies). Regarding the types of non-university educational institutions, we find diverse institutions according to their ownership and source of funding: (1) public schools: owned by the education authority and publicly-funded; (2) private schools: privately owned and privately-funded; and (3) publicly-funded private schools: privately owned but publicly-funded.

2.3.2 Dataset

In this research, we work with the data from the individualized evaluations carried out at the end of the academic year 2016-2017 in the Community of Madrid (Spain) to check the degree of acquisition of the socio-scientific, linguistic, and mathematical competences. Evaluations are conducted at the end of the third year of primary school (8-9 years old), sixth year of primary school (11-12 years old) and fourth year of secondary school (15-16 years old). In this research we focus on analyzing the impact of the use of ICT on academic performance in fourth year of secondary school.

The data are of a census nature, given that all Madrid students from public, publicly-funded private schools and private schools participated. The student and school participation data were as follows: (1) in the third year of primary school, a total of 71,384 students from 1,311 schools; (2) in the sixth year of primary school, a total of 66,625 students from 1,298 schools; (3) and in the fourth year of secondary school a total of 56,175 students from 787 schools However, the data set presents a major problem of missing values (see section 2.4.1 in methodology) and therefore the number of observations in our main models estimates has been significantly reduced from the initial observations.

The evaluations are carried out using tests that combine different item formats (closed response questions, semi-constructed response questions, constructed response questions that require the development of procedures and obtaining results, and open-ended questions) and that are constituted from cases that refer to situations similar to those that students may face in their lives. These assessment tests allow a direct score to be obtained using the Item Response Theory (IRT) methodology, which guarantees that the competences evaluated are adequately measured regardless of the level of difficulty of the tests. The scores are then transformed to a common scale with a mean referenced to 500 points and a standard deviation of 100 points, which is the one that has also been used in international studies such as PISA, PIRLS and TIMSS. In addition, the school principal, teachers, families, and students themselves complete a context questionnaire that allows for the evaluation of social, economic, and cultural factors of students, their families, the teachers and school that can influence the performance of students.

Finally, we would like to point out that one of the great advantages of this dataset, in relation to databases of international relevance such as PISA, is that the teacher questionnaire allows us to identify which teacher teaches which student. In PISA, for example, the database that has been used in most studies that have evaluated the relationship between ICT and academic performance, only the school in which the interviewed teacher teaches is identified, but not the classroom and students, so using the individualized evaluations allows us to perform a more rigorous analysis.

2.3.3 Variables

For the estimation of the models in this research, we have made use of different variables from both the competence tests and the context questionnaires. The dependent, independent and control variables are described below.[11] Tables A.1 to A.4 in the Appendix present the main descriptive statistics and the percentage of missing values for all the variables used in this research.

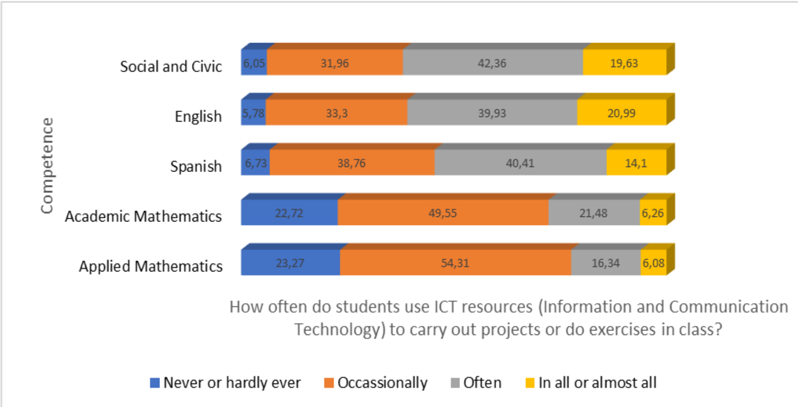
The dependent variable of all our models is the score reached by the students in the different competence tests: English, Spanish, social and civic competence and academic mathematics. Assessment in the field of linguistic communication competence focuses on written comprehension and expression in Spanish and written and oral comprehension and expression in the first foreign language (English). In the field of social and civic competence, assessment is evaluated through the student's knowledge, application, and reasoning about the contents in geography and history. Specifically, the evaluation assessed the ability of the students to carry out the cognitive processes related to knowledge and reproduction of historical facts, concepts and procedures, and their relationship and analysis, based on reasoning and reflection, which allows for the resolution of practical situations (Orden ECD/65/2015). In the field of mathematical competence, assessment involves the application of mathematical knowledge and reasoning for problem solving in functional contexts related to everyday life (Orden ECD/65/2015). As for the mathematical competence, in fourth year of secondary school students have to choose among two types of mathematics: academic mathematics or applied mathematics. Academic mathematics broadens and deepens the content of other courses (algebra and functions) and adds new content that is only seen in it (trigonometry or analytical geometry). This type of mathematics is oriented towards the study of a Bachillerato, of whatever type, that has mathematics. Applied mathematics, on the other hand, focuses on reinforcing the mathematics studied in the third year of secondary school. Instead of new contents as in academic mathematics, other contents already worked on in previous years are basically reviewed. Applied mathematics are geared to study vocational training or to enter the labor market. In this research we have analyzed only the academic mathematics competence, since the number of observations for applied mathematics is very small and the small sample size posed problems when analyzing the suitability of our instruments. Nevertheless, we consider that the results obtained for academic mathematics can be extrapolated to applied mathematics, since these are two highly similar subjects.

The independent variable of interest, whose causal effect on academic performance we want to evaluate, is "use of ICT in the classroom" and has been obtained from the context

[11] The correlation between all the variables included in our estimates has been tested. It is confirmed that the inclusion of all of them is appropriate given that in no case do we find statistically significant correlation coefficients greater than 0.5.

questionnaire made to teachers, in which they were specifically asked: "how often do students use ICT resources (Information and Communication Technology) to carry out projects or do exercises in class?" The response options were never or hardly ever, occasionally, often, and in all or almost all. The variable has been included in the regressions as a categorical variable taking values from 0 to 3, ordered from lowest to highest frequency of use. As evidenced in Figure 1, the frequency of ICT use in the classroom differs by competence. In general, we find that most teachers report an *occasional* or *often* use of ICT in the classroom. However, if we distinguish by competences, we find that those in which the highest percentage of teachers declare to use ICT *often* or *in all or almost all* are social and civic competence and English. Contrary, it can be seen that in mathematics lessons (academic or applied) the use of ICT is less frequent.

Figure 1: Distribution of responses to the variable "Use of ICT in the classroom"

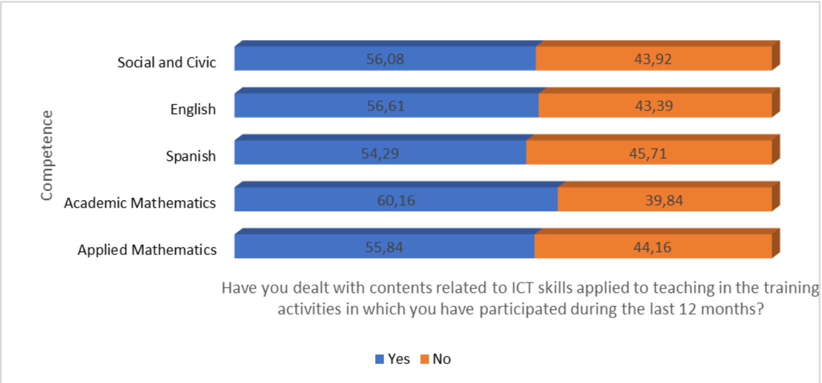


Source: Own elaboration with data from the individualized evaluations (Madrid, 16-17)

Since we use the technique of instrumental variables in our main models, the variable "use of ICT in the classroom" has been instrumented by means of the variable "ICT training of teacher" and "Index of ICT use by teachers of other subjects" which have also been obtained from the teacher questionnaire.[12] The rationale for the choice of these variable as the instruments is explained in section 2.4.2. In the case of the variable "ICT training of teacher", teachers were specifically asked: "have you dealt with contents related to ICT skills applied to teaching in the training activities during the last 12 months?" The response is dichotomous, taking a value of 0 in the case of the answer being "no" and 1 if they answer "yes". As shown in Figure 2, regardless of the competence assessed, just over 50% of teachers indicated that they had received training in ICT skills applied to teaching in the last 12 months.

[12] The "Index of ICT use by teachers of other subjects" was created manually by looking at the modal value in the answers for the variable "Use of ICT in the classroom" of the rest of the teachers in the same school.

Figure 2: Distribution of responses to the variable "ICT training of teacher"



Source: Own elaboration with data from the individualized evaluations (Madrid, 16-17)

Additionally, considering the factors that previous literature has shown to be important determinants of academic performance, different sets of control variables related to the characteristics of students, families, and the school have been included in our models. In relation to the individual and household characteristics of the students we have included the following variables: gender (dichotomous variable that takes value 0 if it is a boy and 1 if it is a girl); grade repetition in secondary school (value 0 indicates that the student has not repeated any course, value 1 that he/she has repeated once and value 2 that he/she has repeated twice or more); native (dichotomous variable that takes value 0 if the student was not born in Spain and 1 if he/she was born in Spain); age of beginning of ISCED 0 (value 0 indicates that it began before the age of two, value 1 indicates that it began with two years, value 2 with three years and value 3 with four years or more); and the educational level of the mother (the variable takes values from 0 (did not go to school) to 8 (doctorate) from lowest to highest educational level).[13]

In relation to the characteristics of the school, we have considered the following variables: the number of students per teacher; size of the school (total number of students enrolled); ownership of the center (the variable takes value 0 if the center is publicly owned, 1 if it is a publicly-funded private schools and 2 if it is private); and school resources and budget (the directors are asked whether the lack of budget and resources limits the effectiveness of the management of the center, it being possible to answer from 0 (not at all) to 4 (a lot)).

2.4 Empirical Strategy

2.4.1 Missing Values

As evidenced in tables A.1 to A.4 in the Appendix, our dataset presents a major problem of missing values. The first step to deal with missing values is to determine whether the

[13] We have chosen to include only the mother's education since it is highly correlated (p=0.6) with the father's education.

missing values are Missing Completely at Random (MCAR), Missing at Random (MAR) or Missing Not at Random (MNAR). MCAR implies that the occurrence of missing values is entirely random: there is no relationship between the missingness of the data and any observed or missing values. MAR means that the missingness just relate to the observed data: there is a systematic association between the propensity of missing values and the observed data and whether an observation is missing has to do with the values of an individual's observed variables. Finally, MNAR indicates that there is a relationship between the propensity of a value to be missing and its values. In the first two cases (MCAR and MAR), it is prudent to delete the data with missing values and including only complete cases. However, in the third case (MNAR) deleting observations with missing values can create a bias in the model. Therefore, to ensure the validity of our estimates, we have carried out a series of tests that suggest us a structure for the missing values in our database.

First, we have checked whether missing values are MCAR by running Little's MCAR test (Little, 1988 and Li, 2013) . Our results reveal that missing values are not MCAR because the p-value is lower than 0.05.[14] Therefore, we need further tests to establish whether the missingness in our variables of interest is related to another variable or variables in the dataset. To do so, we create dummy variables for whether a variable is missing: (1=missing and 0=observed) and we run a series of t-tests (continuous) and chi-square (categorical) tests between our variables of interest and other variables in the dataset to see if the missingness is related to the values of other variables. Some of the tests return a finding of significance and therefore suggest MAR.[15]

According to previous literature, there is a number of alternative ways of handling MAR (Kang, 2013), such as listwise or case deletion, pairwise deletion, mean substitution, regression imputation or multiple imputation. However, the possibility of applying one or another technique will depend on the specific characteristics of our dataset. Although in general multiple imputation is a good approach when analyzing data sets with missing data (Kang, 2013; Mediavilla, 2017), in our case, due to the high percentages of missing values in the database as a whole and not only in our variables of interest, we find inappropriate to carry out a process of multiple imputation. Basically, we would face two problems if we wanted to apply a multiple imputation process: (1) the percentage of missing values for most of the variables is too high and thus the imputation could lead to results that are fundamentally different from the findings based on the dataset complete cases (Adèr, 2008); and (2) the presence of missing values in a generalized way in the database makes imputation unviable since we do not have sufficient information on other variables either and therefore the total gain of observations would be minimal. For these reasons, we have chosen to work with the database in its original format and to consider

[14] Little's MCAR test results available upon request.

[15] T-test results available upon request.

only those students who have complete information for our variables of interest. Even in spite of high percentages of missing values, as suggested by Sun et al. (2012) our sample size is so large that missing data may pose no real problem, since the number of complete case data is sufficient to do any statistical analysis on the complete cases and thus, we expect the estimation results not to be very different without the cases with missing data.

However, in order to guarantee the representativeness of the sample and not to incur in any problem that could be derived from a structure of MAR missing values, we have analyzed the representativeness of the sample by carrying out a series of tests prior to the estimations. Specifically, we have carried out t-tests to test whether there are statistically significant differences between the mean of the variables of interest in our research, depending on whether we analyze the whole database or just the final research database (only including the students who have information for all the variables used, this is deleting the cases with missing information). The results confirm that for all the variables the mean differences are either not statistically significant or if they are, the variation is minimal if we consider the scale of values that the variable can take.[16]

Although we consider that the t-tests of means guarantee the representativeness of the sample we work with, we are aware that there could still be some problem of bias in our analysis. We therefore consider it important to point out that future rounds of the individualized evaluations carried out in the Community of Madrid should pay attention to this problem in order to improve the design of the study and overcome this limitation.

2.4.2 OLS and IV Regression

Traditionally, learning outcomes can be described with an education production function, which models academic performance as a function of different inputs: students, parents, teachers, and schools characteristics. Since the objective of our research is to analyze the impact of the use of ICT resources to carry out projects or do exercises in class on academic performance, educational outcomes on use of ICT should be regressed controlling for the previously mentioned variables regarding students, class, teacher and school characteristics:

$$Y_{ijk} = B_{0jk} + \propto_{jk} X_{jk} + \partial_{ijk} C_{ijk} + \tau_k T_k + U_{ijk} \quad (1)$$

where:
i = 1, 2, 3, …., n (student-level)
j= 1, 2, 3, …., n (class/teacher-level)
k= 1, 2, 3, …., n (school-level)
Y_{ijk}= Test score of student "i" in class "j" in school "k" in the evaluated competence.
B_{0jk}= Constant term.
X_{jk}= Indicator of the frequency of use of ICT to carry out projects or do exercises in class.

[16] T-test results available in table A.5 in the Appendix.

C_{ijk}= Vector of some background characteristics at the student-level (gender, grade repetition, native, ISCED 0 starting age, mother's educational level).
T_k= Vector of some characteristics at the school-level (ratio student-teacher, school size, school ownership and school resources).
U_{ijk}= Disturbance term.

The parameter of interest in the equation 1 is $\propto$, which denotes the effect of the use of ICT resources to carry out projects or do exercises in class on students' achievement in the different competences. However, regressing this equation by ordinary least squares regression (OLS) must be likely to yield biased estimates rather than the causal effect of the use of ICT in class on academic performance. In this sense, the OLS estimates do not allow us to clarify the direction of causality (i.e., our results could indicate that in those classes where students have higher levels of academic achievement, teachers are more inclined to use ICTs).

Selection into using ICT in the classroom can be a crucial issue in our estimation strategy, since there are unobserved factors potentially related to both the decision to use ICT and the students' academic performance. In this sense, teachers' decisions on ICT use can be endogenous for example if teachers who use ICT in their classes are systematically different from teachers who do not use it or have students in their classes systematically different from those whose teachers do not use ICT. It could be that students' academic performance and the use of ICT might correlate with unobservable factors because good teachers are more likely to use ICT or because as Fuchs and Woessman (2002) state: "decision to use computers may not be random, but rather endogenously determined by students' ability. If our control variables do not fully control for student ability and if this ability is related to measured student performance, our estimates on computer use may well reflect this ability bias in addition to any causal effect of computer use".

Hence, if we omit in our regressions some variables that are strongly correlated with the decision to use ICT in the classroom and with academic performance, the error term will be correlated with the explanatory variable and an endogeneity problem will show up. As a consequence, the effect of ICT use on academic performance can be confused with the effect of omitted variables. One way to confirm whether our variable of interest is in fact endogenous is to use the Durbin and Wu-Hausman tests. The null hypothesis of the Durbin and Wu-Hausman tests states that the endogenous variable (in our case "Use of ICT in the classroom") is uncorrelated with the error term. On the other side, the alternative hypothesis assumes a correlation different to cero between "Use of ICT in the classroom" and the error term. The results of the tests confirm that the null hypothesis is rejected and thus the variable "use of ICT in the classroom" is endogenous (see table A.6 in Appendix).

Not considering the problem of endogeneity in an OLS estimation could lead to biased results. In order to cope with these concerns, in this research we complement OLS estimates with an instrumental variable approach (IV) in two stages. In practice, this involves that the first stage of our estimations consists of the estimation of equation 2, where the dependent variable is "Use of ICT in the classroom" and the covariates are the instrumental variable and the set of control variables referred to characteristics of the students, teachers and the school:

$$X_{ijk} = \gamma_{1ijk}C_{ijk} + \gamma_{3k}T_k + \gamma_{4jk}Z_{jk} + U_{ijk} \quad (2)$$

where:
i= 1, 2, 3, …., n (student-level)
j= 1, 2, 3, …., n (class/teacher-level)
k= 1, 2, 3, …., n (school-level)
X_{ijk}= Indicator of the frequency of use of ICT to carry out projects or do exercises in class.
B_{0jk}= Constant term.
C_{ijk}= Vector of some background characteristics at the student-level (gender, grade repetition, native, ISCED 0 starting age, mother's educational level).
T_k= Vector of some characteristics at the school-level (ratio student-teacher, school size, school ownership and school resources).
Z_{jk}= "Use of ICT in the classroom" instrument.
U_{ijk} = a disturbance term.

We consider two variables as instruments (Z) for the variable "Use of ICT in the classroom" (X): (1) the variable "ICT training of teacher"; and (2) the variable "Index of ICT use by teachers of other subjects".[17] IV analyses uses Z to isolate the movements in X that are uncorrelated with U. Then, the isolated part of X that is not correlated with U is used to estimate an unbiased coefficient for X. Specifically, in the second stage, after estimating equation 2, we estimate the initial regression in equation 1 but substituting the original treatment variable ("Use of ICT in the classroom") by the treatment prediction estimated in the preceding stage ($\hat{X}$) and clustering by schools and classes (equation 3). Under this strategy, IV should give a consistent estimate of the causal impact of ICT use in class on students' performance in the different competences:

$$Y_{ijk} = \tau_{0jk} + \tau_{1jk}\hat{X}_{jk} + \tau_{2ijk}C_{ijk} + \tau_{3jk}T_{jk} + U_{ijk} \quad (3)$$

where τ_1 measures the causal effect of ICT use in class on student performance in English, Spanish, social and civic competence, or academic mathematics.

[17] We have chosen to use two instruments since, if both are valid, the use of multiple instruments will increase the precision of the IV estimate compared with the separate IV estimates (Wooldridge, 2002). The resulting IV estimate when multiple instruments are used can be viewed as the efficient linear combination of the separate IV estimates.

The instrument must satisfy two conditions to be valid: (1) it must be correlated with X (relevance condition; corr (Z,X) ≠ 0); but (2) it must not affect students' test scores (Y) directly, only indirectly through X (exclusion restriction; corr (Z, U)=0). First of all, we check whether our instruments satisfy the relevance condition and are sufficiently correlated with X. For doing so, we follow Stock et al. (2002) and we verify that the value of the F-statistic in the first stage of the estimation by instrumental variables (equation 2) exceeds the often-used threshold of 10 in all the competences. These results are shown in table A.6 in the Appendix. Thus, we can reject the null hypothesis that the instruments are weak. The relevance of the instrument can also be justified on logical grounds. Being better trained to use ICT may lead the teachers to be more familiar with ICT devices and the ways of using them, and thus increase their frequency of use (Gerick et al, 2017; Gómez-Fernández and Mediavilla, 2019). Regarding the use of ICT by other teachers, as suggested by Echazarra et al. (2016) teachers from the same school usually adopt similar teaching approaches fostering a school "teaching culture". In this sense, it is expected that teachers will be more likely to use ICT in their classes if the other teachers at school also use them. Thus, we confirm that our instrument satisfies the relevance condition so that corr(Z,X) ≠ 0.

As for the exclusion restriction, the verification of the exclusion restriction for both instruments cannot be guaranteed by any test since the error term is, by definition, unobservable. We can only justify the exogeneity of the instrument on logical grounds. Additionally, as we are considering two instruments, we can use the Sargan's and Basmann's chi-squared tests of overidentifying restrictions to check the exogeneity of our instruments as a set. These tests test whether all instruments are exogeneous assuming that a least one of the instruments is exogenous. Therefore, it is important to note that the tests will not necessarily detect a situation in which all instruments are endogenous. However, the results of these tests, together with the logical justification given below, suggest that the two instruments we employ satisfy the exclusion restriction.

First, we proceed to provide logical arguments supporting the exogeneity of our instruments. The instrument whose exogeneity we believe to be the easiest to argue in logical terms is the "Index of ICT use by teachers of other subjects". We consider that what teachers of other subjects do in their classrooms in terms of ICT use (Z_2), does not have a direct impact on the student's academic performance in the subject specifically evaluated (Y). In this sense, we find that the only way for Z_2 to end up influencing Y, is if the use of ICT by other teachers leads the teacher of the subject in question to also choose to use these tools (X) and this teaching method has an impact on student performance. We believe that by the mere fact of Z_2 being a variable that reflects the behavior of teachers other than the one who teaches that subject to the student, the exogeneity of the variable is demonstrated, this indicating that this variable Z_2 itself does not cause Y. Furthermore, in relation to the choice of Z_2, we find previous research that has used similar instruments to assess the impact of certain teaching strategies on academic performance. Specifically, Cordero and Gil-Izquierdo (2018) apply an instrumental variables' approach to study the impact of different teaching strategies on student achievement in mathematics and instrument the explanatory endogenous variable (teaching strategies in mathematics) by means of the aggregated indices of teaching strategies reported by non-mathematics teachers in the same school. Since the use of ICT can be considered as a teaching strategy, following these authors it seems appropriate to use the "Index of ICT use by teachers of other subjects" as an instrument. As for the other instrument, "ICT training of teacher", we also consider that whether the teacher is better or worse trained in ICT is unlikely to have direct effects on students' test scores after we account for its effects on ICT use in class. In this sense, we believe that the "ICT training of teacher" (Z_1) cannot directly affect academic performance, unless this results in a higher frequency of ICT use in the classroom (X) and this teaching method has an impact on student performance (Y). That is, we consider that this variable Z_1 itself does not cause Y. However, we are aware that the exogeneity of this variable may raise more doubts, since it reflects a characteristic of the teacher who teaches the subject we are evaluating and therefore exogeneity cannot be observed as clearly as in the case of the "Index of ICT use by teachers of other subjects". However, if we assume that the "Index of ICT use by teachers of other subjects" satisfies the exclusion restriction based on the logical argument previously explained, the Sargan's and Basmann's chi-squared tests serve to confirm the exogeneity of the variable "ICT training of teacher". According to these tests, we cannot reject the null hypothesis that our instrument set is valid and correctly specified in any of the competences evaluated (see table A.6 in the Appendix). Therefore, based on our tests we can consider that the variables "ICT training of teacher" and "Index of ICT use by teachers of other subjects" are a good set of instruments for IV since they seem to satisfy both the relevance and exclusion condition.

2.4.3 Quantile IV Regression

In the models described in the previous subsection, we have presumed that the effects of the use of ICT in the classroom are homogeneous and that the relationship between the use of ICT and academic performance is the same for every student in the class. However, the effect of using ICT is likely to be heterogeneous and could vary along with the individual performance of students. In order to examine whether these potential heterogeneous effects of ICT use exist at different points of the achievement distributions, we estimate the effect of the use of ICT at different quantiles (0.05, 0.25, 0.50, 0.75, and 0.95) of the students' test score distributions in the various competences. Following Buchinsky (1998), we estimate a quantile regression model that specifies the conditional quantile as a linear function of covariates. For the θ^{th} quantile, this model can be written as:

$$Y_{ijk} = \propto_{\theta} X'_{,jk} + \partial_{\theta} C'_{ijk} + \beta_{\theta} T'_{jk} + \tau_{\theta} Z'_{k} + u_{\theta ijk},$$
$$Quant_{\theta}(y_{ijk} | X, C, T, Z) = \propto_{\theta} X'_{,jk} + \partial_{\theta} C'_{ijk} + \beta_{\theta} T'_{jk} + \tau_{\theta} Z'_{k} \quad \theta \epsilon (0,1) \qquad (4)$$

where Y_i refers to the score obtained by student "i" n class "j" in school "k", and X'_{ijk}, C'_{ijk}, T'_{jk} *and* Z'_k denote the explanatory and control variables (the same ones included in the OLS and IV models); $u_{\theta ijk}$ is a mean zero error term. $Quant_\theta(y_{ijk}|X, C, T, Z)$ refers to the θ^{th} conditional quantile of the competence score Y_i, conditional on the different explanatory and control variables and $\theta \epsilon (0,1)$. Regarding, the distribution of the error term, it is left unspecified, but it is assumed that $u_{\theta ijk}$ meets the quantile restriction $Quant_\theta(u_{\theta ijk}|X, C, T, Z)$ = 0. The parameter of interest is $\propto_\theta$, that designs the marginal effects of the variable "Use of ICT in the classroom" and might vary over quantiles.

In order to overcome the endogeneity limitations of the variable "Use of ICT in the classroom" when estimating equation 4, we use IV quantile regressions as suggested by Chernozhukov and Hansen (2008). Specifically, we estimate the structural quantile functions defined by Chernozhukov and Hansen (2008) applying the method of Machado and Santos Silva (2019).[18] In this way, we can adequately estimate the impact of ICT use in the classroom on academic performance across various quantiles (0.05, 0.25, 0.50, 0.75, and 0.95).

Finally, we would like to point out that in addition to the possibility of estimating the effect of ICT use on different parts of the distribution of academic performance, the quantile regression method also has other advantages compared to OLS and IV: (1) it is less sensitive to outliers; (2) greater robustness by allowing the marginal effects of the independent variables to vary between quantiles of the dependent variable; and (3) if the error-terms are non-normal, quantile regression may be more efficient (Li, 2015). For all these reasons, the results obtained in the quantile estimates are of particular interest to our research.

2.4.4 Propensity Score Matching

In this section, we present a complementary analysis to instrumental variables as a robustness test of our results. As explained in the methodology section (2.4.2), in order to establish a causal relationship between ICT use and academic achievement in the absence of Randomized Controlled Trials, it is necessary to use quasi-experimental techniques, such as IV or matching methods. Although we have shown that the instruments used in the IV analysis seem to satisfy the necessary conditions to be considered relevant and exogenous, we believe that the use of another quasi-experimental technique and the obtaining of similar results are a guarantee of the robustness of our results. Specifically, in this section we use propensity score matching (PSM) (Rosenbaum and Rubin, 1985) to address the selection bias introduced by ICT use in the classroom.

[18] These estimations were performed using the routine *ivqreg2* in the Stata statistical software (Machado and Silva, 2019).

Using PSM we identify students that are fundamentally equivalent on observable variables but differ in treatment status (T= binary treatment indicator regarding use of ICT in the classroom[19]). The objective is to match similar treated and control individuals to make them as similar as possible in terms of observable variables. Since our data present a multilevel structure, we follow Arpino and Cannas (2016) and apply preferential within-cluster matching.[20] Differences in academic performance (Y^t and Y^c) that remain after these matches provide an accurate estimate of the Average Treatment effect on the Treated (ATT):

$$ATT = E[Y^t - Y^c \mid \text{T=1}] \quad (5)$$

However, it is very important to note that identification of average treatment effects through matching is based on two fundamental assumptions about treatment assignment: (1) conditional independence assumption or unconfoundedness, and (2) overlap assumption (Caliendo and Kopeinig, 2008).

One of the assumptions when using PSM is that unobservable characteristics play no role, and that the researcher observes all variables that simultaneously affect the potential outcome (i.e., test scores) and the treatment (i.e., frequent use of ICT in the classroom). Therefore, given a set of covariates X that are not affected by treatment, potential outcomes (Y^t, Y^c) are independent ($\perp$) of treatment assignment (T): $(Y^t, Y^c) \perp T|X$. This is called the unconfoundedness assumption or the conditional independence assumption. In our case study, we have a very complete database with a lot of information, and we feel confident that our variable list used in the PSM captures much of what differentiates students that use ICT in the class from students that do not. Nevertheless, we are aware that we cannot achieve complete certainty and that unconfoundedness is untestable given that there may exist unobserved characteristics relevant in our research. This is precisely the reason why we chose the IV analysis as the main model for this research, because IV explicitly allow selection on unobservables. However, we consider that assuming that the condition of unconfoundedness is satisfied and complementing IV with this analysis by means of PSM allows us to give robustness to the conclusions reached. Therefore, for the rest of this section we will assume that this condition holds. In addition, we perform a sensitivity analysis that confirms that the results obtained using PSM can be considered robust to violations of the unconfoundedness condition.

The second condition that must be satisfied in PSM is called the overlap assumption and it states that there are treated and untreated students at all values of X: $0 < \Pr(T = 1|X) < 1$. This condition ensures that students with the same X values have a positive probability of being in the treatment group ($\Pr(T = 1|X)$) and the control group ($1 - \Pr(T = 1|X)$).

[19] T=1 (use of ICT often, in all or almost all classes) T=0 (use of ICT never, hardly ever or only occasionally).

[20] The analysis is performed applying the *psmatch2* Stata routine (Leuven and Sianesi, 2002).

This condition is important because if this does not hold ($\Pr(T = 1|X = x') = 1$) we would only have treatment units with $X = x'$ and therefore we could not estimate the counterfactual.

The first step in a PSM study is to decide on the model to be used for estimation and then to identify all the variables to be included in the model. With regard to the model chosen, it is appropriate to use parametric techniques and considering that we are working with a binary treatment variable we opt for a logit estimation:

$$pr(T_i|X_i) = \frac{e^{\varphi \mathrm{h}(X_i)}}{1+e^{\varphi \mathrm{h}(X_i)}} \quad (6)$$

Where $\mathrm{h}(X_i)$ is a function of covariates with linear and higher order terms .The inclusion of higher order terms is only determined by the need to obtain an estimate of the propensity score that satisfies the balancing property (Grilli and Rampichini, 2011).

Once the model has been determined, the variables to be included must be decided, this being one of the key decisions in a PSM study, given that, as explained previously applying matching requires choosing a set of variables X that convincingly satisfy the unconfoundedness condition. Following Brookhart et al. (2006) we decided to include in our PS model variables that influence simultaneously the frequency of use of ICT (treatment) and the academic performance (outcome variable), but also variables that are unrelated to the treatment but related to the outcome. According to Brookhart et al. (2006) the inclusion of the latter type of variables will decrease the variance of an estimated exposure effect without increasing bias. Contrary, the authors find that including variables that are related to the treatment but not to the outcome will increase the variance of the estimated exposure effect without reducing bias. Considering the existing literature in the area of the determinants of academic performance, as well as other variables available in our data set feasibly related to the use of ICT in the classroom and academic performance simultaneously, or only academic performance, we decide to use the set of control variables included in our IV models in our PS model, given their proven relation in previous literature with academic performance and the potential relation of many of them with the treatment variable. To pass the balancing test, we included higher order terms: the second-degree polynomial of the variable "size of the school", based on its distribution, and interaction between the variables "school ownership" and "school resources".

Once the variables have been selected, we proceed to estimate a logistic model in which the previously mentioned variables are used as predictors of treatment, our dependent variable in the logistic regression. In this way, the propensity score (e), defined for each student as the probability to receive the treatment given its covariate values, is obtained:

$$e(X) = \Pr\{\mathrm{T} = 1|\mathrm{X}\} = \mathrm{E}\,\{\mathrm{T}|\mathrm{X}\} \quad (7)$$

The propensity scores obtained are then used to match students who use often, in all or almost all classes use ICT with those who never, hardly ever or only occasionally use ICT in the classroom but have similar e(x). Different algorithms can be used for this matching process. We decide to use the nearest neighbour (NN) matching (with replacement) and we specify the common support option. NN consists of an algorithm that matches each treated student with the non-treated student presenting the closest propensity score. Therefore, running a NN analysis involves deciding the criteria for "closeness". We define closeness by the value of the caliper (maximum permitted difference between matched subjects) and following Guo and Fraser (2010) we set it as $0.25\ x\ \sigma e$ (25% of the standard deviation of the estimated propensity score).

Once the matching process has been carried out, it is necessary to make sure that the balancing assumption (the observable characteristics of treated and non-treated students that were matched during the matching procedure are similar) and common support condition are satisfied after matching.[21] We find that propensity scores balanced well the matched treated and non-treated groups and that the standardized bias after matching (Rosenbaum and Rubin, 1985) is always less than 5% (see table A.7 in Appendix). Additionally, following Rubin (2001) we assess the balancing property using the Rubin's B (standardized difference of means of the linear index of the propensity score in the treated and non-treated group) and Rubin's R (ratio of treated to non-treated variances of the propensity score). Our results show that Rubin's B is below 0.25 and Rubin's R is between 0.5 and 2.0 and thus confirm that the balancing property is satisfied (see table A.7 in Appendix). Furthermore, the propensity score histogram by treatment status shows that the common support condition (there is a similar distribution of propensity scores between the treated and non-treated group) is satisfied (see figure A.1 in Appendix).

2.5 Results

2.5.1 OLS and IV Estimates

In this section, we present the results of the OLS and IV estimates. To begin with, table 1 reports the main results from the estimation of equation 1 by OLS.[22] Regressions have been estimated separately for each competence (English, Spanish, social and civic competence and academic mathematics) and include a set of control variables related to students', teachers' and school characteristics. To consider the clustering of students within classes and schools, we have adjusted the standard errors by computing a cluster robust standard error for the coefficient considering the school and class levels of aggregation.

[21] We check this using the *pstest and psgraph* commands in Stata after using *psmatch2*.

[22] The full results of this model are shown in the appendix: table A.8.

Table 1: OLS main estimates of use of ICT and students' academic performance

VARIABLES	(1) English	(2) Spanish	(3) Social and Civic	(4) Academic Mathematics
Use of ICT	6.142***	3.269**	3.005	4.928**
	(1.776)	(1.454)	(1.984)	(2.091)
Student characteristics	yes	yes	yes	yes
Teacher characteristics	yes	yes	yes	yes
School characteristics	yes	yes	yes	yes
Constant	6.142***	3.269**	3.005	4.928**
	(1.776)	(1.454)	(1.984)	(2.091)
Observations	15,005	16,000	15,391	14,657
R-squared	0.248	0.109	0.133	0.105

Robust standard errors (clustered by school and class) in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Considering the results presented in table 1 and that OLS models estimate an average treatment effect (ATE), we can affirm that there is a positive association between a higher frequency of use of ICT to carry out projects or do exercises in class and better academic performance in English, Spanish and Academic Mathematics. However, for social and civic competence the estimated coefficient is not statistically significant. Nevertheless, as explained in the methodology section, these estimates using OLS do not consider the potential endogeneity that the Durbin and Wu-Hausman tests confirm that exists for our explanatory variable of interest.

To overcome the limitations of OLS estimations due to endogeneity problems, we carry out the estimation by instrumental variables in two stages (IV 2SLS) where the variable "Use of ICT in the classroom" is instrumented by means of the variables "ICT training of teacher" and "Index of ICT use by teachers of other subjects".[23] Table 2 presents the main estimates of the second stage of the IV 2SLS estimation (equation 3) for the different competences.[24] The full results of these models estimated under IV are shown in the appendix (table A.9).

[23] These estimations were performed with the command *ivreg 2sls* in the Stata statistical software.
[24] First stage results available upon request.

Table 2: IV main estimates of the impact of the use of ICT on students' academic performance

VARIABLES	(1) English	(2) Spanish	(3) Social and Civic	(4) Academic Mathematics
Use of ICT	27.74**	8.561	30.85**	33.09**
	(11.17)	(6.119)	(13.25)	(15.68)
Student characteristics	yes	yes	yes	yes
Teacher characteristics	yes	yes	yes	yes
School characteristics	yes	yes	yes	yes
Constant	407.1***	467.0***	428.3***	449.2***
	(19.78)	(12.52)	(25.81)	(20.37)
Observations	7,461	7,044	6,505	6,811

Robust standard errors (clustered by school and class) in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

In table 2, we can observe that the results obtained by the IV estimates in English and academic mathematics are in line with those found by the OLS estimates, while in the case of Spanish the IV results show a non-statistically significant coefficient for the variable "Use of ICT in the classroom" and in social and civic competence the IV results show a statistically significant coefficient indicating a positive impact. However, it is not correct to compare between OLS and 2SLS IV because they apply to different populations. While OLS estimates provide the ATE, as explained by Imbens and Angrist (1994) IVs estimates provide the local average treatment effect (LATE). Therefore, the coefficients of the IVs estimates must be interpreted as the effect of the use of ICT in class on test scores for those students whose teachers were induced to take up treatment (using ICT in class) by the instrument (receiving training in ICT in the last 12 months or having fellow teachers who frequently use ICT in their subjects). This explains that the magnitude of the coefficients of the estimates differs significantly depending on whether they are estimated by OLS or IV. As we are using two instruments, the IV coefficients are a weighted average (depends on the relative strength of each instrument in the first stage) of the causal effects for instrument-specific compliant subpopulations (the two LATEs).

According to table 2 and the definition of the LATE, the estimates in table 2 can be interpret by saying that, in English, social and civic competence and academic mathematics, students whose teachers have dealt with contents related to ICT skills applied to teaching in training activities in the last 12 months or have fellow teachers in the school who frequently use ICT in their subjects (other than the one analyzed in each model), are significantly more likely to use ICT resources to carry out projects or do exercises in class and this use of ICT positively affects students' academic performance. The magnitude of the positive impact is relatively similar for the three competences, although slightly higher in mathematics. In Spanish, the results suggest that no causal effect is identified since the coefficient obtained is not statistically significant. These results therefore indicate that the use of ICT in the classroom has a positive impact on students' academic performance in certain competences. Since we are using quasi-experimental techniques, the effect found is causal and the positive impact of ICT on academic performance can be fully attributed to ICT themselves.

2.5.2 Quantile Regression Estimates

As explained in the methodology section, until now we have assumed in our estimations that the use of ICT affects academic performance in the same way for all students. Nevertheless, it could be that some students benefit (or be harmed) more from the use of ICT. For example, it could be that weaker students in terms of performance are more positively influenced by the use of ICT. This could be explained because ICT are often associated with increased motivation and interest on the part of students (Bullock, 2001; Tüzün et al., 2009), which is usually associated with higher levels of academic performance (Clark, 2014). In this line, previous literature has shown that students with lower levels of motivation are at the bottom of the distribution of test scores, and therefore are the ones who have the most room for improvement in terms of motivation (Mo, 2019). In this line, Scott (2005) analyses an example of the incorporation of ICT in the classroom and finds that students with lower ability levels benefit most from this intervention by greatly improving their motivation and confidence. However, there is also research that suggests that ICT could be very beneficial for most advanced students in the classroom in terms of academic performance. In this line, Avcu and Er (2020) point out that ICT can provide opportunities for the best students to develop and practice higher level thinking skills and achieve even better results. We consider that it is therefore interesting to analyze whether the impact of ICT on performance is similar or different in our specific case, depending on the competence and the quantile analyzed.

Considering this, we use quantile regressions to analyze this potential heterogeneity in the results.[25] Table 3 shows the main results of the quantile instrumental variable regressions that consider the potential endogeneity of the variable "Use of ICT in the classroom" which is instrumented by means of the variables "ICT training of teacher" and “Index of ICT use by teachers of other subjects”.[26]

[25] Table A.9 in the Appendix show the percentile values for the students’ scores in each competence.
[26] Full results of the quantile instrumental variable regressions are available in tables A.11-A.14 in the Appendix.

Table 3: Quantile instrumental variable regression main estimates of the impact of the use of ICT on students' academic performance by competences.

VARIABLES	P5	P25	P50	P75	P95
Use of ICT (English)	49.37***	36.79***	29.26***	22.43***	12.91*
	(8.310)	(5.388)	(4.631)	(5.018)	(6.868)
Student, teacher, and school characteristics	yes	yes	yes	yes	yes
Constant	209.4***	334.2***	409.1***	476.8***	571.3***
	(20.81)	(12.74)	(10.12)	(10.57)	(15.04)
Observations			7,461		
Use of ICT (Spanish)	6.637	6.994**	7.183***	7.380***	7.676**
	(5.793)	(3.508)	(2.699)	(2.581)	(3.810)
Student, teacher, and school characteristics	yes	yes	yes	yes	yes
Constant	353.8***	433.1***	475.2***	518.9***	584.5***
	(16.20)	(9.540)	(7.337)	(7.233)	(11.04)
Observations			7,044		
Use of ICT (Social and civic)	29.58***	32.34***	34.06***	35.85***	38.80***
	(10.88)	(6.969)	(5.462)	(5.517)	(8.735)
Student, teacher, and school characteristics	yes	yes	yes	yes	yes
Constant	277.2***	367.7***	423.8***	482.6***	579.2***
	(21.33)	(13.86)	(11.80)	(13.17)	(20.70)
Observations			6,505		
Use of ICT (Academic Mathematics)	9.896	25.43***	34.83***	45.06***	61.12***
	(9.938)	(7.025)	(7.038)	(8.683)	(13.04)
Student, teacher, and school characteristics	yes	yes	yes	yes	yes
Constant	316.5***	398.7***	448.5***	502.7***	587.7***
	(19.69)	(12.76)	(10.72)	(11.60)	(17.85)
Observations			6,811		

Robust standard errors (clustered by school and class) in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Without losing sight of the fact that the coefficients in table 3 must be interpreted as LATEs, we find that there is a positive and statistically significant effect of the use of ICT to perform school tasks on academic performance in English specially for students at the bottom of the score distribution. Specifically, the results indicate a positive and significant effect for students at the 5th, 25th, 50th and 75th percentiles, from less to more magnitude, respectively. Conversely, the coefficients obtained are not statistically significant for students at the 95th percentiles. Therefore, the instrumental quantile regressions suggest that there are positive effects derived from the use of ICT in English, especially for students located in the bottom part of the score distribution.

In Spanish, table 3 shows that the positive effect of the use of ICT in the classroom on academic performance is observed from the 25th percentile onwards and has a relatively similar magnitude in the different percentiles, although slightly higher in the higher percentiles. However, at the 5th percentile, the coefficient obtained is not statistically significant, which, added to the fact that the magnitude of the coefficients is relatively small, could explain why in the main regressions by instrumental variables (table 2) the coefficient obtained for the Spanish competence was not statistically significant. However, the result in Table 2 should be qualified by the results of the quantile regressions indicating that from the 25th percentile onwards, a positive impact of using ICT in the classroom is observed, although the magnitude is small and much less than that observed for the rest of the competences where this impact also occurs.

In social and civic competence, the results indicate that the positive effect of ICT use is sustained for all students, regardless of their performance percentile. However, if we look at the magnitude of the coefficients, we can see that in the higher percentiles this impact is of greater magnitude. Therefore, the instrumental quantile regressions suggest that there are positive effects derived from the use of ICT in social and civic competence, especially for students located in the upper part of the score distribution.

Finally, in the academic mathematics competence, table 3 suggests that ICT use does not affect academic performance of students located in the bottom part of the distribution (5th percentile) but do affect academic performance from the 25th percentile onwards. Specifically, the results suggest that there is a statistically significant positive effect of using ICT in class and that the magnitude of this positive effect increases as we move to the higher part of the distribution, reaching its maximum at the 95th percentile. In fact, the coefficient for the 95th percentile in academic mathematics is the highest of all the estimated models.

These findings reveal interesting information that could not be identified in our OLS and IV models. Disparities in the impact of ICT use on academic performance exist at the 5th through the 95th quantiles. Specifically, the results of the estimates of the quantile instrumental variable regressions considering the potential endogeneity of the variable "Use of ICT in the classroom" suggest that the positive effect of the use of ICT in the classroom on academic performance is particularly beneficial for students at the lower end of the distribution of scores in English. Conversely, in Spanish, social and civic competence and academic mathematics this positive effect is especially significant for students in the middle and upper percentiles of academic achievement.

2.5.6 Propensity Score Matching

The results obtained using PSM methodology (table 4) and applying preferential within-cluster matching suggest similar conclusions to those obtained using IV. It is confirmed that a frequent use of ICT in the classroom seems to have a positive impact on academic performance in English, social and civic competence and academic mathematics. In line with the IV results, the magnitude of the positive impact is relatively similar for the three competences, although slightly higher in academic mathematics.

Table 4: PSM estimates of the impact of the use of ICT on students' academic performance

	(1) English	(2) Spanish	(3) Social and Civic	(4) Academic Mathematics
ATT (Use of ICT)	11.089**	7.974*	10.746**	13.753**
	(2.398)	(2.632)	(2.320)	(3.405)
Observations	15,629	16,731	15,882	16,224

Robust standard errors (clustered by school and class) in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

As explained in section 2.4.4, matching relies on the unconfoundedness assumption, which is not testable. Next, we run a sensitivity analysis to assess the bias of causal effect estimates in case the unconfoundedness assumption is not verified (Ichino et al. 2008). This analysis simulates a potential confounder to assess the robustness of the estimated treatment effects with respect to deviations from the unconfoundedness assumption. For doing so, we follow Ichino et al. (2008) and simulate a binary cofounder whose parameters are equal to those of a matching variable. This is justified because the unobserved cofounder (U) and the covariates used in the matching process are expected to have similar parameters of association. Once the cofounder is simulated, it is included as an additional regressor in the estimation of the propensity score and in the following calculation of the ATT. This procedure is repeated for 100 simulations of the cofounder and the ATT is then computed as the average of the individual ATT obtained for the different simulations.[27] The results of this sensitivity analysis (see table A.15 in Appendix) confirm that unobservable cofounders seem to be not strong enough to explain the entire difference in academic performance between the treated and non-treated students and therefore suggest that our baseline estimate is rather robust to deviations from the unconfoundedness assumption.

[27] We use the *sensatt* command in Stata with the confounder U calibrated in order to mimic the variable "student gender".

2.6 Final Considerations

The results obtained in this research suggest that the use of ICT in class to carry out projects or do exercises positively affects the academic performance of secondary education students in some competences and that this positive effect is particularly relevant for certain quantiles of academic performance.

With regard to the competences evaluated, the results for the set of students in IV models show that the positive impact of using ICT in the classroom is observed in English, social and civic competence and academic mathematics, while in Spanish the coefficients obtained for our explanatory variable of interest are not statistically significant. Furthermore, based on the magnitude of the coefficients, the results indicate that this positive impact is particularly relevant in mathematics. It should be remembered that since we are working with IV and we have instrumented the variable "use of ICT in the classroom" by means of the variables "ICT training of teacher" and "Index of ICT use by teachers of other subjects", the correct interpretation of our results is as a LATE: the effect of the use of ICT in class on test scores for those students whose teachers were induced to take up treatment (using ICT in class) by the instrument (receiving training in ICT in the last 12 months or having fellow teachers who frequently use ICT in their subjects).

These previously described results are estimated by the method of IV that models the conditional mean of the response. However, the results obtained through the technique of quantile IV regression allow us to know more specific information, since as has been explained this technique is the generalized form of median regression for the determined quantiles and allow the marginal effects of our independent variable to differ across the quantiles of academic performance (our dependent variable). The results obtained through the use of this technique continue to suggest that there is a positive impact of the use of ICT on academic performance in English, social and civic competence, and academic mathematics, but they incorporate new details about the students that are particularly affected by the use of ICT and about the impact of ICT use on academic performance in Spanish. Specifically, the results show that the use of ICT in the classroom is particularly beneficial for students at the lower end of the distribution of scores in English, and students in the upper percentiles in Spanish, social and civic competence and academic mathematics. In Spanish, the results show that there is a positive effect, but only for students from the 25th percentile onwards and from a relatively small magnitude. These two facts explain why a positive impact was not observed when we only modelled the conditional mean of the dependent variable in the regressions by instrumental variables.

We believe it is important to emphasize that these results have been obtained for the specific case of the Autonomous Community of Madrid and therefore it is not correct to draw generalized conclusions applicable to any context. The characteristics of Madrid's classrooms in terms of ICT use may differ greatly from those of other territories, outside Spain or even within the country itself. This is precisely one of the reasons that explains the disparity of results in the previous literature and one of the motivations for carrying out this research by focusing on a particular context. For all these reasons, the interpretation of these results and the suggestions made below on the basis of them must always be read without losing sight of the fact that they refer to a specific context.

The results we have obtained lead us to conclude that ICT can be a great tool to incorporate more frequently in the classroom given its positive effects on academic performance. However, these same results call for further research on the impact of these tools in order to better understand the causes of the impacts we encounter. Below we point out some potential explanations for the results obtained. However, in any case these are merely hypotheses that would of course require future research in order to provide an accurate response, something that is only possible by carrying out studies, preferably of a qualitative nature, that allow us to investigate in detail how ICT are used in the classroom and not merely how often they are used.

With regard to the differential effect by competences, the fact that they affect some competences more than others could be an indication that ICTs have been better adapted to the curricula of some subjects than others. In this sense, it could be that - in spite of being both linguistic competences - the positive effect on the competence of English is of greater magnitude than that obtained for Spanish due to the fact that in this subject there has traditionally been a greater use of technological tools, such as the use of audios or videos to improve listening comprehension. Having implemented technological resources over the years, teachers and curricula could have been better adapted to the use of ICT and therefore be able to take greater advantage of their use. Furthermore, it also plays in their favor that since it is a subject taught in almost every school in the world, it is easy to find much more educational software available (such as online games, videos and podcasts, portals with online lessons). This last point could also explain the magnitude of the positive impact on social and civic competence and academic mathematics since there are also multiple ICT resources that can be found, for example on the internet, for learning these competences. The result for academic mathematics is especially relevant, given that despite the fact that it is the subject where ICT is least frequently implemented (figure 1), the results seem to suggest that those teachers who implement them are using them properly and taking advantage of their potential benefits.

However, it remains to be explained, for example, why in English the use of ICT seems to particularly affect students at the lower end of the distribution, while for the other competences an inverse trend is observed. This is one of the most relevant results of our research, but at the same time it is also one of the results that we believe should be studied in more depth. These results could indicate that for our specific case of analysis, the Community of Madrid and the fourth-year students of secondary education, the practical application of ICT would be better oriented to one group of students than to another, in terms of academic performance. In English, it seems that ICT could be used to improve the learning of the worse performing student. In this sense, it could be that the best students in terms of performance require ICT tools that allow them to develop and practice higher level thinking skills and achieve even better results (Avcu and Er, 2020), while the tools used in the classrooms in the English competence do not fit this purpose, but only go in the direction of awakening motivation, something that primarily affects the worst performing students (Scott, 2005). Conversely, in the other competences, the opposite seems to be happening and ICT tools seem to be better oriented towards students at the top of the distribution of scores, so that this group of students ends up benefiting most from them.

In order to find out with certainty what is the concrete cause of the differential causal effects that we find, qualitative research to investigate the specific uses of ICTs is needed. However, we consider this research relevant as it opens the way and serves as a starting point for forthcoming studies. Additionally, as future lines of research, we think that it would be interesting to analyze the impact of ICT use in the classroom on academic performance at other educational levels, such as primary education. It could be that the impact of ICTs may differ from that found for secondary education because of the different characteristics of the students.

Finally, we consider it relevant to point out that teacher training in ICT is a key aspect in ensuring that these tools are used appropriately in schools. In this sense, we believe it is essential to emphasize that only with teachers correctly trained in the use of these tools will it be possible to make a successful use of them, allowing ICTs to become one more element of teaching that will improve the quality of education and the acquisition of competences by students. The literature shows that theoretically ICTs offer many advantages for the educational sphere (Fu, 2013), but only a correct use of them is a guarantee that they will finally succeed in having a positive impact on the academic performance of all the students and in all the competences. Therefore, in terms of educational policy recommendations, we believe that ICT training for teachers should be improved and that policies aimed at increasing the use of ICT in schools should be carefully designed and based on quantitative and qualitative studies that allow us to discern in which subjects and in what way they should be applied to have a positive impact on the learning process.

2.7 Appendix

Table A.1: Descriptive statistics and percentages of missing values (Subsample containing complete cases for English)

Variable	Obs	Mean	Std. Dev.	Min	Max	% Missing Values
English score	7,461	506.47	91.50	240.71	734.80	15.18
Use of ICT in English	7,461	1.79	0.84	0	3	37.60
ICT training of English teacher	7,461	0.55	0.50	0	1	47.76
Index of ICT use in other subjects	7,461	1.50	0.52	0	3	60.22
Student gender	7,461	0.50	0.50	0	1	0.11
Grade repetition	7,461	0.22	0.49	0	2	43.07
Native Student	7,461	0.88	0.32	0	1	42.00
ISCED 0 starting age	7,461	1.20	0.93	1	3	41.94
Mother's educational level	7,461	4.02	1.88	0	8	44.34
Ratio students-teacher in English	7,461	26.97	4.81	1	45	0,00
School size (total number of students)	7,461	754.41	437.31	4	2,638	22.12
School ownership	7,461	0.62	0.69	0	2	18.20
School resources	7,461	2.11	0.86	0	3	18.39

*The descriptive statistics have been calculated for the subsamples of complete cases considered in the main estimates (instrumental variables) of this research.

Table A.2: Descriptive statistics and percentages of missing values (Subsample containing complete cases for Spanish)

Variable	Obs	Mean	Std. Dev.	Min	Max	% Missing Values
Spanish score	7,044	515.39	80.54	68.42	775.86	15.13
Use of ICT in Spanish	7,044	1.56	0.88	0	3	34.72
ICT training of Spanish teacher	7,044	0.57	0.50	0	1	47.66
Index of ICT use in other subjects	7,044	1.56	0.53	0	3	61.60
Student gender	7,044	0.50	0.50	0	1	0.11
Grade repetition	7,044	0.21	0.48	0	2	43.07
Native Student	7,044	0.89	0.31	0	1	42.00
ISCED 0 starting age	7,044	1.18	0.93	0	3	41.94
Mother's educational level	7,044	4.06	1.89	0	8	44.34
Ratio students-teacher in Spanish	7,044	26.96	4.85	5	39	0.00
School size (total number of students)	7,044	772.01	464.87	5	2,638	22.12
School ownership	7,044	0.65	0.69	0	2	18.2
School resources	7,044	2.10	0.89	0	3	18.39

* The descriptive statistics have been calculated for the subsamples of complete cases considered in the main estimates (instrumental variables) of this research.

Table A.3: Descriptive statistics and percentages of missing values (Subsample containing complete cases for social and civic competence)

Variable	Obs	Mean	Std. Dev.	Min	Max	% Missing Values
Social and Civic score	6,505	510.57	97.25	0	1015,61	17.17
Use of ICT in Social and Civic	6,505	1.75	0.82	0	3	37.00
ICT training of Social and Civic teacher	6,505	0.53	0.50	0	1	50.15
Index of ICT use in other subjects	6,505	1.51	0.55	0	3	60.64
Student gender	6,505	0.50	0.50	0	1	0.11
Grade repetition	6,505	0.22	0.49	0	2	43.07
Native Student	6,505	0.88	0.32	0	1	42.00
ISCED 0 starting age	6,505	1.18	0.94	0	3	41.94
Mother's educational level	6,505	4.04	1.88	0	8	44.34
Ratio students-teacher in Social and Civic	6,505	27.05	4.92	5	39	0.00
School size (total number of students)	6,505	772.98	469.37	6	2,638	22.12
School ownership	6,505	0.61	0.68	0	2	18.20
School resources	6,505	2.14	0.87	0	3	18.39

* The descriptive statistics have been calculated for the subsamples of complete cases considered in the main estimates (instrumental variables) of this research.

Table A.4: Descriptive statistics and percentages of missing values (Subsample containing complete cases for Academic Mathematics)

Variable	Obs	Mean	Std. Dev.	Min	Max	% Missing Values
Academic Mathematics score	6,811	505.16	97.95	159.87	1034,28	25.63
Use of ICT in Academic Mathematics	6,811	1.10	0.80	0	3	34.64
ICT training of Ac. Mathematics teacher	6,811	0.58	0.49	0	1	41.21
Index of ICT use in other subjects	6,811	1.75	0.56			61.73
Student gender	6,811	0.51	0.50	0	1	0.11
Grade repetition	6,811	0.15	0.41	0	2	43.07
Native Student	6,811	0.89	0.31	0	1	42.00
ISCED 0 starting age	6,811	1.17	0.93	0	3	41.94
Mother's educational level	6,811	4.12	1.87	0	8	44.34
Ratio students-teacher in Ac. Mathematics	6,811	27.23	4.76	5	37	0.00
School size (total number of students)	6,811	800.39	488.56	5	2,638	22.12
School ownership	6,811	0.60	0.68	0	2	18.20
School resources	6,811	2.13	0.83	0	3	18.39

* The descriptive statistics have been calculated for the subsamples of complete cases considered in the main estimates (instrumental variables) of this research.

Table A.5: T-test results (Comparison of mean values between the complete cases and the sample of students included in our final estimates)

	Complete cases (1)		*Missing group (0)*		*Minimum and maximum values*		*T-test* *diff= mean(0) - mean(1) Ho: diff = 0 and Ha: diff!=0*	
Variable	**Obs.**	**Mean**	**Obs.**	**Mean**	**Min**	**Max**	**Diff.**	**Pr(|T| > |t|)**
				English				
Mean Score	40,198	497.15	7,461	506.47	240.71	734.80	-9,32	0.00
Use of ICT	27,603	1.75	7,461	1.79	0	3	-0.04	0.00
ICT training	21,891	0.57	7,461	0,55	0	1	0.02	0.00
ICT use in other subjects	14,890	1,46	7,461	1,50	0	3	-0,03	0.00
Gender	48,679	0.50	7,461	0.50	0	1	-0.01	0.44
Repeater	24,530	0.23	7,461	0.22	0	2	0.01	0.04
Native	25,130	0.87	7,461	0.88	0	1	-0.01	0.00
Starting age of ISCED 0	25,166	1.22	7,461	1.20	1	3	0.02	0.04
Mother educational level	23,815	4.12	7,461	4.02	0	8	0.10	0.00
Student-Teacher ratio	48,730	27.21	7,461	26.97	1	45	0.24	0.00
School size	36,298	817.87	7,461	754.41	4	2,638	63.46	0.00
School ownership	38,506	0.49	7,461	0.62	0	2	-0.12	0.00
School lack of resources	38,394	2.21	7,461	2.11	0	3	0.09	0.00
				Spanish				
Mean Score	40,645	495.91	7,044	515.39	68.42	775.86	-19.47	0.00
Use of ICT	29,638	1.63	7,044	1.56	0	3	0,07	0.00
ICT training	22,364	0.54	7,044	0.57	0	1	-0.03	0.00
ICT use in other subjects	14,534	1.53	7,044	1.56	0	3	-0.02	0.00
Gender	49,087	0.50	7,044	0.50	0	1	0.00	0.67
Repeater	24,947	0.23	7,044	0.21	0	2	0.02	0.00
Native	25,547	0.87	7,044	0.89	0	1	-0.02	0.00
Starting age of ISCED 0	25,583	1.22	7,044	1.18	1	3	0.04	0.00
Mother educational level	24,432	4.10	7,044	4.06	0	8	0.04	0.08
Student-Teacher ratio	49,147	27.21	7,044	26.95	1	45	0.26	0.00
School size	36,715	813.39	7,044	774.01	4	2,638	39.38	0.00
School ownership	38,923	0.49	7,044	0.65	0	2	-0.15	0.00
School lack of resources	38,811	2.21	7,044	2.10	0	3	0.10	0.00

Table A.5: T-test results (*continuation*)

	Complete cases (1)		*Missing group (0)*		*Minimum and maximum values*		*T-test* diff= mean(0) - mean(1) Ho: diff = 0 and Ha: diff!=0*	
Variable	**Obs.**	**Mean**	**Obs.**	**Mean**	**Min**	**Max**	**Diff.**	**Pr(|T| > |t|)**
Social and civic competence								
Mean	40,038	496.67	6,505	510.58	0	1015.61	-13.90	0.00
Use of ICT	28,897	1.76	6,505	1.75	0	3	0.01	0.54
ICT training	21,508	0.57	6,505	0,53	0	1	0.04	0.00
ICT use in other subjects	15,613	1.47	6,505	1.51	0	3	-0.04	0.00
Gender	49,626	0.50	6,505	0.50	0	1	0.00	0.76
Repeater	25,486	0.23	6,505	0.22	0	2	0.01	0.16
Native	26,086	0.87	6,505	0.88	0	1	-0.14	0.00
Starting age of ISCED 0	26,122	1.22	6,505	1.28	1	3	0.04	0.00
Mother educational level	24,711	4.11	6,505	4.04	0	8	0.07	0.01
Student-Teacher ratio	49,686	27.19	6,505	27.05	1	45	0.14	0.02
School size	37,254	812.99	6,505	772.98	4	2,638	40.02	0.00
School ownership	39,462	0.50	6,505	0.60	0	2	0.10	0.00
School lack of resources	39,350	2.20	6,505	2.14	0	3	0.06	0.00
Academic mathematics								
Mean	34,980	498.48	6,811	505.16	159.87	1182.01	-6.69	0.00
Use of ICT	29,913	1.11	6,811	1.10	0	3	0.01	0.10
ICT training	26,221	0.60	6,811	0.58	0	1	0.03	0.00
ICT use in other subjects	14,693	1.67	6,811	1.74	0	3	-0.96	0.00
Gender	49,320	0.49	6,811	0.50	0	1	0.00	0.13
Repeater	25,180	0.24	6,811	0.15	0	2	0.09	0.00
Native	25,780	0.87	6,811	0.89	0	1	0.02	0.00
Starting age of ISCED 0	25,816	1.22	6,811	1.18	1	3	0.04	0.00
Mother educational level	24,465	4.09	6,811	4.11	0	8	-0.03	0.23
Student-Teacher ratio	49,380	27.17	6,811	27.23	1	45	-0.06	0.32
School size	36,948	808.28	6,811	800.39	4	2,638	7.88	0.22
School ownership	39,156	0.50	6,811	0.60	0	2	0.10	0.00
School lack of resources	39,044	2.20	6,811	2.13	0	3	0.07	0.00

*Complete cases group includes the original complete cases in our database and missing group includes only the cases that have been considered in our main estimates given that have values for all the dependent and independent variables used in this research for each of the competences.

Table A.6: Durbin and Wu-Hausman tests for endogeneity*, first-stage F-test for relevance**, and Sargan's and Basmann's chi-squared tests for exogeneity***

English			
Durbin (score) chi2(1)	23,16	*p-value*	0,00
Wu-Hausman F(1,7449)	23,20	*p-value*	0,00
First-stage F statistic	226,54	*Prob > F*	0,00
Sargan (score) chi2(1)	0.34	*p-value*	0.56
Basmann chi2(1)	0.34	*p-value*	0.56
Spanish			
Durbin (score) chi2(1)	3,62	*p-value*	0,05
Wu-Hausman F(1,7032)	3,61	*p-value*	0,05
F-statistic (Relevance)	477,10	*Prob > F*	0,00
Sargan (score) chi2(1)	2.04	*p-value*	0.15
Basmann chi2(1)	2.03	*p-value*	0.15
Social and Civic			
Durbin (score) chi2(1)	16,15	*p-value*	0,00
Wu-Hausman F(1,6493)	16,16	*p-value*	0,00
F-statistic (Relevance)	227,269	*Prob > F*	0,00
Sargan (score) chi2(1)	0.02	*p-value*	0.90
Basmann chi2(1)	0.02	*p-value*	0.90
Academic Mathematics			
Durbin (score) chi2(1)	19,75	*p-value*	0,00
Wu-Hausman F(1,6799)	19,78	*p-value*	0,00
F-statistic (Relevance)	173,62	*Prob > F*	0,00
Sargan (score) chi2(1)	0.70	*p-value*	0.40
Basmann chi2(1)	0.70	*p-value*	0.40

*The null hypothesis of the Durbin and Wu–Hausman tests is that the variable under consideration can be treated as exogenous. **The null hypothesis of the F-test is that the coefficient of all instruments is equal to 0. We consider that our instrument is not weak if the first-stage F statistic exceeds 10. *** The null hypothesis of the Sargan's and Basmann's chi-squared tests of overidentifying restrictions is that the instruments as a group are exogenous.

Table A.7: % Bias, Rubin's B and Rubin's B (Balancing property)

	English	Spanish	Social and Civic	Academic Mathematics
Variable	%Bias*			
Student gender	-0.8	-3.1	0.6	2.7
Grade repetition	-1.5	-3.1	-4.6	-4.3
Native student	4.3	4.6	4.5	3.8
ISCED 0 starting age	-2.0	-3.3	-3.5	-4.2
Mother's educational level	-4.3	4.2	2.9	4.2
Ratio students-teacher in English	2.0	-2.9	-2.6	-1.0
School size (total number of students)	-3.5	0.6	2.4	0.4
School ownership	4.9	3.8	4.9	4.6
School resources	-3.8	-3.0	-4.8	-3.8
Rubin's B	0.16	0.13	0.14	0.19
Rubin's R	0.93	0.97	0.97	0.88

* Bias (%): standardized percentage difference in all the covariates between the treated and control samples after matching.

Figure A.1: Propensity score histogram for the treated and not-treated groups

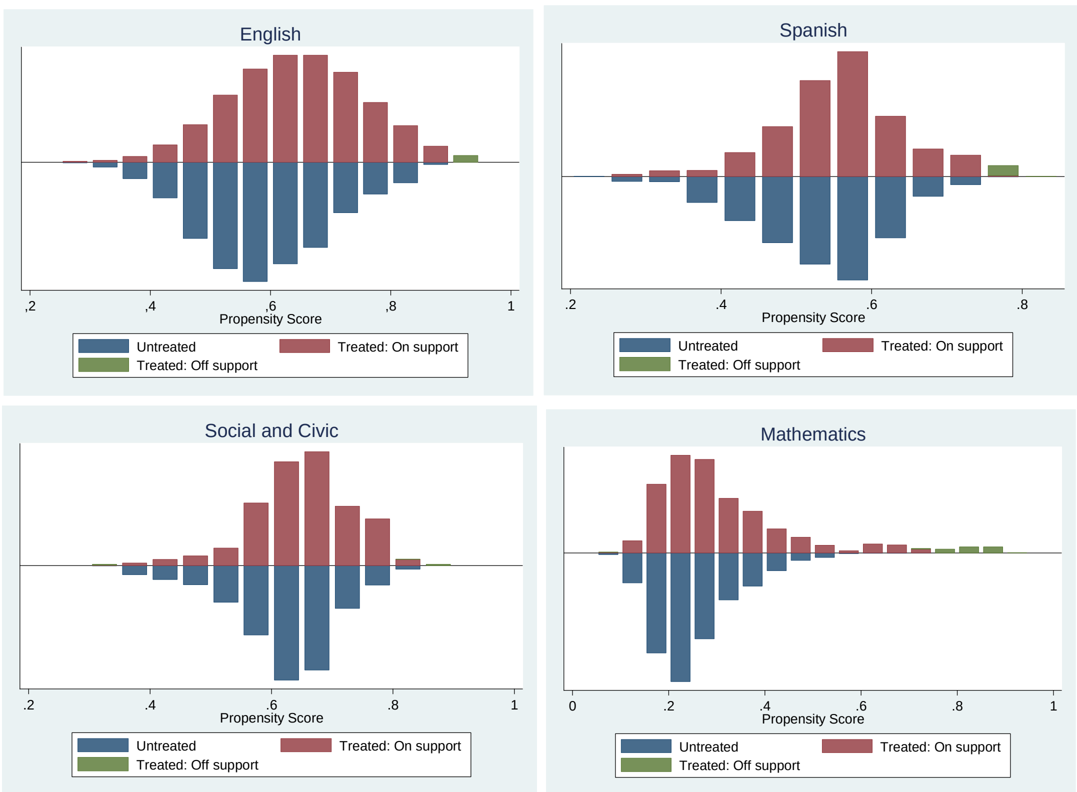


Table A.8: OLS estimates of use of ICT and students' academic performance

VARIABLES	(1) English	(2) Spanish	(3) Social and Civic	(4) Academic Mathematics
Use of ICT	6.142***	3.269**	3.005	4.928**
	(1.776)	(1.454)	(1.984)	(2.091)
Student gender	9.572***	13.89***	-10.54***	-26.77***
	(1.513)	(1.355)	(1.717)	(1.813)
Grade repetition	-49.90***	-24.78***	-34.66***	-27.61***
	(1.878)	(2.032)	(1.912)	(2.099)
Native Student	15.14***	24.39***	15.79***	17.95***
	(2.561)	(2.644)	(2.632)	(2.691)
ISCED 0 starting age	-4.198***	-3.376***	-2.904***	-4.587***
	(0.808)	(0.772)	(0.889)	(0.896)
Mother's educational level	11.81***	5.116***	7.007***	6.481***
	(0.506)	(0.434)	(0.543)	(0.518)
Ratio students-teacher	0.324	0.252	0.294	0.0204
	(0.292)	(0.270)	(0.371)	(0.389)
School size	0.00635**	0.000717	0.00880***	0.00595*
	(0.00280)	(0.00268)	(0.00338)	(0.00357)
School ownership	15.30***	12.02***	19.09***	13.93***
	(2.622)	(2.126)	(3.205)	(3.618)
School resources	-5.198***	-5.080***	-5.932***	-5.813***
	(1.712)	(1.414)	(2.086)	(2.053)
Constant	6.142***	3.269**	3.005	4.928**
	(1.776)	(1.454)	(1.984)	(2.091)
Observations	15,005	16,000	15,391	14,657
R-squared	0.248	0.109	0.133	0.105

Robust standard errors (clustered by school and class) in parentheses
*** p<0.01, ** p<0.05, * p<0.

Table A.9: IV estimates of use of ICT and students' academic performance

VARIABLES	(1) English	(2) Spanish	(3) Social and Civic	(4) Academic Mathematics
Use of ICT	27.74**	8.561	30.85**	33.09**
	(11.17)	(6.119)	(13.25)	(15.68)
Student gender	8.583***	11.48***	-12.13***	-25.98***
	(2.386)	(2.127)	(2.558)	(3.073)
Grade repetition	-45.09***	-19.78***	-32.26***	-24.91***
	(2.813)	(2.664)	(3.012)	(2.790)
Native Student	14.10***	24.28***	17.76***	21.20***
	(4.035)	(3.424)	(4.316)	(4.126)
ISCED 0 starting age	-4.049***	-4.166***	-2.533*	-4.609***
	(1.250)	(1.151)	(1.433)	(1.405)
Mother's educational level	11.03***	4.571***	7.440***	5.811***
	(0.834)	(0.692)	(0.873)	(0.922)
Ratio students-teacher	-0.102	-0.218	-0.748	0.0300
	(0.485)	(0.400)	(0.625)	(0.564)
School size	0.00223	0.00561	0.0122**	0.00559
	(0.00562)	(0.00444)	(0.00564)	(0.00645)
School ownership	16.03***	12.24***	16.68***	9.054*
	(3.994)	(3.246)	(4.426)	(4.769)
School resources	-2.747	-3.927**	-0.365	-5.422*
	(2.681)	(1.889)	(3.130)	(3.018)
Constant	407.1***	467.0***	428.3***	449.2***
	(19.78)	(12.52)	(25.81)	(20.37)
Observations	7,461	7,044	6,505	6,811

Robust standard errors (clustered by school and class) in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.10: Percentiles values of the students' scores by competences

Percentile	English	Spanish	Social and Civic	Academic Mathematics
5th	356,42	400,52	374,36	366,97
25th	448,24	474,08	465,12	459,88
5th	518,55	513,09	504,97	496,61
7th	578,53	556,38	578,39	561,7
95th	648,61	626,25	674,8	680,29

Table A.11: Quantile IV Regression of use of ICT and students' academic performance (English)

VARIABLES	P5	P25	P50	P75	P95
Use of ICT	49.37***	36.79***	29.26***	22.43***	12.91*
	(8.310)	(5.388)	(4.631)	(5.018)	(6.868)
Student gender	3.167	6.813***	9.000***	10.98***	13.74***
	(3.509)	(2.256)	(1.876)	(1.971)	(2.689)
Grade repetition	-40.36***	-43.77***	-45.81***	-47.67***	-50.24***
	(3.818)	(2.469)	(2.050)	(2.132)	(2.880)
Native Student	15.18**	13.79***	12.96***	12.21***	11.16**
	(6.265)	(4.041)	(3.368)	(3.535)	(4.803)
ISCED 0 starting age	-5.717***	-4.536***	-3.828***	-3.187***	-2.293
	(1.971)	(1.270)	(1.057)	(1.109)	(1.508)
Mother's educational level	10.90***	10.84***	10.80***	10.76***	10.72***
	(0.970)	(0.634)	(0.538)	(0.569)	(0.766)
Ratio students-teacher	0.607	0.196	-0.0506	-0.274	-0.585*
	(0.382)	(0.249)	(0.213)	(0.228)	(0.310)
School size	0.0679	0.0383	0.0205	0.00442	-0.0180
	(0.0440)	(0.0279)	(0.0226)	(0.0232)	(0.0318)
School ownership	32.90***	22.54***	16.34***	10.72***	2.881
	(3.220)	(2.057)	(1.650)	(1.654)	(2.225)
School resources	-9.415***	-5.590***	-3.297***	-1.220	1.674
	(2.090)	(1.347)	(1.153)	(1.251)	(1.723)
Constant	209.4***	334.2***	409.1***	476.8***	571.3***
	(20.81)	(12.74)	(10.12)	(10.57)	(15.04)
Observations	7,461	7,461	7,461	7,461	7,461

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.12: Quantile IV Regression of use of ICT and students' academic performance (Spanish)

VARIABLES	P5	P25	P50	P75	P95
Use of ICT	6.637	6.994**	7.183***	7.380***	7.676**
	(5.793)	(3.508)	(2.699)	(2.581)	(3.810)
Student gender	14.00***	12.38***	11.51***	10.62***	9.273***
	(3.852)	(2.300)	(1.723)	(1.606)	(2.418)
Grade repetition	-18.05***	-19.56***	-20.37***	-21.20***	-22.46***
	(4.673)	(2.769)	(1.983)	(1.683)	(2.549)
Native Student	34.04***	27.46***	23.97***	20.34***	14.90***
	(7.729)	(4.532)	(3.246)	(2.840)	(4.415)
ISCED 0 starting age	-7.009***	-5.000***	-3.934***	-2.826***	-1.164
	(2.180)	(1.299)	(0.970)	(0.899)	(1.356)
Mother's educational level	4.218***	4.448***	4.570***	4.697***	4.887***
	(1.063)	(0.638)	(0.489)	(0.471)	(0.705)
Ratio students-teacher	-0.196	-0.233	-0.253	-0.274	-0.305
	(0.404)	(0.244)	(0.189)	(0.184)	(0.272)
School size	0.129***	0.0790***	0.0525***	0.0250	-0.0164
	(0.0460)	(0.0277)	(0.0201)	(0.0170)	(0.0247)
School ownership	24.36***	15.85***	11.33***	6.630***	-0.416
	(3.424)	(2.032)	(1.526)	(1.433)	(2.169)
School resources	-7.690***	-5.118***	-3.753***	-2.335**	-0.207
	(2.337)	(1.388)	(1.034)	(0.961)	(1.459)
Constant	353.8***	433.1***	475.2***	518.9***	584.5***
	(16.20)	(9.540)	(7.337)	(7.233)	(11.04)
Observations	7,044	7,044	7,044	7,044	7,044

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.13: Quantile IV Regression of use of ICT and students' academic performance (social and civic competence)

VARIABLES	P5	P25	P50	P75	P95
Use of ICT	29.58***	32.34***	34.06***	35.85***	38.80***
	(10.88)	(6.969)	(5.462)	(5.517)	(8.735)
Student gender	-5.147	-9.185***	-11.69***	-14.32***	-18.63***
	(3.971)	(2.674)	(2.325)	(2.558)	(3.870)
Grade repetition	-24.45***	-28.88***	-31.62***	-34.50***	-39.22***
	(4.384)	(2.912)	(2.390)	(2.453)	(3.692)
Native Student	20.94***	18.83***	17.52***	16.15***	13.89**
	(6.793)	(4.529)	(3.879)	(4.232)	(6.455)
ISCED 0 starting age	-4.633**	-3.454**	-2.721**	-1.954	-0.694
	(2.150)	(1.448)	(1.284)	(1.450)	(2.212)
Mother's educational level	8.094***	7.764***	7.559***	7.344***	6.991***
	(1.075)	(0.734)	(0.658)	(0.741)	(1.117)
Ratio students-teacher	0.593	-0.276	-0.815***	-1.381***	-2.308***
	(0.480)	(0.322)	(0.272)	(0.288)	(0.432)
School size	0.0200	0.0835***	0.123***	0.164***	0.232***
	(0.0461)	(0.0304)	(0.0259)	(0.0285)	(0.0439)
School ownership	9.708***	13.78***	16.31***	18.96***	23.31***
	(3.179)	(2.173)	(1.990)	(2.299)	(3.487)
School resources	-11.24***	-4.525***	-0.356	4.014***	11.18***
	(2.339)	(1.565)	(1.364)	(1.513)	(2.307)
Constant	277.2***	367.7***	423.8***	482.6***	579.2***
	(21.33)	(13.86)	(11.80)	(13.17)	(20.70)
Observations	6,505	6,505	6,505	6,505	6,505

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A.14: Quantile IV Regression of use of ICT and students' academic performance (academic mathematics)

VARIABLES	P5	P25	P50	P75	P95
Use of ICT	9.896	25.43***	34.83***	45.06***	61.12***
	(9.938)	(7.025)	(7.038)	(8.683)	(13.04)
Student gender	-19.69***	-23.46***	-25.75***	-28.23***	-32.14***
	(3.967)	(2.689)	(2.350)	(2.571)	(3.809)
Grade repetition	-16.50***	-21.28***	-24.18***	-27.33***	-32.27***
	(4.854)	(3.259)	(2.680)	(2.685)	(3.893)
Native Student	24.82***	22.66***	21.35***	19.92***	17.69***
	(6.818)	(4.561)	(3.889)	(4.170)	(6.221)
ISCED 0 starting age	-3.933*	-4.318***	-4.551***	-4.805***	-5.203**
	(2.251)	(1.512)	(1.307)	(1.423)	(2.123)
Mother's educational level	4.384***	5.246***	5.768***	6.335***	7.226***
	(1.089)	(0.751)	(0.680)	(0.766)	(1.129)
Ratio students-teacher	0.789*	0.335	0.0612	-0.237	-0.706
	(0.471)	(0.312)	(0.276)	(0.316)	(0.483)
School size	0.0635	0.0586*	0.0556*	0.0524	0.0473
	(0.0499)	(0.0331)	(0.0293)	(0.0335)	(0.0513)
School ownership	-0.409	5.382**	8.889***	12.70***	18.69***
	(3.920)	(2.626)	(2.332)	(2.644)	(4.002)
School resources	-8.959***	-6.991***	-5.799***	-4.504**	-2.470
	(2.508)	(1.690)	(1.540)	(1.793)	(2.722)
Constant	316.5***	398.7***	448.5***	502.7***	587.7***
	(19.69)	(12.76)	(10.72)	(11.60)	(17.85)
Observations	6,811	6,811	6,811	6,811	6,811

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.15: Estimates of ATT with and without simulated confounder (sensitivity analysis)

	ATT	**Standard Error**	**Outcome effect**	**Selection effect**
English				
Original PSM Model (using psmatch2)	11.089	2.398		
Original PSM Model (using sensatt)	10.781	2.273		
PSM Model with simulated confounder	8.487	3.040	1.189	1.025
Spanish				
Original PSM Model (using psmatch2)	7.974	2.632		
Original PSM Model (using sensatt)	7.610	2.446		
PSM Model with simulated confounder	7.232	2.828	1.428	1.064
Social and Civic				
Original PSM Model (using psmatch2)	10.746	2.320		
Original PSM Model (using sensatt)	11.000	2.216		
PSM Model with simulated confounder	7.347	2.481	1.122	1.015
Academic Mathematics				
Original PSM Model (using psmatch2)	13.753	3.405		
Original PSM Model (using sensatt)	21.270	6.620		
PSM Model with simulated confounder	19.980	6.773	1.234	1.212

* None of the treatment estimates reach zero, hence we can presume that hidden bias would not significantly affect the conclusions of our research.

CHAPTER 3

Technology In The Classroom: Factors Influencing Teachers' Use Of ICT*.

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3.1 Introduction

The incorporation of Information and Communication Technology (ICT) into the educational process offers numerous advantages. The implementation of ICT in the classroom to complement traditional teaching methods is associated with greater student motivation thanks to the use of more attractive, entertaining and fun tools (Bullock, 2001; Tüzün et al., 2009). Likewise, ICT enables greater interactivity in learning, with more opportunities for cooperation and an improvement in communication between teachers and students (Schulz et al., 2002). ICT also stimulates initiative and creativity (Allegra et al., 2001; Wheeler et al., 2002) and facilitates the individualization and flexibilization of education (Abell, 2006). These advantages, among others, can improve the students' acquisition of knowledge and have a positive influence on students' academic performance. Nevertheless, the use of ICTs for educational purposes in Spain - the country to which the Autonomous Community of Madrid analysed in this study belongs - is rather modest and there is still room to increase their frequency of use in the classroom (see descriptive statistics in section 3.3.2). Furthermore, the results of chapter two of this thesis suggest that the use of ICT to carry out projects or do exercises in class seems to have a positive impact on the academic performance of fourth year secondary school students in the specific case of the Community of Madrid. In view of these two facts (the modest presence of ICT in the classroom and the positive association between ICT use and academic performance that seems to be taking place according to Chapter 2) it is crucial to continue research on the use of ICT in schools.

Considering that the integration of ICT for educational purposes in the classroom is ultimately decided by the teacher of each subject, it is of great interest to analyse what factors determine whether a teacher is more or less conducive to the use of these tools. Specifically, the aim of this research is to determine the personal characteristics of teachers, as well as those of the school and class environment, which make them more likely to use ICT in their classes. This information will allow us to be able to elaborate recommendations in terms of educational policy oriented to increase the frequency of use of ICT in the classrooms in order to take advantage of all the potential benefits that the use of these tools entails. For that purpose, we estimate multilevel logistic models for three different educational levels with census data from the individualized evaluations carried out at the end of the 2018-2019 academic year in the 3rd year of primary education, 6th year of primary education, and 4th year of secondary education in the Autonomous Community of Madrid (Spain).

This research is novel and supposes a contribution to the previous literature for five fundamental reasons: (1) the scarce attention given in literature to date to the determining factors of the use of ICT in the classroom; (2) the analysis of potentially explanatory factors for the frequency of ICT use that have not been explored in previous studies (e.g., level of disturbance in the class); (3) the comparison of three educational levels; (4) and the use of an administrative census database with enough respondents to have a high degree of statistical confidence in the survey results.

Our results suggest that the use of ICT in the classroom by teachers is influenced by variables of a personal nature (e.g., motivation and ICT training), by variables related to the class environment (e.g., disruptive behaviours and students' ICT use at home), and by the school climate (e.g., lack of technological devices). Some of the determinants are common for all the educational levels, but we also find different results by educational levels for some of the studied variables.

The paper is structured as follows. Section 3.2 presents a review of previous literature about the factors that affect the degree of use of ICT by teachers in their classes. Then, section 3.3 describes the data and variables used in the analysis and the methodological approach. Section 3.4 presents the results of the empirical analysis and, finally, section 3.5 concludes with the final considerations reflecting on the main research findings and developing educational policy recommendations.

3.2 Literature Review

Information and communication technologies (ICT) can complement, enrich and transform education. That is why, since their incorporation into the educational field, they have come to be considered as an additional factor in the analysis of the determinants of academic performance (Cox et al., 2004; Condie and Munro, 2006; and Claro, 2010).

As mentioned in the introduction, the use of ICT in the classroom is associated with a number of potential advantages (Allegra et al., 2001; Bullock, 2001; Schulz et al., 2002; Wheeler et al., 2002; Abell, 2006; and Tüzün et al., 2009) that could lead to improved student competence acquisition and better academic performance. However, it is important to point out that the real effect of the use of ICT for educational purposes on academic performance will depend on the effective use of these tools in the classroom. That is to say, despite all their potential advantages, an inadequate use of ICTs in the classrooms might not allow to take advantage of these advantages or even be detrimental to the academic performance of the students. This could occur if teachers are not properly trained or familiar with the use of ICTs for educational purposes, as evidenced by Cruz et al. (2018) in the Community of Madrid. Insufficient teacher training could lead to an inadequate incorporation of ICT into the teaching process and end up negatively affecting the way the subject content is taught and therefore the student's academic performance. In this sense, we believe it is relevant to contextualize what effect the use of ICTs for educational purposes is having on Spanish schools, the country to which the autonomous community that is the subject of this study belongs. Therefore, before beginning the review of studies directly related to the object of this research, we will briefly mention the most recent studies that have analysed the relationship between the use of ICT in schools and academic performance in Spain.

In the case of Spain, the literature to date does not provide clear evidence of the association between the use of ICT for educational purposes and academic performance in primary and secondary education. There are several studies that have analysed the relationship between the availability of ICT (mainly computers) in schools and academic performance (Choi and Calero, 2013; Cabras and Tena, 2013; Cordero et al., 2015; Mediavilla and Escardíbul, 2015; and Escardíbul and Mediavilla, 2016). However, we consider that what is really important is to analyse the use of ICTs and not merely their availability, since it could be that a school has a high ratio of computers per student but paradoxically makes very little use of them. In this sense, a number of studies in Spain have also analysed the relationship between the frequency of use of ICT and academic performance (Escardíbul and Mediavilla, 2016; Vilaplana, 2016; and Gómez-Fernández and Mediavilla, 2021; and Gorjón et al., 2021).

Regarding the analysis of the availability of ICT resources in schools, Choi and Calero (2013) find evidence that the proportion of computers with internet connection and the number of computers in schools does not show statistically significant effects on academic performance. Considering this result, the authors point out the ineffectiveness of increasing the volume of computers in schools to reduce school failure. Conversely, Cabras and Tena (2013), Cordero et al. (2015), Mediavilla and Escardíbul (2015) and Escardíbul and Mediavilla (2016) find that having computers in schools for educational purposes has a positive effect on academic performance.

Focusing on the use of ICT and not merely on availability, Vilaplana (2016) analyses the impact on academic performance of the Escuela 2.0 program approved in 2009 in Spain. The objectives of the program were to provide each student with a notebook, transform all classrooms into digital classroom, instruct teachers in the use of ICT and prepare new digital contents. The author finds that the participation in the program had a positive impact on academic performance, albeit small. In this line of research, Escardíbul and Mediavilla (2016) find a negative association between the use of ICT in schools for educational purposes and academic performance. This result is in line with the recent study by Gómez-Fernández and Mediavilla (2021), who also find that a greater use of ICT in schools is associated with lower academic performance. Considering this result, the authors suggest the ineffectiveness of the implementation of ICT in schools in Spain and point out that one of the main explanations for this result could be the lack of teacher training in the educational use of these tools. Gorjón et al. (2021) also find that in Spain while low and medium use of ICTs in schools improves academic results, a very intensive use of ICTs worsens academic performance in mathematics. However, in Chapter 2, when we focus our analysis on the specific case of the Community of Madrid and on a specific use of ICT in the classroom (to carry out projects or do exercises), applying quasi-experimental methodologies, we find a positive impact of the use of ICT in the classroom in the particular context we are analyzing. There seems therefore to be no clear evidence on the impact of ICT use in schools in Spain, which, as noted in Chapter 2, emphasizes the need for further research in this area with both quantitative and qualitative studies.

Once this contextualization on the effect of the availability and use of ICT in Spanish schools on academic performance has been made, we proceed to focus on the object of this research. Below, we cite previous studies that have focused on analysing which factors are related to the frequency of ICT use in the classroom by teachers for educational purposes. Specifically, considering our object of study, we focus on previous studies that have analysed these factors in the context of primary and secondary education. As can be seen in the literature review presented below, there are not many studies on our object of research in recent years. Precisely for this reason and considering the pace at which everything related to ICTs is evolving, our research is very relevant and novel to provide recent empirical evidence on the factors influencing teachers' use of ICT.

Previous research in the field on the use of ICT by teachers in the classroom categorizes factors that affect the degree of use of ICT into two main groups: i) personal characteristics of teachers, and ii) external environment.

Personal characteristics of teachers

Teacher´s characteristics can influence the adoption of an innovation such as ICT (Rogers, 1995; and Schiller, 2003). In this line of research, Inan and Lowther (2010) develop a research-based path model to explain causal relationships between different factors and technology integration in the classroom. They find that teachers’ demographic characteristics (years of teaching and age) negatively affect their technology integration in the classroom, while teachers’ computer proficiency positively affects their technology integration. Considering different psychological factors, Sang et al. (2011) analyse Chinese primary school teachers and find that motivation variables have a direct effect on the implementation of ICT in the classroom. In Spain, specifically in the Valencian Community, Suárez et al. (2012) find that the personal use that teachers make of ICTs is key to explaining their frequency of use of these tools in the classroom. In Norway, Scherer et al. (2015) find that teachers' perceived usefulness of ICT is positively related to the use of ICT, whereas the relation to age is negative. Shin (2015) shows that in Korean elementary schools teachers’ aptitude, disposition and attitudes toward ICT are the main determinants of teachers' use of ICT in the classroom for educational purposes. Drossel et al. (2017) carry out multiple regression analyses of the frequency of computer use by teachers for instruction in five countries (Netherlands, Denmark, Australia, Poland and Germany) and find that antecedents concerning teachers’ attitudes have more of an impact on the teachers´ use of ICT in the classroom than school characteristics or teacher collaboration on the process level. In the Czech Republic, Gerick et al. (2017) show using a multilevel approach with ICILS (2013) data that the self-efficacy of teaching staff plays a key role in implementing ICT in the lessons. In Chile, Ibieta et al. (2017) use data from a questionnaire administered to teachers and find that their decision to use of ICT in the classroom mainly depends on their perceptions of ICT impact on professional practice and that less experienced teachers use ICT more frequently. More recently, Petko et al. (2018) build a structural equation model with data from Swiss primary schools and find that educational technology integration is dependent on the readiness of individual teachers based on perceived skills and beliefs.

To summarize, these previous studies show that the personal characteristics of teachers are key to determining the use of ICT in the classroom. In this sense, based on the review carried out, it seems that the factors most commonly indicated as determining the use of ICT in classrooms are those related to teachers' aptitude, disposition, and attitudes toward ICT.

External environment

Although most previous research has focused on factors related to individual teacher characteristics, there is also previous research that has studied the teacher's external environment, i.e., analysing how the characteristics of the classroom and school influence the teacher's decision to implement ICT. In this line, Inan and Lowther (2010) analysing data from Tennessee public school teachers find that school-level factors such as the technical and overall support positively affect teachers' technology integration. Eickelmann et al. (2017) show by means of a multi-level regression model as well as a multi-level path model that characteristics at school level (IT equipment of schools, school leadership, and aspects of school goals and educational strategies) do play a major role in the integration of ICT into teaching and learning of mathematics in the five educational systems analysed (Australia, Germany, the Netherlands, Norway and Singapore). In Germany, Gerick et al. (2017) find that pedagogical ICT support seems to be crucial for the use of ICT in teaching. The authors also show that in Australia the participation of teaching staff in professional development activities organized by the school can be identified as relevant for the use of ICT in the class. More recently, Petko et al. (2018) find that the use of ICT in lessons in Swiss primary schools is influenced by the educational technology resources in classrooms, the perceived importance of technology integration in the school, goal clarity, head teacher support, as well as formal and informal exchange among teachers.

As can be seen, although there are previous studies that have analysed the factors that make teachers more likely to use ICT in the classroom, literature in this area is fairly limited. Therefore, we believe that it is important to continue researching this topic and to provide new empirical evidence that can be used both for future research and for the development of educational policy recommendations.

3.3 Data and Methodological Approach

3.3.1 Data: Individualized Evaluations for Madrid

Individualized evaluations are carried out annually for all students in Spanish schools at the end of the 3rd year of primary education (8-9 years old), 6th year of primary education (11-12 years old) and 4th year of secondary education (15-16 years old). The purpose of these evaluations is to verify the degree of acquisition of linguistic (English and Spanish) and mathematical competences in all courses, science and technology competences in the 6th year of primary education, and social and civic competence in the 4th year of secondary education. In addition to the test carried out by the students for each of the previously mentioned competences, the school principal, teachers, families and students themselves complete a context questionnaire that serves to evaluate the social, economic and cultural factors of the students and their families, the teachers and the school.

In this research we use the data from the individualized evaluations carried out at the end of the 2018-2019 academic year in the Community of Madrid in the three corresponding educational levels.[28] The data are of a census nature, given that all students, teachers and school principals from public, semiprivate [29] and private schools participated in these evaluations. The student, teacher and school participation data were as follows: (1) in the 3rd year of primary school, a total of 69,977 students and 6,310 teachers from 1,320 schools; (2) in the 6th year of primary school, a total of 69,355 students and 7,917 teachers from 1,308 schools; (3) and in the 4th year of secondary school a total of 62,165 students and 5,775 teachers from 803 schools. Although the number of initial observations is very high as it is census data, the data set presents a significant problem of missing values that leads to a significant reduction in the number of final observations initially included in our models (see section 3.3.3).

Given the object of our research, in this study we work with context questionnaires answered by students and their families, teachers and school principals. These context questionnaires provide us with information about different variables (see section 3.3.2) that potentially can be factors that explain the decision of the teacher on the frequency of use of ICT in the classroom.

3.3.2 Variables and Descriptive Analysis

The variables that have been considered for the econometric analysis are detailed in this section. Being that the objective of our research is to clarify the determinants of the use of ICT in the classroom for educational purposes, the dependent variable is defined as the "use of ICT resources to carry out projects or do exercises in class". This variable has been

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[28] These are the most recent data available since in the 2019-2020 academic year the test could not be performed due to the COVID-19 health crisis.

[29] Publicly-funded private schools: privately owned but publicly-funded.

obtained from the teachers' questionnaire and can take values 0 (indicates that the ICTs are not used or are only occasionally used) or 1 (indicates that the ICTs are used frequently or always). As explanatory variables we have used different information from the context questionnaire completed by students and their families, teachers, and school principals.[30] The selection of explanatory variables has been carried out based on previous literature and considering those that we believe could potentially have an impact on the decision of the teacher to use ICT in the classroom.

From the student and family questionnaire, we have included information on the student gender; whether the student was born in Spain or abroad; grade repetition (only available in 6th year of primary education and 4th year of secondary education); the number of books at home (as a proxy of the socio-economic status); the frequency of use of computer and tablet at home; and the total number of students per class (class size).[31]

From the teachers' questionnaire, we have included the following variables as explanatory variables: teacher's gender; year of the teacher's birth; school ownership [32]; time dedication; ICT training received in the last 12 months; disturbance of order in class; satisfaction with the profession (proxy of motivation); and the subject taught. From the school principals' questionnaire, we have included three explanatory variables: lack of a teacher training plan; lack of autonomy to take decisions; and lack of digital devices for teaching.

The explanatory variables previously enumerated can be subdivided into two main groups: variables directly of interest and other independent variables. Those variables directly of interest are the ones we initially consider could be highly related to the use of ICT in the classroom because they are directly related to these tools: teachers' ICT training, lack of digital devices in the school, and use of computer and tablets by students and their families at home. The rest of the variables are classified as other independent variables, as we have included them in our regressions because we consider that they could somehow influence the probability that the teacher uses ICT, but to a lesser extent than those directly of interest, since they seem to have a less direct relationship. Nevertheless, the results of our research confirm that some of these independent variables are determining factors that greatly affect the decision to use or not use ICT in the classroom.

Tables 1 to 3 shows the main descriptive statistics of the dependent and independent variables of our analysis for the three educational levels analysed, as well as the percentage

[30] The correlation matrix between all the dependent and independent variables has been calculated. We have not included variables showing a correlation coefficient higher than 0.4.

[31] The variable "total number of students per class" has been created manually from the center and group codes indicated in the student questionnaire.

[32] Although this variable refers to a characteristic of the school, it has a lower percentage of missing values in the teachers' questionnaire than in the principals' questionnaire, so it was decided to obtain it from the teachers' questionnaire.

of missing values that has been taken into consideration for the imputation process (section 3.3.3). Table A.1 of the Appendix presents the exact definition of each of them.

The descriptive statistics in tables 1 to 3 show some relevant characteristics of the teachers and students regarding the dependent variable and the variables directly of interest of this research. Firstly, with regard to the use of ICT resources to carry out projects or do exercises in class, it is observed that, regardless of the level of education that we analyse, the use of ICT is modest, given that there is still a high percentage of teachers who answer that never or hardly ever use ICT in their classrooms. Therefore, there is still room to increase their frequency of use in the classroom for educational purposes and be able to take advantage of all the potential benefits that these tools present. If we focus on comparing levels of ICT use by educational level, we observe that the educational level at which ICTs are most frequently used is 6th year of primary education (65%), followed by 4th year of secondary education (57%) and in last place 3rd year of primary education (52%).

In relation to the variables classified as directly of interest, a relevant result is that only about a half of all teachers at all the educational levels indicate that they had received ICT training in the previous 12 months. Taking into account that ICTs are tools that evolve very quickly and that require continuous training in their use, this result seems to suggest that in our specific case of analysis, the Community of Madrid, there is still a high percentage of teachers who have not recently participated in ICT training activities and therefore may not be adequately trained to use them properly or to take full advantage of their use. Regarding the use of ICTs in students' homes, it is observed that in most homes ICTs are used frequently, every day or almost every day. Only about 5% of the students or families stated that ICTs are never or infrequently used at their home. Finally, regarding schools' characteristics, although few teachers consider the lack of technological resources to be a serious problem, we find that only a 39% of principals stated that they considered that there was no problem with the lack of availability of digital resources in their school. This result indicates that there is still significant room for improvement in the availability of ICT resources in schools.

Table 1: Descriptive statistics (3rd year of primary education)

Variable	Obs.	%/Mean*	Std. Dev.	Min./Max.	% Missing
Student and family Questionnaire					
Female	69,902	0: 48.58 1: 51.42	0.50	0/1	0.55
Immigrant	34,623	0: 95.87 1: 4.13	0.20	0/1	50.74
Books at home	34,916	0: 5.77 1: 24.07 2: 27.35 3: 19.72 4: 23.10	1.22	0/4	50.62
Computer/tablet use at home	34,709	0: 5.16 1: 94.84	0.22	0/1	50.32
Class size	69,977	24.54	2.95	1/36	0.44
Teacher Questionnaire					
ICT use in class	6,055	0: 47.63 1: 52.37	0.450	0/1	4.04
Female	6,297	0: 22.06 1: 77.94	0.42	0/1	0.21
Year of birth	6,287	1977.27	9.88	1948/1997	0.36
School ownership	6,263	0: 58.74 1: 34.15 2: 7.11	0.63	0/2	0.74
Time dedication	6,291	0: 4.48 1: 95.52	0.21	0/1	0.30
ICT training	4,964	0: 47.63 1: 52.37	0.50	0/1	21.33
Disturbance of order in class	6,124	0: 23.64 1: 35.58 2: 26.55 3: 14.22	0.99	0/3	2.95
Satisfaction (motivation)	6,261	0: 2.80 1: 10.32 2: 52.13 3: 34.75	0.73	0/3	0.78
Director Questionnaire					
Lack teacher training	1,228	0: 29.97 1: 44.38 2: 22.96 3: 2.69	0.80	0/3	1.76
Lack autonomy	1,227	0: 26.30 1: 41.08 2: 28.36 3: 4.24	0.84	0/3	1.84
Lack technological devices	1,234	0: 39.30 1: 33.31 2: 21.23 3: 6.16	0.92	0/3	1.28

*In the case of categorical variables, the relative frequencies are presented, while for continuous variables the mean is used.

Table 2: Descriptive statistics (6th year of primary education)

Variable	Obs.	%/Mean	Std. Dev.	Min. /Max.	% Missing
Student and family Questionnaire					
Female	69,330	0: 48.41 1: 51.59	0.50	0/1	0.50
Immigrant	28,969	0: 95.46 1: 4.54	0.21	0/1	58,42
Repeater	46,548	0: 87.30 1: 12.70	0.33	0/1	33.19
Books at home	29,200	0: 4.27 1: 20.64 2: 26.10 3: 20.45 4: 28.53	1.22	0/4	58.09
Computer/tablet use at home	29,078	0: 3.37 1: 96.63	0.18	0/1	58.27
Class size	69,343	24.46	3.11	1/40	0.48
Teacher Questionnaire					
ICT use in class	7,588	0: 35.04 1: 64.96	0.48	0/1	4.16
Female	7,887	0: 30.02 1: 69.98	0.46	0/1	0.38
Year of birth	7,866	1975.64	10.19	1950/1996	0.64
School ownership	7,815	0: 59.01 1: 33.04 2: 7.95	0.64	0/2	1.29
Time dedication	7,880	0: 3.49 1: 96.51	0.18	0/1	0.47
ICT training	6,485	0: 44.92 1: 55.08	0.50	0/1	18.09
Disturbance of order in class	7,656	0: 27.13 1: 35.96 2: 23.26 3: 13.65	0.99	0/3	3.30
Satisfaction (motivation)	7,854	0: 3.62 1: 10.13 2: 51.67 3. 34.58	0.75	0/3	0.80
Director Questionnaire					
Lack teacher training	1,215	0: 29.88 1: 44.53 2: 22.88 3: 2.72	0.80	0/3	1.86
Lack autonomy	1,214	0: 26.28 1: 41.02 2: 28.42 3: 4.28	0.84	0/3	1.94
Lack technological devices	1,221	0: 39.31 1: 33.25 2: 21.21 3: 6.22	0.92	0/3	1.37

*In the case of categorical variables, the relative frequencies are presented, while for continuous variables the mean is used.

Table 3: Descriptive statistics (4th year of secondary education)

Variable	Obs.	%/Mean	Std. Dev.	Min./Max.	% Missing
Student Questionnaire					
Female	62,150	0: 50.04 1: 49.96	0.50	0/1	1.32
Immigrant	34,457	0: 87.93 1: 12.07	0.33	0/1	45.29
Repeater	30,848	0: 84.94 1: 15.06	0.50	0/1	51.02
Books at home	34,548	0: 6.88 1: 22.19 2: 25.09 3: 21.21 4: 24.63	1.26	0/4	45.14
Computer/tablet use at home	34,355	0: 7.28 1: 92.72	0.26	0/1	45.45
Class size	62,166	27.35	4.07	1/48	1.29
Teacher Questionnaire					
ICT use in class	5,543	0: 43.51 1: 56.49	0.50	0/1	0.00
Female	5,753	0: 35.49 1: 64.51	0.48	0/1	0.38
Year of birth	5,739	1973.86	9.49	1947/1997	0.62
School ownership	5,730	0: 49.95 1: 40.19 2: 9.86	0.66	0/2	0.78
Time dedication	5,755	0: 9.04 1: 90.96	0.29	0/1	0.35
ICT training	4,605	0: 45.45 1: 54.55	0.50	0/1	20.26
Disturbance of order in class	5,603	0: 15.92 1: 39.82 2: 30.64 3: 13.62	0.91	0/3	2.98
Satisfaction (motivation)	5,740	0: 2.16 1: 10.91 2: 49.97 3: 36.97	0.72	0/3	0.61
Director Questionnaire					
Lack teacher training	717	0: 32.22 1: 45.04 2: 21.34 3: 1.39	0.77	0/3	3.11
Lack autonomy	718	0: 27.58 1: 35.10 2: 28.55 3: 8.77	0.94	0/3	2.97
Lack technological devices	722	0: 39.89 1: 35.32 2: 19.11 3: 5.68	0.90	0/3	2.43

*In the case of categorical variables, the relative frequencies are presented, while for continuous variables the mean is used.

3.3.3 Missing Values and Imputation

The databases we work with present a significant problem of missing values. Therefore, in spite of being data of a census nature and having summoned all the students, teachers and school principals of the Community of Madrid to carry out these evaluations, the students, teachers and principals who are finally included in our estimates are much less than those officially enrolled in the different courses.

This loss of observations is explained because we find some questions of interest in our research that have not been answered by a high percentage of students, families, teachers or school principals. That is, there are students, families, teachers and principals who do not answer some of the questions in the context questionnaires we include in our estimations and are therefore initially excluded from our estimates. The percentage of missing variables for each of our questions of interest is reflected in the last column of tables 1 to 3. As can be seen, the data with the highest percentages of missing values are those from the student and family questionnaire. However, in the teachers' questionnaire - with the exception of the ICT training variable - and the principals' questionnaire, very low percentages of missing values are found. In summary, there are five variables with high percentages of missing values: immigrant, repeater, books at home, use of ICT at home and ICT training.

In the presence of missing values, there are different ways to proceed. Next, we proceed to explore the pattern of the missing values (Rubin, 1976) to see if the application of techniques of imputation of missing values is possible in order to increase the number of final observations in our models. A first option is to ignore these missing values and perform a complete case analysis, that is, to include in our regressions only the observations for which we have information on all the variables explained in section 3.3.2. However, as suggested by Jakobsen et al. (2014), complete case analysis is only appropriate if the percentages of missing values are less than 5% (as a rule of thumb) or if the missing mechanism is missing completely at random (MCAR). Our data do not satisfy the rule of thumb, since we have variables with percentages of missing values greater than 5%, and the results of Little's MCAR test (Little, 1988 and Li, 2013) reveal that missing values at the student and teacher levels (the levels where we find percentages of missing values higher than 5%) are not MCAR because the p-value is less than 0.05 in all the cases.[33] Since it has been shown that an MCAR mechanism cannot be considered to exist, it is not appropriate to proceed with a complete case analysis that includes variables with percentages of missing values greater than 5% and not MCAR.

Once it has been determined that the analysis of complete cases is not the best, we analyse whether it would be appropriate to use imputation techniques that allow replacing missing data with substituted values. The reason for imputation is to avoid losing

[33] Results are not presented for brevity but are available upon request.

observations because they contain missing values and to increase the power of statistical tests by increasing the number of observations used. The first step of analysis to be carried out to assess the possibility of imputing the missing values, is to determine if the missing values are Missing at Random (MAR) or Missing Not at Random (MNAR). To check this, we create a new indicator variable for each of our research variables with percentages of missing values greater than 5%. This variable takes the value of 1 if an observation is missing that variable and 0 if it is not. Then, we run a set of logit models and t-tests to examine if any of the other variables in the dataset predict missingness. In the case of the student and family questionnaire, the results confirm that some of the variables are statistically significantly associated with missingness of the variables: immigrant, repeater, books at home, and computer/tablet use at home.[34] For example, we find that worst performing students are more likely to decline to answer some questions (i.e., test scores predict missingness on another variable). As for the teachers' questionnaire, we also find that some of the variables are statistically significantly associated with missingness of the variable ICT training. In this sense, we find that for example teachers who never use ICT in their classes are more likely to decline to answer the question about ICT training (i.e., use of ICT in the class predict missingness on ICT training).Therefore, our results suggest that our missing values (in the variables immigrant, repeater, books at home, use of ICT at home and ICT training) are MAR and that whether an observation is missing has to do with the values of some of the student's or teacher's observed variables.

Previous literature shows that there are different alternatives for handling MAR (Kang, 2013): case deletion, pairwise deletion, mean substitution, regression imputation or multiple imputation. In this research, we opt for the use of the most popular and recommended method (Kang, 2013): multiple imputation (MI). MI uses the distribution of the observed data to estimate a set of plausible values for the missing data. Specifically, considering that the variables we want to impute are categorical, we use the method of multiple imputation by chained equations (White at al., 2011) using the "mi" command in Stata 14. The imputation through this technique involves a sequence of univariate imputation methods with fully conditional specifications of prediction equations (Royston and White, 2011). We impute the five variables included in our models from the student, family and the teacher questionnaire with a percentage of missing values higher than 5% (immigrant, repeater, books at home, use of ICT at home and ICT training) from an empirical approach of an ordered logistic regression, and following Schafer (1999) we decide to use 5 imputations (m=5). After the imputation process, we perform imputation model diagnostics using the "midiagplot" command in Stata to compare the distributions of the observed, imputed, and completed values. The results of the imputation model diagnostics suggest a good overlap between observed and completed data.[35]

[34] Results are not presented for brevity but are available upon request.

[35] Results of the imputation model diagnostics are not presented for brevity but are available upon request.

Despite having performed a careful imputation process that overcomes the model diagnostics and allows us to increase the number of total observations, considering that we had a high number of missing values, it is true that there could be a criticism that our final results are driven in large part by our imputation model rather than the observed data. To try to overcome this criticism and as a robustness test, in addition to estimating our main models with the imputed values, we have performed the following analyses: (1) complete case analysis using only the variables with percentages of missing values lower than 5% (rule of thumb); (2) and complete case analysis including all the variables described in section 3.3.2.[36] The results of these analyses suggest similar conclusions to those obtained in the main models of this research.

3.3.4 Methodology

To study the determinants of the use of ICT for educational purposes in the classroom, it is suitable to use maximum likelihood estimates, such as logit or probit. The main difference between logit and probit models lies in the assumption on the distribution of the error terms in the model. Specifically, in a logit model, the errors are assumed to follow a standard logistic distribution whereas in a probit, the errors are presumed to follow a Normal distribution. Considering that we are working with large sample sizes, we follow Cakmakyapan and Goktas (2013) and opt for the estimation of a binomial logistic model.[37] In addition, the estimation of a logit allows a simpler interpretation of the coefficients obtained in terms of odd ratios, a common measure of effect size for proportions.

The structure of our data (e.g., students nested within classes and teachers, and classes and teachers nested within schools) and the use in our estimates of variables measured at different levels of the hierarchy make it appropriate to build models that consider this hierarchical structure of the data since nesting may lead to a statistical dependency among the observations in the sample. That is, it could be that there is statistical dependence because it can be expected that students and teachers from the same school share more similarities among themselves than with students and teachers from another school (they share teachers or students, use similar school resources, belong to certain neighbourhoods) or that, for example, if characteristics common to the school are used to determine the probability of using ICT in the classroom, given that all teachers in a school have the same value for that variable, statistical dependence can also be observed. In the presence of this statistical dependence, the ordinary estimation of a logit model may involve unbiased regression coefficients but the standard errors associated with those coefficients may be biased and increase the probability of Type I error leading to incorrect conclusions regarding the statistical significance (Julian, 2001). Multilevel regression techniques allow

[36] Results of complete case analyses are available in tables A.2 and A.3 in the Appendix.

[37] The regressions have also been estimated using the probit technique in order to test the robustness of our results. The probit results are available in table A.4 in the Appendix and confirm the results obtained by estimating a logit.

to control the hierarchical structure of the data and produce unbiased estimates of the standard errors (Hox, 2010).

Our objective in this research is to predict a teacher-level outcome variable (use of ICT in the classroom) from variables measured at the student, teacher and school level. Considering that students are nested within classes/teachers, and classes/teachers are nested within schools, our dependent variable is placed at the intermediate level (teacher-level) and our objective is to estimate it as a function of both variables related to characteristics of a lower level (student) and a higher level (school). In multilevel modelling, when the dependent variable measured at the lower level (in our case, teacher-level) is predicted by variables measured at that lower or a higher level (school-level), this is referred to as a macro-micro situation. Contrary, when a dependent variable defined at a higher group level (in our case, the teacher-level) is predicted or explained on the basis of independent variables measured at a lower level (student-level), this is referred to as a micro-macro situation. Therefore, in this research we are confronted with both a macro-micro situation and a micro-macro situation.

As far as macro-micro situations are concerned, these have been frequently studied in the literature on multilevel modelling (Greenland, 2000) and the statistical software we employed in this research (Stata 14) allows us to control for this multilevel structure which implies that teachers are nested in schools by means of the "melogit" command (StataCorp, 2013). However, as far as the micro-macro situation is concerned, the models for micro-macro data have been until recently been mostly neglected in the literature on multilevel modelling (Croon and Van Veldhoven, 2007) and the analysis techniques are scarce. We are therefore faced with two options traditionally used to deal micro-macro situations: (1) aggregating the variables that are not measured at the teacher level by assigning the mean or the mode of the respective teacher students to teachers [38]; or (2) disaggregating the teacher variables to the student level by assigning all students in the same class the same score on the teacher-level variable as if it were measured at the student-level. We decide to use the aggregation technique, since the disaggregation procedure violates one of the basic assumptions of regression analysis: the independent observations assumption (Keith, 2006). This may result in downwardly biased standard error estimates, excessively large test statistics and inflated Type I Error Rates (Krull and MacKinnon, 2001). Using the aggregation technique, we eliminate the correlation among individual error terms. However, it is important to note that the aggregation technique reduces the variability in the data, and this may also result in inappropriate estimates of the standard errors of the regression parameters (Croon and Van Veldhoven, 2007). For this reason, the results obtained for the variables related to student characteristics should be interpreted with caution.

[38] In the case of categorical variables with more than two categories (number of books at home) the mode was used as a measure of aggregation. For the rest of the variables, the mean was used.

We proceed to estimate a multilevel logit in which the binomial dependent variable is the "use of ICT resources to carry out projects or do exercises in class" and the explanatory variables are those mentioned in section 3.3.2 related to the student, teacher and school. According to Gujarati (2004) the mathematical formula of a logit model is:

$$P_i = F(z) = \frac{e^{z_i}}{1+ e^{z_i}} \qquad (1)$$

Where, P_i is the probability of using ICT in the class for the ith student and it ranges from 0-1. z_i is a function of n-explanatory variables which can be expressed as:

$$z_i = B_0 + \sum_i^n B_i X_i \quad (2)$$

where:
i = 1, 2, 3, …., n
B_0 = Intercept
B_i= Regression coefficients to be estimated or logit parameters
X_i= Students', teachers', and schools' characteristics

In our empirical work, we estimate the following:

$$\text{logit } (P_i) = \ln\left(\frac{P_i}{1-P_i}\right) = B_0 + \sum_i^n B_i X_i + u_i \quad (3)$$

where:
u_i= The error term

According to Gujarati (2004), the coefficient of the logistic model result can be written in terms of the odds and log of the odds ratio. The regression coefficient obtained by performing a logistic regression is the estimated increase in the log odds of the dependent variable per unit increase in the value of the independent variable of interest. Given that log odds are difficult to interpret on their own, we convert the log odds to normal odds (OR) using the exponential function to facilitate the interpretation of the estimated coefficients. OR are defined as the ratio of the probability that the student will be using ICT in the class (P_i) and the probability that the student will not use ICT (1- P_i). The formula of the probability that a student will not use ICT in the class is:

$$1 - P_i = \frac{1}{1+ e^{z_i}} \qquad (4)$$

The odds ratio can be written as the ratio between equation (1) and (4):

$$\frac{P_i}{1-P_i} = \frac{1+ e^{z_i}}{1+ e^{-z_i}} = e^{z_i} \quad (5)$$

An odds ratio greater than 1 describes a positive relationship indicating that as the independent variable value increases, the odds of using ICT in the classroom increase, while an odds ratio less than 1 describes a negative relationship. Specifically, the estimated odds ratio represents the factor that multiplies the probability of using ICT in the classroom for the corresponding independent variable when it increases by one unit on the scale of the variable and the remaining variables stay constant.

3.4 Results

Table 4 shows the results of the multilevel logistic models for the association between student, teacher and school characteristics and the frequency of ICT use to carry out projects or do exercises in class. As explained in section 3.3.4, the results are expressed in terms of odds ratios (OR) and the interpretation of OR differs according to the type of variable analysed (Ranganathan et al., 2017). For categorical explanatory variables, the OR is with respect to a reference category. For example, the OR for teacher gender refers to the odds of using ICT in class in women versus men. If a categorical variable has more than two categories (e.g., public, semi-private or private school), then separate ORs are calculated for each of the other categories relative to the reference category (semi-private vs. public; private vs. public). For continuous predictors (e.g., teacher's year of birth), the OR represents the increase or decrease in odds of the outcome of interest (using ICT in the class) with every one unit increase in the explanatory continuous variable. In this regard, it is important to point out that the ordinal variables (e.g., teacher's motivation or disturbance in class) can be entered in the logistic models as a continuous variable or as a categorial one using dummy indicator variables for each level (Pasta, 2009).Treating an ordinal predictor as a continuous variable implies assuming that a simple linear or polynomial function can adequately explain the relationship between the response and the predictor. However, treating an ordinal predictor as a categorical variable, we do not assume a linear or proportional effect along the scale but in turn more data are required to obtain viable results. Considering the characteristics of our data (low number of observations in some categories of various ordinal variables) we included as the main model (table 4) the estimates in which the ordinal predictors have been introduced as continuous predictors. However, we have also performed the estimations including these variables as categorical predictors (table 5) to complement our results, given that in those cases in which we find a sufficient large number of observations in each of the response categories, it is appropriate to look at the results obtained in table 5. The main conclusions of the research are maintained regardless of how ordinal variables are introduced in the estimations.

If we focus on analysing first the variables classified as variables of interest in this research - those that potentially seem to have a stronger relationship with the use of ICT in the classroom - the results confirm that in all the educational levels the three of them are statistically significant for explaining the probability of using ICT in the classroom for educational purposes. Specifically, the results show that the most important factor for increasing the probability that the teacher decides to use ICTs in the classroom for educational purposes is the students' use of ICT at home. In this sense, it is observed that the greater the number of students in the classroom who use ICT frequently, every day or almost every day at home, the greater the probability that the teacher decides to use these tools in his or her class at all the educational levels analysed (odds ratio = 2.234; odds ratio = 9.582; odds ratio = 4.765). With respect to teacher characteristics, the results show that odds are 1.302 (3rd year of primary education), 1.787 (6th year of primary education) and 1.242 (4th year of secondary education) times higher that a teacher who has received ICT training will use ICT in his or her classes compared to a teacher who has not received ICT training. These findings are in line with Inan and Lowther (2010), Shin (2015) and Gerick et al. (2017) and suggest that teachers trained in the use of ICT are more likely to use ICT in their classes. In this sense, we consider that these results highlight the need to implement training programs in the use of ICTs in order to increase their frequency and quality of use in schools as has also been suggested in previous literature (Bullock, 2001; Allegra et al., 2001; Wheeler et al., 2002; Schulz et al., 2002; Abell, 2006; Tüzün et al., 2009).

Finally, in relation to the availability of ICT resources in school, the results show that this is also a relevant factor and that the greater the lack of ICT resources in the school, the less likely teachers are to use ICT. Specifically, the results show that with every one unit increase in the value of the variable “Lack of technological devices”, there is around a 20% lower likelihood of teachers using ICT in the class. This result is in line with Eickelmann et al. (2017) and Petko et al. (2018).

Table 4: Determinants of ICT use in the classroom (multilevel logistic models)

VARIABLES	(1) 3rd year primary education	(2) 6th year primary education	(3) 4th year secondary education
ICT use at home (Student)	**3.234*** **	**9.582** **	**4.765** **
	(1.423)	(9.331)	(3.289)
ICT training (Teacher)	**1.302*** **	**1.787*** **	**1.242*** **
	(0.101)	(0.131)	(0.0908)
Lack of tech. devices (Director)	**0.787*** **	**0.808*** **	**0.792*** **
	(0.0536)	(0.0567)	(0.0507)
Books at home (Student)	0.981	1.026	0.981
	(0.0392)	(0.0370)	(0.0368)
Immigrant (Student)	0.526	0.355	**0.440***
	(0.233)	(0.287)	(0.219)
Female (Student)	0.660	1.339	1.090
	(0.241)	(0.495)	(0.293)
Repeater (Student)	N.A.	**0.340** **	0.976
		(0.161)	(0.394)
Female (Teacher)	0.955	1.056	0.962
	(0.0927)	(0.0856)	(0.0745)
Year of birth (Teacher)	1.002	1.004	1.002
	(0.00420)	(0.00371)	(0.00391)
Motivation (Teacher)	**1.408*** **	**1.195*** **	**1.099***
	(0.0770)	(0.0594)	(0.0555)
Time dedication (Teacher)	**1.810*** **	0.953	**1.334** **
	(0.367)	(0.199)	(0.175)
Disturbance in class (Teacher)	**0.892*** **	0.967	**0.898*** **
	(0.0364)	(0.0371)	(0.0372)
Class Size (Student)	1.004	0.991	0.987
	(0.0164)	(0.0158)	(0.0102)
School ownership (semi-private school)	0.854	0.915	1.122
	(0.114)	(0.125)	(0.139)
School ownership (private school)	**1.886** **	**1.625***	1.064
	(0.490)	(0.432)	(0.224)
Lack of teacher training (Director)	0.955	0.895	**0.788*** **
	(0.0787)	(0.0750)	(0.0622)
Lack of autonomy (Director)	0.973	**1.264*** **	**1.183** **
	(0.0750)	(0.0991)	(0.0790)
Subject (Spanish)	0.991	**0.757*** **	**4.130*** **
	(0.0803)	(0.0677)	(0.407)
Subject (English)	**1.877*** **	**0.837***	**5.659*** **
	(0.159)	(0.0762)	(0.580)
Subject (Science and Tec./Social and Civic)	N.A.	**0.495*** **	**5.234*** **
		(0.0443)	(0.536)
Constant	0.00614	8.64e-05	0.00236
	(0.0513)	(0.000642)	(0.0183)
Observations	5,366	6,785	4,773
Number of schools	1,105	1,083	656

**Standard error in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

***Results are expressed in odd ratios.*

Table 5: Determinants of ICT use in the classroom (multilevel logistic models with ordinal variables entered as categorical variables)

VARIABLES	(1) 3rd year primary education	(2) 6th year primary education	(3) 4th year secondary education
ICT use at home (Student)	**3.155****	**10.63****	**4.809****
	(1.416)	(10.62)	(3.318)
ICT training (Teacher)	**1.294*****	**1.817*****	**1.245*****
	(0.101)	(0.135)	(0.0912)
Lack of tech. devices = 1 (Director)	**0.784***	**0.679*****	**0.584*****
	(0.113)	(0.102)	(0.0763)
Lack of tech. devices = 2 (Director)	**0.632*****	**0.663****	**0.622*****
	(0.106)	(0.116)	(0.0973)
Lack of tech. devices = 3 (Director)	**0.477*****	**0.525****	**0.523*****
	(0.127)	(0.142)	(0.128)
Books at home = 1 (Student)	0.913	0.118	0.885
	(0.231)	(0.110)	(0.377)
Books at home = 2 (Student)	0.932	0.140	0.777
	(0.243)	(0.131)	(0.336)
Books at home = 3 (Student)	0.888	0.114	0.741
	(0.244)	(0.107)	(0.326)
Books at home = 4 (Student)	0.864	0.139	0.807
	(0.232)	(0.130)	(0.353)
Immigrant (Student)	0.504	0.314	0.448
	(0.229)	(0.257)	(0.227)
Female (Student)	0.703	1.426	1.097
	(0.258)	(0.530)	(0.295)
Repeater (Student)	N.A.	**0.346****	0.891
		(0.165)	(0.362)
Female (Teacher)	0.961	1.073	0.965
	(0.0942)	(0.0876)	(0.0749)
Year of birth (Teacher)	1.002	1.004	1.002
	(0.00423)	(0.00375)	(0.00392)
Motivation = 1 (Teacher)	1.126	0.909	1.012
	(0.0961)	(0.0728)	(0.0791)
Motivation = 2 (Teacher)	**2.248*****	**1.495*****	1.186
	(0.315)	(0.199)	(0.148)
Motivation = 3 (Teacher)	**3.044*****	**2.070*****	**1.828****
	(0.791)	(0.459)	(0.494)
Time dedication (Teacher)	**1.884*****	0.925	**1.320****
	(0.384)	(0.194)	(0.174)
Disturbance in class = 1 (Teacher)	**0.577*****	**0.836***	**0.793****
	(0.0604)	(0.0763)	(0.0885)
Disturbance in class = 2 (Teacher)	**0.514*****	**0.682*****	**0.692*****
	(0.0592)	(0.0722)	(0.0825)
Disturbance in class = 3 (Teacher)	**0.782***	1.068	**0.724****
	(0.105)	(0.137)	(0.0999)
Class Size (Student)	1.005	0.996	0.988
	(0.0165)	(0.0160)	(0.0103)
School ownership (semi-private school)	0.827	0.894	1.122
	(0.110)	(0.123)	(0.139)
School ownership (private school)	**1.824****	**1.588***	1.070
	(0.476)	(0.428)	(0.225)

Table 6: Determinants of ICT use in the classroom (multilevel logistic models with ordinal variables entered as categorical variables) (*continuation)*

VARIABLES	(1) 3rd year primary education	(2) 6th year primary education	(3) 4th year secondary education
Lack of teacher training = 1 (Director)	0.835	0.853	**0.756****
	(0.123)	(0.129)	(0.102)
Lack of teacher training = 2 (Director)	0.958	0.792	**0.666****
	(0.173)	(0.146)	(0.111)
Lack of teacher training = 3 (Director)	0.740	1.047	**0.392****
	(0.307)	(0.462)	(0.177)
Lack of autonomy = 1 (Director)	0.924	1.263	1.209
	(0.143)	(0.200)	(0.176)
Lack of autonomy = 2 (Director)	0.843	**1.494****	**1.596*****
	(0.147)	(0.269)	(0.262)
Lack of autonomy = 3 (Director)	1.392	**2.518*****	**1.515***
	(0.460)	(0.857)	(0.343)
Subject (Spanish)	0.994	**0.755*****	**4.109*****
	(0.0810)	(0.0680)	(0.405)
Subject (English)	**1.896*****	**0.838***	**5.680*****
	(0.162)	(0.0768)	(0.584)
Subject (Science and Tec./Social and Civic)	N.A	**0.492*****	**5.219*****
		(0.0443)	(0.535)
Constant	0.0167	0.00157	0.00661
	(0.141)	(0.0118)	(0.0516)
Observations	5,366	6,785	4,773
Number of schools	1,105	1,083	656

**Standard error in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

***Results are expressed in odd ratios.*

The results also show the importance of other variables included in the regressions, which, although not directly related to ICTs, seem to clearly influence the probability of teachers' use of ICT. In this sense, at the teacher-level a very relevant result is the positive association between the motivation of teachers (approximated by their satisfaction with the profession) and the probability of using ICT in the class. Our regressions suggest that with every one unit increase in the value of the variable "Motivation" the odds are around a 40% higher in 3rd year of primary education and around a 20% higher in 6th year of primary education that teachers will use ICT in the classroom. In 4th year of secondary education, the odds ratio obtained when the variable "Motivation" is introduced as a continuous predictor is only statistically significant at the 0.10 significance level and in this research we consider 0.05 as the threshold to discriminate significant from non-significant results. However, if we complement these results with those obtained in Table 5 when this variable is introduced as a categorical variable, we observe that at this educational level there is a clear difference between the probability of ICT use by teachers who answer that they are totally satisfied with their profession (maximum level of satisfaction) and those who answer that they are not at all satisfied with their work (reference category) since the odds ratios are statistically significant at the 0.05 significance level. Specifically, the results suggest that the teachers who strongly agree with the satisfaction statement are around 80% more likely to use ICT in the classes than those who are not at all in agreement with the statement. Based on these results, it can be concluded that more motivated teachers are more likely to use ICT in the classroom, as also suggested by Sang et al. (2011).

With respect to other teacher characteristics, the gender and age of the teacher do not affect the probability of ICT use based on our results. However, we do observe that teachers who work full time (compared to those who work part time) are more likely to use ICT in their classroom in 3rd year of primary education (odds 1.810) and 4th year of secondary education (odds = 1.334).

Another particularly interesting result is that, in 3rd year of primary education and 4th year of secondary education, we find that with every one unit increase in the value of the variable "Disturbance in class" the odds are around a 10% lower that teachers will use ICT in their classes. In the case of 6th year of primary education, although the results in Table 4 reflect an odds ratio that is not statistically significant, we believe it is interesting to complement the interpretation of this result with the data in Table 5. In this sense, Table 5 shows that when the variable "Disturbance in class" is introduced as a categorical predictor, it is observed that the teachers who indicate that disturbance is a moderate problem are around a 30% less likely to use ICT in the classes than those who indicate that disturbance is not a problem. It seems, therefore, that teachers who teach in classrooms with good student behavior are more likely to use ICT as a teaching method.

As for other variables included that have to do with the characteristics of the students taught by each teacher, we find that the greater the number of repeater students in the classroom, the lower the probability that the teacher decides to use ICT in his or her class in 6th year of primary education (odds ratio = 0.340). However, for the rest of the student-level variables included in our logistic regressions (gender, immigration status and number of books at home) - leaving aside the use of ICTs at home by students- the odds ratios estimated are not statistically significant. Class size also shows no statistical significance.

Regarding the school climate, we can conclude that the ownership of the school seems to be a determining factor in the use of ICT in the classroom only in the 3rd year of primary education. Specifically, for this educational level we find that private schools– as compared to public schools - are more likely to have teachers who use ICT in the classroom. In the rest of the educational levels and types of schools, ownership is not a determining factor. In relation to the characteristics of the educational centre, we find that in 4th year of secondary education, with every one unit increase in the value of the variable "Lack of teacher training" the odds are around a 20% lower that teachers will use ICT in their classes. However, this relationship is not observed in the rest of the educational levels. On the other hand, the lack of decision-making autonomy at the school level seems to be positively related to the likelihood of implementing ICT in the classroom in 6th year of primary education (odds = 1.264) and 4th year of secondary education (odds = 1.183).

Finally, with regard to the subjects taught, the results clearly show that the probability of using ICT differs by subject. In this sense, in the 3rd year of primary education it is observed that odds are 1.877 times higher that a teacher who teaches English will use ICT in his or her classes compared to a teacher who teaches mathematics (reference category), while neither higher nor lower odds are observed in the case of Spanish compared to mathematics. In the 6th year of primary education, the results indicate that if the teacher teaches Spanish or Science and Technology, there is around a 25% and 50%, respectively, lower likelihood of he or she uses ICT in the class as compared to a mathematics teacher. Finally, in 4th year of secondary education, the results suggest that odds are 4.130 (in Spanish), 5.659 (in English) and 5.234(in social and civic competence) times higher that a teacher who teaches Spanish, English or social and civic competence will use ICT in his or her classes compared to a teacher who teaches mathematics.

3.5 Final Considerations

The logistic regressions estimated with the data from the individualized evaluations carried out at the end of the 2018-2019 academic year in the Community of Madrid show that some variables related to the characteristics of teachers, their students and schools are key to explaining the probability of using ICT in the classroom to carry out projects or do exercises in the different educational levels analysed: 3rd year of primary education, 6th year of primary education, and 4th year of secondary education. These results are relevant and suppose a contribution to the scarce previous literature to date on this topic.

We have obtained some results that deserve special attention. In relation to the characteristics of the students in the classroom, we find that certain students' individual characteristics are relevant in explaining the frequency of use of ICT in the classroom. In this sense, if teachers have classes with students that frequently, every day or almost everyday use ICT at home, they are more likely to use ICT in the class than if their students never, almost never or only occasionally use ICT at home. This finding indicates that students' familiarization with ICT matters for teachers and that they are more likely to introduce ICT in the classroom if students are familiar with these tools through their regular use at home. In addition to increasing the likelihood of ICT use in the class, in previous literature the frequency of ICT use by children and adolescents at home has also been positively related to academic performance (Skryabin et al., 2015). Although the majority of students surveyed report frequent use of ICTs, we still find some students at all levels of education who report not using these technologies at home. Considering this and in order to increase the presence of ICTs in schools to take advantage of all their potential benefits, we believe that it would be advisable for governments to develop public policies aimed at providing technological resources to households who cannot afford to purchase them and policies to promote a frequent but responsible use of these technologies.

Student behavior in the classroom also appears to be a determining factor in the use of ICT in the classroom. According to our estimations teachers who report having a problem with disturbance in their class are less likely to use ICT in the classes than those who indicate not having problems at all with disrupting behaviours in all the educational levels. This result seems to indicate that teachers find problems in applying new technologies in the classroom when they find a negative classroom climate and that they are more likely to innovate with new technologies if students are calm and their class is respectful. This finding shows that the classroom environment is very important and affects the teacher's decision to use ICT.

Regarding the teachers' characteristics, we find that the teachers who have received ICT training in the last 12 months are more likely to use ICT in their classes in the three educational levels evaluated in this research. This result becomes relevant since it highlights the importance of implementing ICT training programs for teachers to encourage greater and better use of ICT and to take advantage of the potential benefits of these tools. We also observe that teachers' motivation seems to be a key aspect in explaining the implementation of ICT in the classroom in all the educational levels. Higher levels of teachers' motivation increase the probability of using ICT in the classroom. This finding highlights the relevance of teacher motivation in promoting innovation (such as using ICT) in the classroom.

Finally, in relation to the school characteristics, we find that the greater the lack of ICT resources in the school, the less likely teachers are to use ICT. In this sense, the results show that, as might be expected, the decision to use ICTs by teachers is influenced by the availability of ICTs in schools. In this regard, the descriptive statistics showed that only 39% of principals stated that they considered that there was no problem with the lack of availability of digital resources in their school. This shows that there is still ample room for improvement in this regard and that public policies are needed to improve the availability of ICT resources in schools.

All the results obtained in this research allow us to draw a typical profile of teachers who are more likely to use ICT to carry our projects or do exercises in class. Based on our results, a motivated teacher (satisfied with the profession) who has received ICT training and teaches in a calm and respectful class in a school where the lack of digital devices is not a problem and with students who frequently use ICT at home, has a high predisposition to use ICT in his/her classes. The configuration of this profile is relevant as it can help guide educational policy measures aimed at increasing the presence of ICT in the classroom in order to take advantage of its potential benefits. In this regard, as we have already mentioned, our recommendations go in the direction of increasing teacher training in ICT and the provision of technological resources in schools, as well as promoting the availability and responsible use of these technologies at home. In parallel to these recommendations aimed at increasing the frequency of ICT use by teachers, we believe it is very necessary to continue research on the use of ICT in schools, in order to understand why the introduction of these tools does not always have positive effects on academic performance as evidenced in the literature review section. In this sense, policies aimed at increasing the use of ICT in the classroom should be accompanied by a good program of recommendations on their use that will allow teachers to take full advantage of these tools, and thanks to their introduction in the classroom, achieve better academic performance of students.

3.6 Appendix

Table A.1: Definition of dependent and independent variables

DEPENDENT VARIABLE	
Teacher questionnaire	
ICT use in class	0 = never, almost never or occasionally 1= frequently, every day or almost everyday
INDEPENDENT VARIABLES	
Student questionnaire	
Female	0 = male 1 =female
Immigrant	0 = student was born in Spain. 1 = student was not born in Spain.
Repeater	0 = never repeated 1 = repeated once or more
Books at home	0 = from 0 to 10 1 = from 11 to 50 2 = from 51 to 100 3 = from 101 to 200 4 = more than 200
Frequency of computer or tablet use at home	0 = never, almost never or occasionally 1 = frequently, every day or almost everyday
Class size	"Number of students in class"
Teacher questionnaire	
Female	0 = male 1= female
Year of birth	Year number
School ownership	0 = public school 1= semiprivate school 2 = private school
Time dedication	0 = part time 1 = full time
ICT training in the last 12 months	0 = No 1 = Yes
Disturbance of order in class	0 = not a problem 1 = slight problem 2 = moderate problem 3 = serious problem
Satisfaction with the profession (motivation)	Degree of agreement / disagreement with the statement: "If I could decide again, I would continue to choose this job". 0 = nothing in agreement 1 = little bit of agreement 2 = quite agree 3 = strongly agree

Table A.1: Definition of dependent and independent variables (*continuation*)

INDEPENDENT VARIABLES	
Teacher questionnaire	
Subject taught	*3rd year of primary education:* 1 = Mathematics 2 = Spanish 3 = English *6th year of primary education:* 1 = Mathematics 2 = Spanish 3 = English 4 = Science and technology *4th year of secondary education:* 1 = Academic mathematics 2 = Spanish 3 = English 4 = Social and Civic
School questionnaire	
Lack of a teacher training plan	0 = absolutely 1 = very little 2 = to some extent 3 = a lot
Lack of autonomy to decide	0 = absolutely 1 = very little 2 = to some extent 3 = a lot
Lack of technological devices for teaching	0 = absolutely 1 = very little 2 = to some extent 3 = a lot

Table A.2: Determinants of ICT use in the classroom (complete case analysis)

VARIABLES	(1) 3rd year primary education	(2) 6th year primary education	(3) 4th year secondary education
ICT use at home (Student)	**2.173****	**4.766****	**5.390****
	(1.107)	(5.268)	(4.130)
ICT training (Teacher)	**1.597*****	**2.232*****	**1.346*****
	(0.152)	(0.202)	(0.113)
Lack of tech. devices (Director)	**0.791*****	**0.822****	**0.795*****
	(0.0611)	(0.0662)	(0.0551)
Books at home (Student)	1.013	1.044	0.955
	(0.0467)	(0.0433)	(0.0401)
Immigrant (Student)	0.813	0.390	0.425
	(0.418)	(0.369)	(0.235)
Female (Student)	0.747	1.080	1.040
	(0.314)	(0.493)	(0.310)
Repeater (Student)		**0.365***	0.967
		(0.199)	(0.430)
Female (Teacher)	0.910	1.082	0.932
	(0.102)	(0.103)	(0.0813)
Year of birth (Teacher)	1.004	1.002	1.006
	(0.00496)	(0.00433)	(0.00441)
Motivation (Teacher)	**1.407*****	**1.314*****	**1.105***
	(0.0903)	(0.0758)	(0.0631)
Time dedication (Teacher)	**1.887*****	0.864	**1.379****
	(0.441)	(0.209)	(0.200)
Disturbance in class (Teacher)	**0.877*****	0.939	**0.891****
	(0.0417)	(0.0424)	(0.0415)
Class Size (Student)	1.013	0.993	0.991
	(0.0188)	(0.0187)	(0.0114)
School ownership (semi-private school)	0.929	0.996	**1.294***
	(0.140)	(0.157)	(0.175)
School ownership (private school)	**1.860****	**1.716***	1.113
	(0.537)	(0.526)	(0.252)
Lack of teacher training (Director)	1.017	0.917	0.738***
	(0.0950)	(0.0887)	(0.0627)
Lack of autonomy (Director)	0.957	**1.278*****	**1.244*****
	(0.0831)	(0.115)	(0.0894)
Subject (Spanish)	0.975	**0.693*****	**4.022*****
	(0.0913)	(0.0717)	(0.448)
Subject (English)	**1.907*****	0.897	**5.233*****
	(0.190)	(0.0947)	(0.595)
Subject (Science and Tec./Social and Civic)		**0.444*****	**5.220*****
		(0.0460)	(0.614)
Constant	0.000175	0.0219	6.38e-07
	(0.00173)	(0.190)	(5.58e-06)
Observations	4,244	5,557	3,818
Number of schools	1,039	1,030	652

**Standard error in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

***Results are expressed in odd ratios.*

Table A.3: Determinants of ICT use in the classroom (complete case analysis with % missing <5%)

VARIABLES	(1) 3rd year primary education	(2) 6th year primary education	(3) 4th year secondary education
Lack of tech. devices (Director)	**0.778*** **	**0.792*** **	**0.782*** **
	(0.0528)	(0.0566)	(0.0506)
Female (Student)	0.740	1.251	1.088
	(0.267)	(0.463)	(0.292)
Female (Teacher)	0.945	1.007	0.967
	0.740	1.251	1.088
Year of birth (Teacher)	1.002	1.005	1.002
	(0.00418)	(0.00370)	(0.00391)
Motivation (Teacher)	**1.379*** **	**1.180*** **	**1.103* **
	(0.0748)	(0.0585)	(0.0557)
Time dedication (Teacher)	**1.871*** **	1.029	**1.387** **
	(0.377)	(0.214)	(0.182)
Disturbance in class (Teacher)	**0.890*** **	0.956	**0.890*** **
	(0.0360)	(0.0365)	(0.0367)
Class Size (Student)	1.004	1.004	0.989
	(0.0158)	(0.0158)	(0.0102)
School ownership (semi-private school)	0.898	0.993	1.169
	(0.118)	(0.136)	(0.144)
School ownership (private school)	**1.952*** **	**2.003*** **	1.125
	(0.495)	(0.529)	(0.233)
Lack of teacher training (Director)	0.939	0.876	**0.778*** **
	(0.0768)	(0.0747)	(0.0619)
Lack of autonomy (Director)	0.966	**1.268*** **	**1.184** **
	(0.0742)	(0.101)	(0.0796)
Subject (Spanish)	0.995	**0.755*** **	**4.057*** **
	(0.0801)	(0.0674)	(0.399)
Subject (English)	**1.876*** **	**0.837* **	**5.592*** **
	(0.158)	(0.0759)	(0.572)
Subject (Science and Tec./Social and Civic)		**0.503*** **	**5.188*** **
		(0.0448)	(0.530)
Constant	0.0101	0.000241	0.00444
	(0.0835)	(0.00177)	(0.0343)
Observations	5,401	6,785	4,773
Number of schools	1,114	1,083	656

**Standard error in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

***Results are expressed in odd ratios.*

Table A.4: Determinants of ICT use in the classroom (multilevel probit models)

VARIABLES	(1) 3rd year primary education	(2) 6th year primary education	(3) 4th year secondary education
ICT use at home (Student)	**0.684*****	**1.323****	**0.937****
	(0.260)	(0.571)	(0.412)
ICT training (Teacher)	**0.157*****	**0.334*****	**0.130*****
	(0.0460)	(0.0430)	(0.0436)
Lack of tech. devices (Director)	**-0.141*****	**-0.126*****	**-0.140*****
	(0.0403)	(0.0411)	(0.0382)
Books at home (Student)	-0.0112	0.0158	-0.0126
	(0.0236)	(0.0212)	(0.0224)
Immigrant (Student)	-0.382	-0.586	-0.490*
	(0.264)	(0.474)	(0.297)
Female (Student)	-0.241	0.163	0.0489
	(0.217)	(0.216)	(0.160)
Repeater (Student)		**-0.637****	-0.0287
		(0.277)	(0.240)
Female (Teacher)	-0.0280	0.0352	-0.0237
	(0.0572)	(0.0475)	(0.0461)
Year of birth (Teacher)	0.00100	0.00243	0.00126
	(0.00248)	(0.00216)	(0.00233)
Motivation (Teacher)	**0.202*****	**0.106*****	**0.0557***
	(0.0322)	(0.0291)	(0.0301)
Time dedication (Teacher)	**0.348*****	-0.0278	**0.173****
	(0.120)	(0.123)	(0.0782)
Disturbance in class (Teacher)	**-0.0670*****	-0.0181	**-0.0630****
	(0.0241)	(0.0225)	(0.0247)
Class Size (Student)	0.00239	-0.00562	-0.00782
	(0.00966)	(0.00933)	(0.00618)
School ownership (semi-private school)	-0.0985	-0.0482	0.0722
	(0.0788)	(0.0796)	(0.0737)
School ownership (private school)	**0.379****	**0.289***	0.0429
	(0.154)	(0.155)	(0.125)
Lack of teacher training (Director)	-0.0287	-0.0641	**-0.143*****
	(0.0489)	(0.0491)	(0.0470)
Lack of autonomy (Director)	-0.0162	**0.138*****	**0.101****
	(0.0457)	(0.0459)	(0.0398)
Subject (Spanish)	-0.00368	**-0.161*****	**0.850*****
	(0.0482)	(0.0524)	(0.0582)
Subject (English)	**0.369*****	**-0.101***	**1.038*****
	(0.0500)	(0.0532)	(0.0600)
Subject (Science and Tec./Social and Civic)		**-0.411*****	**0.993*****
		(0.0523)	(0.0602)
Constant	-2.825	-5.492	-3.643
	(4.942)	(4.331)	(4.635)
Observations	5,366	6,785	4,773
Number of schools	1,105	1,083	656

**Standard error in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

CONCLUSIONS

In this section, I present some general conclusions of this doctoral thesis that allow for a joint interpretation of the empirical evidence obtained in the three research studies that make up this document. Additionally, considering the results obtained, I point out future lines of research that would complement the analyses presented in this thesis and reflect on recommendations for educational policy, as well as for teachers and school principals.

This concluding section is further structured into different sub-sections: (1) summary and reflection on the main results obtained in the different chapters; (2) discussion on the differential effects (negative or positive on academic performance) according to the type of ICT use; (3) implications of the thesis results for policy makers; (4) implications for teachers and school principals; and (5) future lines of research.

Main results of the three chapters of the thesis

In Chapter 1, the analysis of PISA 2015 data through the estimation of multilevel models and quantile regressions suggests that ICT are related to the academic performance in reading comprehension, science and mathematics of 15-year-old students. One of the great novelties and contributions of this research is that it focuses on analyzing a set of ICT variables related to the presence and use of these tools both in the social environment and in the students' educational environment. In this sense, the results of this first chapter show that it is not possible to speak of a general impact of ICT on academic performance, but rather that the influence of ICT on performance depends on the specific ICT variable being analysed. Furthermore, quantile regressions show that the associations found in this chapter are particularly relevant for those students who are at the lower end of the distribution of PISA scores. This last result is an important contribution to the scientific literature given that there are no previous studies that have focused on analyzing the relationship between the types of ICT use studied in chapter 1 and academic performance distinguished by student achievement percentile.

In particular, Chapter 1 finds that ICT use is associated with higher levels of academic achievement if it is used for entertainment purposes at home. In other words, it is concluded that more frequent use of ICT at home for activities such as playing games, chatting, watching films or listening to music is associated with higher levels of academic performance. On the other hand, a negative relationship is observed between a higher frequency of ICT use at home for homework and students' academic performance. These results on the impact of ICT use at home on academic performance are in line with those found in previous research (Biagi and Loi, 2013; Mediavilla and Escardíbul, 2015; Agasisti et al., 2020). However, Chapter 1 of this thesis brings new empirical evidence to the scientific literature given that the previously mentioned studies were based on data from PISA rounds (PISA 2009 and PISA 2012) prior to the one used in this thesis (PISA 2015).

Therefore, the updated results of this thesis considering the information available in PISA 2015 confirm that the purpose of ICT use at home continues to be key in explaining the effect of technology use on academic performance.

With regard to students' attitudes towards ICT, the results show that those who start using these technologies at an earlier age have higher levels of academic performance, in line with Mediavilla and Escardíbul (2015) and Escardíbul and Mediavilla (2016). In addition, it is observed that students with a greater degree of interest in ICT also show better academic performance, while, conversely, those who attach more importance to ICT in their social interactions show lower levels of academic performance in reading comprehension. These last two results are novel given that no previous research has assessed these relationships and therefore constitute an important contribution to the scientific debate on the impact of ICT use on academic performance.

When focusing the analysis on the school context, the results suggest that a higher frequency of ICT use at school is associated with poorer levels of academic performance, while a higher number of computers per student at the educational institution is associated with better levels of academic performance. This negative association between the frequency of ICT use at school and academic performance is in line with the results found in previous research that also uses as an independent variable the index of ICT use at school provided by PISA (Gumus and Atalmis, 2011; Biagi and Loi, 2013; Skryabin et al., 2015; Mediavilla and Escardíbul, 2015; Escardíbul and Mediavilla, 2016; Petko et al., 2017; Hu et al., 2018; Gorjón et al., 2021). However, it is important to note that the PISA index measuring ICT use at school in Chapter 1 encompasses different types of use, some for educational purposes and some not. Therefore, this negative association needs to be explored further in order to determine the effect on academic performance of each of the different types of ICT use in schools. In the following subsection, potential reasons that could explain this negative relationship are outlined. In summary, the results obtained in Chapter 1, which point to a negative association between ICT use in schools and academic performance, call for further research in this respect in order to try to answer the question of how ICT should be used in schools.

Considering the result on the use of ICT in schools found in Chapter 1, in Chapter 2 of this thesis I focus on the use of ICT in schools exclusively for educational purposes using data from the individualized assessments carried out in the Community of Madrid. My aim is to discern whether the negative relationship found in the first article can be attributed to the incorporation of these tools in teaching. Applying instrumental variables and propensity score matching techniques, the results show that the use of ICT in the classroom to carry out projects or exercises (i.e., for purely educational purposes) has a positive impact on academic performance in English, social and civic competence and academic mathematics in the fourth year of secondary education. This result is in line with previous studies suggesting that the use of ICT in schools has a positive impact on academic performance (Lai et al., 2015; Ferraro et al., 2018; Fernández-Gutiérrez et al., 2020). However, the main contribution of the chapter to the scientific debate is that the analysis carried out focuses exclusively on analyzing the use of ICT in the classroom for educational purposes for the completion of tasks and exercises. Moreover, the possibility of associating teachers and students in the database used is a relevant contribution to the previous literature, as it allows the use of ICT to be measured separately for each of the subjects. In this way, the results achieved overcome the main limitations of previous studies and allow specific recommendations to be drawn up, which are detailed in the corresponding subsections of this conclusions section.

The results of the instrumental variables models in Chapter 2 are complemented by instrumental variables quantile regressions showing that the positive impact of using ICT in the classroom is particularly relevant for students at the lower end of the distribution of scores in English, and for students in the middle and upper percentiles of academic achievement in Spanish language proficiency, social and civic competence and academic mathematics. As in Chapter 1, this analysis by achievement percentiles is novel and makes a significant contribution to the previous literature.

It is important to note that one of the main strengths of Chapter 2 is the use of quasi-experimental techniques (instrumental variables and instrumental variables quantile regressions), which overcomes the limitations of the regression techniques (multilevel analysis and quantile regression) used in Chapter 1. The non-use of instrumental variables techniques in the first chapter is mainly due to the difficulty in finding convincing instruments for the set of ICT variables analysed. In this regard, it should be noted that after a detailed analysis of the different variables included in the PISA 2015 database, no robust instruments were found for any of the variables. One explanation for this lies for example in the fact that, compared to the data in Chapter 2, in PISA 2015 there is no information on the use of ICT in individual subjects, but students were simply asked about the general use of ICT at school, and it is not possible to link students and teachers. However, the PISA 2018 data do provide more detailed information on ICT use - disaggregating the level of use by subject - so a new line of research would be to replicate the analysis in Chapter 1 using PISA 2018 data and using the instrumental variables technique for the analysis of some of the ICT variables in this chapter, as specified in the subsection on future lines of research.

From Chapter 2 I therefore conclude that using ICT as a teaching tool in the classroom is positive for student achievement. However, again it should be noted that we are referring to a specific use - to carry out projects or exercises - and are therefore excluding other types of ICT use that can also be made for educational purposes, such as using ICT to visualize teaching material or to communicate via e-mail with the teacher. In this sense, as I point out in the reflections in Chapter 2, it is necessary to complement the results of this research with future research that will provide more detailed information on the use of ICT in schools in order to study the impact of the different types of use on academic performance.

Considering that, based on the results of Chapter 2, more frequent use of ICT in the classroom for projects and exercises has a positive impact on academic performance in certain competences, in Chapter 3 I focus on the factors that lead teachers to frequently use ICT in their classes as a teaching tool. The results of the multilevel logistic regressions show that teachers' decisions to implement ICT are motivated by a series of personal characteristics, those of their students and of the educational institution where they teach. Specifically, it is observed that those teachers with higher levels of satisfaction with their profession and those who have taken part in ICT training courses in the last 12 months are more likely to use these tools in the classroom. The positive relationship between job satisfaction and frequency of ICT use is in line with the previous study by Sang et al. (2011). With regard to ICT training, the result obtained is also in line with those obtained by previous studies (Inan and Lowther, 2010; Shin, 2015; Gerick et al., 2017) and shows the importance of teachers receiving training in the use of ICT. Furthermore, the environment matters, those teachers who teach a group of students who behave well in the classroom and who frequently use ICT at home are also more likely to use ICT in their classes. As far as the school is concerned, the results show that the availability of digital devices is a key factor in increasing the frequency of teachers' use of these tools, in line with Eickelmann et al. (2017) and Petko et al. (2018). The results of this research are novel given that, as explained in detail in Chapter 3, there are very few studies that have analysed this topic. Furthermore, this thesis presents a detailed study by educational levels and includes variables that have not been previously explored in the literature. For all these reasons, the results obtained represent an interesting contribution to the scientific debate on the use of ICT by teachers in schools.

Positive versus negative effects of ICT use on academic performance

The results of this thesis show that depending on the type of ICT use, its effect on academic performance differs. This result is very interesting and deserves enough attention to devote a subsection exclusively to the analysis of the nature of these different results.

First, I proceed to analyse the differences in ICT use at home. These differences are analysed in Chapter 1, which concludes that depending on the purpose of ICT use, the relationship with academic performance may be negative or positive. Specifically, it is concluded that the use of ICT at home for entertainment purposes is associated with higher levels of academic achievement, while the use of ICT at home for homework is associated with lower levels of academic achievement. While the analyses in this thesis cannot determine the causal relationship between ICT use and academic performance, possible hypotheses are outlined below. However, to confirm how these causal relationships are explained, further research would be necessary. One possible explanation for this result could be that the use of ICT for entertainment purposes causes students to unintentionally develop their reading and critical thinking skills by surfing the Internet, chatting with friends or playing computer games. This could result in improved academic performance. Additionally, the use of ICT for entertainment may be associated with an increase in motivation and general interest in using technology. This may mean that those who frequently use ICT for entertainment may also decide to voluntarily use ICT for educational purposes (e.g., to seek additional information about concepts explained in the classroom) and thus see an improvement in their academic performance. However, a very novel and interesting finding of this thesis is that the level of importance attached to ICT in social interactions is negatively associated with academic performance. The information solicited to reflect this level of importance includes questions related to interest in meeting friends to play video games. This result seems to point to the need to diversify the uses of ICT by children and adolescents. It seems that an over-emphasis on use for social interaction has a negative impact on performance. This could be explained by the fact that this importance is associated with excessive periods of time using these technologies for activities that do not contribute to learning (non-educational video games) and therefore with less time for other types of ICT use that do contribute to learning and, in general, less time for doing homework at home.

On the other hand, the fact that the use of ICT at home for homework is associated with lower levels of academic achievement seems to suggest that ICT is not being adequately implemented in the educational context and that teachers need to improve the assignment of ICT tasks. This could be explained by several reasons, such as: (i) students are not sufficiently familiar with the specific use of ICT for school tasks; (ii) when using ICT resources, for example a computer or *tablet*, they could easily get sidetracked and end up consulting resources that do not contribute to learning; and (iii) it could be that the tasks are not adequately set by teachers and do not contribute to learning. In the sub-section on recommendations for teachers in this conclusions section, proposals for improvement are put forward to try to reverse this negative relationship found between the use of ICT for homework and academic performance.

In relation to the use of ICT in schools, as mentioned in the main results subsection, although at first sight the results in Chapter 1 and 2 may seem contradictory, the potential explanation lies in the variety of uses of ICT that can be found in schools. In this sense, it is important to point out that the index measuring the frequency of ICT use at school in chapter 1 encompasses different types of use, some for educational purposes and others not. However, in Chapter 2, the variable used to measure ICT use in schools focuses only on use for carrying out tasks and exercises in the classroom. Considering the nature of the variables used in Chapters 1 and 2 to measure the frequency of ICT use at schools, it cannot be concluded from the result of Chapter 1 that using ICT for educational purposes (e.g., for homework and exercises) is associated with worse performance, given that behind this variable there are also uses that are not necessarily related to educational purposes (e.g., chatting). Furthermore, the result in the first chapter could also be explained by the fact that not all uses of ICT for educational purposes have the same impact on academic performance. In this sense, it could be the case that using ICT to solve exercises or assignments is beneficial for performance, as evidenced in Chapter 2, but for example using ICT as an instrument to visualize material or communicate with the teacher is detrimental as a consequence of an incorrect implementation of these tools. In any case, in the absence of confirming the explanation of the causal relationships found, these results highlight the relevance of continuing research into the different types of ICT use in schools in order to be able to guide the incorporation of these tools in teaching in an appropriate way.

Recommendations for policy makers

Considering the results obtained in this thesis, it is of particular interest to elaborate recommendations for policy makers at national and regional level in relation to the promotion of ICT use at home and in schools. In this sense - as discussed in the preceding subsection - it is important to remember that this thesis shows that not all types of ICT use have the same impact on academic performance. Therefore, it is not only a matter of increasing the provision of ICT resources in homes and schools and encouraging their use, but also of promoting the appropriate use of these tools that results in positive effects on learning.

Firstly, recommendations for policy makers regarding the availability and use of ICT at home are outlined. This thesis has shown that an early introduction to ICT use is associated with higher levels of academic achievement, so it seems appropriate to ensure that all children have access to ICT resources from an early age. According to data from the National Statistics Institute (INE, 2021), in the last ten years the percentage of Spanish households without internet access has fallen from 40% to 5% and the percentage of households without a computer available has fallen from 30% to 19%. These data are positive, but they show that there is still a digital divide in Spain and that part of the population faces barriers to access ICT use at home. In this sense, the closure of schools in March 2020 as a consequence of the COVID-19 health crisis highlighted the inequality between those students who could use ICT and the internet at home and those who could not. Specifically, in the case of Spain, 9% of households with children lack internet access (INE, 2021), which means that around 100,000 households with children did not have connectivity during the home confinement, thus turning the digital divide into an educational divide. Therefore, considering these data and the results of this thesis, it seems necessary to continue developing public policies aimed at reducing the digital divide and achieving digital inclusion, either through financial aid in cases of the affordability digital divide, or by improving connectivity in rural or marginalized areas facing a location digital divide.

In parallel to the implementation of measures aimed at improving the availability of ICT resources at home, it is crucial to develop policies aimed at ensuring the correct use of ICTs by children and adolescents. The results of this research show that the use of ICT for entertainment purposes and the degree of interest in ICT are positively related to academic performance. However, the degree of importance given to ICT in social interactions is negatively related to performance. Taking these results into account, a good policy could be to promote social awareness campaigns aimed at raising awareness among children, and especially among young people, of all the possibilities of using ICT resources for entertainment purposes, beyond their uses related merely to social interaction: blogs, newspapers, books, series and films, *webinars*, courses, games, music, etc.

As regards the use of ICT in the school context, the results in Chapter 2 show that the use of ICT for homework and exercises in schools has positive effects on academic performance. In addition, Chapter 3 shows that the more ICT resources there are at school, the more teachers are inclined to use these tools in the classroom, so that if their use is to be promoted, it is essential to increase the provision of ICT resources at educational centers. However, it is important to stress that investment in ICT resources is not a sufficient condition. It must be accompanied by parallel measures that guarantee the appropriate use of these tools by students and teachers. In this sense, it is crucial to accompany investment in ICT resources with measures aimed at training teachers and students in the use of these tools. Computers, *tablets* or digital whiteboards do not per se guarantee an improvement in academic performance and their presence could even be detrimental to it, as shown by the results in Chapter 1. The key seems to be to accompany investment in ICT resources with measures aimed at training teachers in the use of these tools, so that they can be properly incorporated into teaching to carry out tasks and allow for an improvement in academic performance, as shown in Chapter 2. Furthermore, considering that in Chapter 3, both ICT training for teachers and the degree of familiarization of students with the use of ICT turn out to be determining factors when deciding to use these tools in the classroom, it is more than evident that if we want to promote the use of ICT, it is essential to offer specific training to teachers and improve students' familiarization with these tools.

Finally, considering the results obtained in the quantile regressions, it is also interesting to highlight the relevance of ICT as another element to be considered in the fight against school failure. Spain is the second worst EU country in terms of early school leavers (Eurostat, 2021): 16% of young people do not complete secondary education. This figure places the country far from the targets set by the European Union. Considering this scenario and the results of chapter 1, it seems interesting to consider ICT as an additional factor to be considered in the fight against early school leaving. Based on the results obtained, encouraging the start of ICT use from an early age, the use of ICT at home for entertainment purposes and general interest in these tools would be especially beneficial for the lowest performing students and therefore policy makers should take ICT tools into account when designing educational policies aimed at reducing levels of school failure. However, in the case of the use of ICT tools in schools, the results in Chapter 2 show that depending on the subject, students at the top or bottom of the achievement distribution benefit more. Therefore, for this particular type of use, it would be necessary to further study its effect on low achievers in order to consider its inclusion or not as a key element in the fight against school failure.

In summary, recommendations for policy makers go in the direction of: (1) increasing the availability of ICT resources at home to achieve a reduction of the digital divide; (2) complementing the previous measure with campaigns aimed at raising awareness of the different uses of ICT for entertainment purposes, beyond social interaction; (3) increasing the availability of ICT resources in schools; (4) complementing the previous measure with specific training programmes for teachers on the use of ICT as a teaching tool and with programmes aimed at improving students' familiarization with these tools; and (5) considering ICT as an additional element in the fight against school failure.

Recommendations for teachers and school principals

The recommendations suggested for policy makers must necessarily be complemented by recommendations directly suggested to schools. In this sense, beyond the measures that require the intervention of Public Administrations, there are a series of measures that could be directly applied by school principals and teachers based on the results obtained in this thesis.

A very relevant result of this thesis is the identification in Chapter 1 of a negative relationship between the use of ICT at home for homework and academic performance. This result shows that teachers should pay special attention to the materials and tools provided to students for homework using ICT. Therefore, it is very important for them to make sure, before sending homework, that students will be able to use ICT independently to carry out the activities requested of them. It seems relevant, for example, that students have previously worked with these tools in the classroom and that they are not confronted with their use at home for the first time. In addition, it would also be advisable to consider the possibility that students may end up using ICT resources for purposes other than homework (games, chatting, etc.), as they are not supervised by the teacher. In this sense, the recommendation would be to foster the relationship between the family and the educational center, so that teachers explain to parents the importance of supervising their children while they are using ICT resources for homework in order to ensure the correct use of these resources. Of course, teachers are recommended to ensure that the activities to be carried out with ICT resources are well thought out and contribute positively to learning. It is not just a matter of asking pupils to use the computer to do the task, but it is key to design the activity in such a way as to take advantage of the potential benefits of ICT.

In relation to the use of ICT at school, considering that there is a positive effect of the use of these tools to carry out tasks and exercises in class on academic performance, it would be advisable for school principals to emphasize to teaching staff the potential advantages of using these tools in the classroom. Of course, this recommendation for use should be accompanied by specific training which, in parallel to that received from the Public Administrations, can be enhanced by internal training measures at the schools. In this respect, it is also crucial for teaching staff to be aware of the need to pay special attention to the activities to be carried out with ICT resources and to ensure that they adequately complement the other teaching methods used in the classroom. In addition, bearing in mind that these are new and rapidly evolving resources, it would be advisable to encourage regular group dynamics between the different teachers at the educational center in order to improve the use of ICT in the classroom by sharing the experiences of the different teachers. Finally, considering the results of the quantile regressions, it also seems relevant to recommend that teachers consider the fact that ICT may affect different students in the class in diverse ways. In this sense, they should pay attention when using these tools to ensure that all students follow the flow of the class and make the most of these resources.

In summary, the recommendations for school principals are along the following lines: (1) fostering an appropriate relationship between families and educational centers to guarantee the correct use of ICT at home; (2) stressing to the teaching staff the relevance of implementing ICT in the classroom; (3) organizing internal training courses in relation to the use of ICT for educational purposes; and (4) encouraging group dynamics among teachers to discuss the use of ICT in the classroom. As far as teachers are concerned, the recommendations would be to: (1) ensure the suitability of homework to be done with ICT at home (previous experience with ICT in the classroom); (2) guarantee an adequate family-teacher relationship to certify the correct use of ICT at home; (3) attend training courses on the use of ICT in teaching; (4) incorporate ICT as an additional teaching resource, ensuring that it adequately complements the rest of the teaching methods; (5) participate in group dynamics with other teachers at the educational institution to draw conclusions on how to improve the use of ICT in the classroom; and (6) pay attention in practice to the differences that may be observed in the use of ICT resources according to the student's level of performance, in order to ensure that all students benefit from the use of these tools.

Future lines of research

Considering the empirical evidence obtained in the three chapters of this doctoral thesis, I point out below future lines of research that would complement the results obtained here and corroborate their external validity.

Firstly, it would be interesting to replicate this research with more up-to-date data. In Chapter 1 I work with data from PISA 2015 (the most up-to-date data available at the time the research began) but replicating the analysis with data from PISA 2018 would allow us to assess whether the associations I find in this first chapter are maintained or have been modified over time. Given the pace at which ICTs are evolving in the current context, it is of particular interest to be able to carry out analyses that are as up-to-date as possible. In the case of Chapter 2, I work with data from the 2016-2017 academic year (the most recent data available at the time the research began). One of the future lines of research is to replicate the empirical analysis of this chapter using data from the individualized assessments of the 2018-2019 academic year, which I use in chapter 3. However, it is not possible to work with data from these individualized assessments that are more up-to-date than those I use in chapter 3, given that these tests have not been carried out since 2020 and were not conducted in the 2019-2020 academic year as a result of the COVID-19 health crisis. Precisely for this reason, another of the future lines of research is to replicate these analyses with other updated databases at international, country or autonomous community level, which contain information related to the use of ICT in schools and allow us to continue research in this line.

Secondly, as mentioned when explaining the main results of Chapter 2, a future line of research would be to replicate the analysis in Chapter 1 on the impact of different types of ICT use at home and at school but using quasi-experimental methodologies. In this sense, one option would be to use the instrumental variables method and instrument some of the ICT variables used in this chapter for which potentially appropriate instruments are observed in the PISA 2018 database. An example of this would be to use the information available in the ICT student questionnaire on the use of ICT in different subject classes. This information was not available in PISA 2015 but is included in PISA 2018. Following the methodology in Chapter 2, the information available would allow the variable reflecting the use of ICT in each subject to be instrumented by means of the values of this same variable in the rest of the subjects, thus making it possible to approximate the culture of ICT use that exists at the educational institution. However, there is no possibility of associating teachers and students - contrary to what the individualized assessments in chapter 2 allow - and therefore, although detailed information on teachers' ICT training is included as a new feature in PISA 2018, it would not be possible to use the other instrument used in chapter 2: teachers' level of ICT training. With respect to the other variables analysed in Chapter 1, a detailed study of potential instruments would be required based on the new information available in the most up-to-date PISA data.

Thirdly, it would be interesting to extend the analysis of the impact of ICT on academic performance to educational levels other than Secondary Education. In this sense, it would be interesting, for example, to explore the use of databases that focus on primary education at international level (PIRLS or TIMSS) and at national level (individualized assessments for the 2018-2019 academic year or future tests to be carried out). The use of ICT in the context of primary school students is very different from that of secondary school students, which is precisely why I consider this line of research to be very interesting and can help to develop educational policy recommendations adapted to each particular educational level. In addition, I also think it would be interesting to analyse the impact of ICT use in other countries. This would allow us to contextualize the results obtained for Spain and, in the event that different effects are observed depending on the country, to be able to investigate potential explanations considering the social and cultural context of each country.

Finally, as I have pointed out in the reflections in the different chapters, I consider that this research topic needs to be complemented with qualitative research that provides the detailed information necessary to understand the empirical evidence obtained in this thesis. For example, finding out the impressions, opinions and perspectives of students, teachers and school principals in relation to ICTs would provide the different chapters of this thesis with a deeper understanding of how ICTs are being implemented in the social and educational context. In this sense, a possible line of future research would be to accompany the statistical analyses of these and future research projects with information obtained from qualitative questionnaires.

At a time of digital revolution in schools as a consequence of the period of school closures experienced after the COVID-19 health crisis, it is important to situate the results obtained in this thesis and to indicate what they contribute to the current debate on the role of distance learning and the use of ICT in schools. To do so, first of all, it is necessary to remember that the results shown in this thesis are obtained using data from the pre-pandemic period, so it can be expected that some of the conclusions obtained may be altered as a consequence of the impact of the COVID-19 health crisis on the use of ICT in the educational context. In this sense, it would be particularly relevant to replicate the analyses of this thesis when national and international databases are published with information on ICT use after the home confinement (e.g., PISA 2022 data).

So far, scientific evidence suggests that the shift from face-to-face to online teaching at the home confinement stage had negative consequences on student learning (Donnelly and Patrinos, 2021; Reimers, 2022). However, it is important to note that it should not be concluded from this result that the use of ICT for teaching is negative, but rather that many families and teachers were not prepared for such a profound and unexpected change.

However, despite this negative impact, the forced learning that teachers faced in March 2020 can be expected to have boosted the level of teacher ICT training. Considering the results in Chapter 3, this increased level of ICT training should translate into greater use of ICT in the classroom now and in the future. Indeed, the recent BlinkLearning study (2021) shows that, after the home confinement and return to face-to-face classrooms, the percentage of Spanish teachers surveyed who reported using ICT in the classroom on a daily basis increased from 58% to 83%. This evidence suggests that the pandemic seems to have prompted an educational reform in terms of ICT use.

In this context of the increased role of ICT in schools, this thesis provides evidence of the potential positive impact on academic performance of using ICT in the classroom for educational purposes. However, the results of the thesis highlight the importance of implementing ICT appropriately and of being aware that the effects of these tools differ by subject, student profile (level of academic achievement) and type of use (in the classroom vs. for homework). Therefore, all the recommendations made as a result of the results of this thesis should be considered in the post-pandemic world to ensure that the increased role of ICT in schools translates into improvements in academic performance.

As a general conclusion, the results obtained in this thesis highlight the importance of ICT as another factor to be considered when analyzing the determinants of academic performance. The educational system must consider that these tools have potential advantages and that, correctly implemented, they can help to improve the process of acquisition of competences in students. Therefore, as has been pointed out in the different chapters, educational policies must take ICT into account as another teaching tool and should promote the frequent and appropriate use of these tools in the classroom and at home.

CONCLUSIONES

En esta sección, se presentan unas conclusiones generales de esta tesis doctoral que permiten interpretar de forma conjunta la evidencia empírica obtenida en las tres investigaciones que componen este documento. Adicionalmente, teniendo en cuenta los resultados obtenidos, se reflexiona sobre posibles recomendaciones en materia de política educativa, así como para docentes y directores de centros educativos, y se señalan futuras líneas de investigación que permitirían complementar los análisis presentados en esta tesis.

Esta sección de conclusiones se estructura a su vez en diferentes subsecciones: (1) resumen y reflexión sobre los principales resultados obtenidos en los distintos capítulos; (2) discusión sobre los efectos diferenciales (negativos o positivos sobre el rendimiento académico) según el tipo de uso de las TIC; (3) implicaciones de los resultados de la tesis para responsables políticos; (4) implicaciones para profesores y directores de centros educativos; y (5) futuras líneas de investigación.

Principales resultados de los tres capítulos de la tesis

En el capítulo 1, el análisis de los datos de PISA 2015 mediante la estimación de modelos multinivel y regresiones cuantílicas sugiere que las TIC guardan relación con el rendimiento académico en las competencias en comprensión lectora, ciencias y matemáticas de los estudiantes de 15 años. Una de las grandes novedades y aportaciones de esta investigación es que se centra en analizar un conjunto de variables TIC relacionadas con la presencia y el uso de estas herramientas tanto en el entorno social, como en el entorno educativo de los estudiantes. En este sentido, los resultados de este primer capítulo muestran que no se puede hablar de un impacto general de las TIC sobre el rendimiento académico, sino que la influencia de las TIC en el rendimiento depende de la variable TIC concreta que estemos analizando. Asimismo, las regresiones cuantílicas muestran que las asociaciones encontradas en este capítulo son especialmente relevantes para aquellos estudiantes que se encuentran en la parte baja de la distribución de las puntuaciones obtenidas en PISA. Este último resultado supone una importante aportación a la literatura científica dado que no existen estudios previos que hayan centrado la atención en analizar la relación entre los tipos de uso de las TIC estudiados en el capítulo 1 y el rendimiento académico distinguiendo por el percentil de rendimiento del alumnado.

En concreto, en el capítulo 1 se encuentra que el uso de las TIC se asocia con mayores niveles de rendimiento académico si se realiza con fines de entretenimiento en el hogar. Es decir, se concluye que mayor frecuencia de uso de las TIC en el hogar para realizar actividades como jugar, chatear, ver películas o escuchar música, se asocia con mejores niveles de rendimiento académico. Contrariamente, se observa una relación negativa entre una mayor frecuencia de uso de las TIC en el hogar para realizar tareas escolares y el rendimiento académico de los estudiantes. Estos resultados sobre el impacto del uso de las TIC en el hogar sobre el rendimiento académico están en línea con los encontrados en investigaciones previas (Biagi y Loi, 2013; Mediavilla y Escardíbul, 2015; Agasisti et al., 2020). Sin embargo, el capítulo 1 de esta tesis aporta nueva evidencia empírica a la literatura científica dado que los estudios previamente mencionados se basaban en datos de rondas de PISA (PISA 2009 y PISA 2012) previas a la utilizada en esta tesis (PISA 2015). Por tanto, los resultados actualizados de esta tesis considerando la información disponible en PISA 2015 confirman que la finalidad del uso de las TIC en el hogar continúa siendo clave a la hora de explicar el efecto del uso de la tecnología sobre el rendimiento académico.

Con respecto a las actitudes de los estudiantes hacia las TIC, los resultados evidencian que aquellos que se inician más tempranamente en el uso de estas tecnologías presentan mayores niveles de rendimiento académico, en línea con lo sugerido por Mediavilla y Escardíbul (2015) y Escardíbul y Mediavilla (2016). Adicionalmente, se observa que los estudiantes con mayor grado de interés por las TIC muestran también un mejor rendimiento académico, mientras que, contrariamente, aquellos que conceden más importancia a las TIC en sus interacciones sociales, presentan menores niveles de rendimiento académico en comprensión lectora. Estos dos últimos resultados son novedosos dado que no existen investigaciones previas que hayan evaluado estas relaciones y por tanto constituyen una importante aportación al debate científico sobre el impacto del uso de las TIC en el rendimiento académico.

Cuando se centra el análisis en el contexto escolar, los resultados sugieren que una mayor frecuencia de uso de las TIC en la escuela se asocia con peores niveles de rendimiento académico, mientras que un mayor número de ordenadores por estudiantes en el centro educativo se asocia con mejores niveles de rendimiento académico. Esta asociación negativa entre la frecuencia de uso de las TIC en la escuela y el rendimiento académico está en línea con los resultados encontrados en investigaciones previas que también utilizan como variable independiente el índice de uso de las TIC en la escuela proporcionado por PISA (Gumus y Atalmis, 2011; Biagi y Loi, 2013; Skryabin et al., 2015; Mediavilla y Escardíbul, 2015; Escardíbul y Mediavilla, 2016; Petko et al., 2017; Hu et al., 2018; Gorjón et al., 2021). No obstante, es importante señalar que el índice de PISA que mide el uso de las TIC en la escuela en el capítulo 1 engloba distintos tipos de uso, algunos con fines educativos y otros no. Por ello, esta asociación negativa debe ser explorada en mayor profundidad para poder determinar el efecto sobre el rendimiento académico de cada uno de los distintos tipos de uso de las TIC en las escuelas. En la subsiguiente subsección, se señalan potenciales razones que podrían explicar esta relación negativa. En resumen, los resultados obtenidos en el capítulo 1 que señalan una asociación negativa entre el uso de las TIC en las escuelas y el rendimiento académico, hacen necesario ampliar la investigación a este respecto para tratar de dar respuesta a cómo se deben utilizar las TIC en los centros educativos.

Teniendo en cuenta el resultado sobre el uso de las TIC en las escuelas encontrado en el capítulo 1, en el capítulo 2 de esta tesis se centra la atención en el uso de las TIC en las escuelas exclusivamente con fines educativos utilizando datos de las evaluaciones individualizadas realizadas en la Comunidad de Madrid. El objetivo es discernir si la relación negativa que se encuentra en el primer artículo se puede atribuir a la incorporación de estas herramientas en la docencia. Aplicando las técnicas de variables instrumentales y emparejamiento por puntaje de propensión, los resultados evidencian que el uso de las TIC en el aula para realizar tareas o hacer ejercicios (es decir, con fines exclusivamente educativos) tiene un impacto positivo sobre el rendimiento académico en inglés, competencia social y cívica y matemáticas académicas en cuarto curso de educación secundaria. Este resultado está en línea con estudios previos que sugieren que el uso de las TIC en los centros educativos tiene un impacto positivo sobre el rendimiento académico (Lai et al., 2015; Ferraro et al., 2018; Fernández-Gutiérrez et al., 2020). Sin embargo, la principal aportación del capítulo al debate científico es que el análisis realizado se centra exclusivamente en analizar el uso de las TIC en el aula con fines educativos para la realización de tareas y ejercicios. Además, la posibilidad de asociar a profesores y estudiantes en la base de datos utilizada supone una relevante aportación a la literatura previa, ya que permite medir el uso de las TIC separadamente en cada una de las asignaturas. De esta forma, los resultados alcanzados superan las principales limitaciones de los estudios previos y permiten elaborar recomendaciones concretas que se detallan en las subsecciones correspondientes de esta sección de conclusiones.

Los resultados de los modelos de variables instrumentales del capítulo 2 se complementan con las regresiones cuantílicas con variables instrumentales que muestran que el impacto positivo de usar las TIC en el aula es especialmente relevante para los estudiantes que se encuentran en el extremo inferior de la distribución de las puntuaciones en inglés, y para los estudiantes que se encuentran en los percentiles medio y superior del rendimiento académico en competencia lingüística en español, competencia social y cívica y matemáticas académicas. Al igual que en el capítulo 1, este análisis por percentiles de rendimiento es novedoso y supone una relevante aportación a la literatura previa.

Es importante señalar que una de las principales fortalezas del capítulo 2 es la utilización de técnicas cuasiexperimentales (variables instrumentales y regresiones cuantílicas con variables instrumentales), lo que permite superar las limitaciones de las técnicas de regresión (análisis multinivel y regresión cuantílica) empleadas en el capítulo 1. La no utilización de técnicas de variables instrumentales en el primer capítulo se fundamenta principalmente en la dificultad para encontrar instrumentos convincentes para el conjunto de variables TIC analizadas. En este sentido, cabe señalar que tras un análisis pormenorizado de las distintas variables incluidas en la base de datos de PISA 2015, no se encontraron instrumentos sólidos para ninguna de las variables. Una explicación de esto radica por ejemplo en que, en comparación a los datos del capítulo 2, en PISA 2015 no hay información sobre el uso de las TIC en cada una de las asignaturas, sino que simplemente se les preguntaba a los alumnos por el uso general de las TIC en la escuela y además no es posible vincular a estudiantes y profesores. Estos dos hechos impiden por ejemplo la utilización de los instrumentos empleados en el capítulo 2. No obstante, los datos de PISA 2018 sí aportan como novedad información más detallada sobre el uso de las TIC – desagregando el nivel de uso por asignaturas – por lo que una nueva línea de investigación sería replicar el análisis del capítulo 1 usando datos de PISA 2018 y empleando la técnica de variables instrumentales para el análisis de algunas de las variables TIC de este capítulo, tal y como se concreta en la subsección de futuras líneas de investigación.

Del capítulo 2 se extrae por tanto la conclusión de que usar las TIC como una herramienta docente en el aula es positivo para el rendimiento de los estudiantes. Sin embargo, de nuevo cabe señalar que nos estamos refiriendo a un uso concreto - para realizar proyectos o ejercicios - y se están excluyendo por tanto otros tipos de uso de las TIC que también se pueden hacer con fines educativos, tales como usar las TIC para visualizar el material docente o comunicarse vía e-mail con el profesor. En este sentido, tal y como se señala en las reflexiones del capítulo 2, es necesario complementar los resultados de esta investigación con futuras investigaciones que permitan conocer con más detalle el uso de las TIC que se realiza en las escuelas para poder así estudiar el impacto de los distintos tipos de uso sobre el rendimiento académico.

Considerando que, en base a los resultados del capítulo 2, una mayor frecuencia de uso de las TIC en el aula para realizar proyectos y ejercicios tiene un impacto positivo en el rendimiento académico en determinadas competencias, en el capítulo 3 se centra la atención en los factores que llevan a los profesores a emplear frecuentemente las TIC en sus clases como una herramienta docente. Los resultados de las regresiones logísticas multinivel muestran que la decisión de implementar las TIC por parte de los docentes viene motivada por una serie de características personales, de sus estudiantes y del centro educativo en el que imparten docencia. Concretamente, se observa que aquellos docentes con mayores niveles de satisfacción con la profesión y aquellos que han participado en los últimos 12 meses en cursos de formación en el uso de las TIC, son más propicios a utilizar estas herramientas en el aula. La relación positiva entre satisfacción con la profesión y frecuencia de uso de las TIC está en línea con el estudio previo de Sang et al. (2011). Por lo que respecta a la formación en TIC, el resultado obtenido coincide también con los obtenidos por estudios previos (Inan y Lowther, 2010; Shin, 2015; Gerick et al., 2017) y evidencia la importancia de que los docentes reciban formación en el uso de las TIC. Además, el entorno importa. Aquellos docentes que dan clase a un grupo de estudiantes que se comporta adecuadamente en el aula y que usa frecuentemente las TIC en el hogar, presentan también una mayor probabilidad de utilizar las TIC en sus clases. Por lo que respecta al centro educativo, los resultados evidencian que la disponibilidad de dispositivos digitales es un factor clave si se pretende incrementar la frecuencia de uso de estas herramientas por parte de los docentes, en línea con lo sugerido por Eickelmann et al. (2017) y Petko et al. (2018). Los resultados de esta investigación son novedosos dado que, tal y como se ha explicado en detalle en el capítulo 3, existen muy pocos estudios que hayan analizado esta temática. Además esta tesis presenta un estudio detallado por niveles educativos e incluye variables que no habian sido previamente exploradas en la literatura previa. Por todo ello, los resultados alcanzados suponen una interesante aportación al debate científico sobre el uso de las TIC por parte de los docentes en los centros educativos.

Efectos positivos versus efectos negativos del uso de las TIC sobre el rendimiento académico

Los resultados de esta tesis muestran que dependiendo del tipo de uso de las TIC, su efecto sobre el rendimiento académico difiere. Este resultado es muy interesante y merece la atención suficiente como para dedicar una subsección exclusivamente para en análisis de la naturaleza de estos diferentes resultados.

En primer lugar, se procede a analizar las diferencias en el uso de las TIC en el hogar. Estas diferencias son analizadas en el capítulo 1, en el que se concluye que dependiendo de la finalidad del uso de las TIC, la relación con el rendimiento académico puede ser negativa o positiva. Concretamente, se concluye que el uso de las TIC en el hogar con fines de entretenimiento se asocia con mayores niveles de rendimiento académico, mientras que el uso de las TIC en el hogar para realizar tareas escolares se asocia con peores niveles de rendimiento académico. Si bien los análisis de esta tesis no pueden determinar la relación causal entre el uso de las TIC y el rendimiento académico, a continuación se señalan posibles hipótesis al respecto. No obstante, para confirmar cómo se explican estas relaciones causales, serían necesarias investigaciones complementarias. Una posible explicación a este resultado podría ser que el uso de las TIC con fines de entretenimiento ocasionara que, involuntariamente, los estudiantes desarrollen sus habilidades de lectura y pensamiento crítico al navegar por internet, chatear con amigos o jugar con los ordenadores. Esto podría traducirse como consecuencia en mejoras del rendimiento académico. Adicionalmente, el uso de las TIC para entretenerse puede asociarse con un aumento de la motivación y el interés general por el uso de la tecnología. Esto puede propiciar que aquellos que usan frecuentemente las TIC para entretenerse también decidan usarlas voluntariamente con fines educativos (por ejemplo para buscar información adicional sobre conceptos explicados en el aula) y de esta manera vean mejorado su rendimiento académico. Sin embargo, un resultado muy novedoso e interesante de esta tesis es que el nivel de importancia que se concede a las TIC en las interacciones sociales se asocia negativamente con el rendimiento académico. Entre la información que se solicita para reflejar este grado de importancia se incluyen preguntas relacionadas con el interés por reunirse con amigos para jugar a videojuegos. Este resultado parece apuntar a que es necesario diversificar los usos de las TIC por parte de niños y adolescentes. Parece que una importancia excesiva al uso con fines de interacción social repercute negativamente en el rendimiento. Esto podría explicarse porque esta importancia se asocie con periodos de tiempo excesivos usando estas tecnologías para realizar actividades que no contribuyen al aprendizaje (videojuegos no educativos) y por tanto con menor tiempo para otros tipos de uso de las TIC que sí contribuyen al aprendizaje y, en general, con menor tiempo para la realización de tareas escolares en el hogar.

Por otra parte, que el uso de las TIC en el hogar para realizar tareas escolares se asocie con peores niveles de rendimiento académico, parece sugerir que las TIC no se están implementando adecuadamente en el contexto educativo y que los docentes deben mejorar la asignación de tareas a realizar con estas tecnologías. Esto podría explicarse por distintos motivos, tales como que: (i) los alumnos no están suficientemente familiarizados con el uso especifico de las TIC para realizar tareas escolares; (ii) al emplear recursos TIC, por ejemplo un ordenador o una *tablet*, podrían evadirse fácilmente y acabar consultando recursos que no contribuyen al aprendizaje; y (iii) podría ser que las tareas no estén adecuadamente planteadas por parte del profesorado y no contribuyan al aprendizaje. En la subsección de recomendaciones a docentes de esta sección de conclusiones, se plantean propuestas de mejora para tratar de invertir esta relación negativa encontrada entre el uso de las TIC para realizar tareas escolares y el rendimiento académico.

En relación al uso de las TIC en las escuelas, tal y como se ha comentado en la subsección de principales resultados, aunque a priori los resultados del capítulo 1 y 2 puedan parecer contradictorios, la potencial explicación estaría en la variedad de usos de las TIC que se puede dar en las escuelas. En este sentido, es importante señalar que el índice que mide la frecuencia de uso de las TIC en la escuela en el capítulo 1 engloba distintos tipos de uso, algunos con fines educativos y otros no. Sin embargo, en el capítulo 2, la variable utilizada para medir el uso de las TIC en las escuelas se centra únicamente en el uso para la realización de tareas y ejercicios en el aula. Teniendo en cuenta la naturaleza de las variables empleadas en los capítulos 1 y 2 para medir la frecuencia de uso de las TIC en los centros educativos, del resultado del capítulo 1 no puede concluirse que usar las TIC con fines educativos (por ejemplo para hacer tareas y ejercicios) se asocie con un peor rendimiento, dado que detrás de esta variable también se incluyen usos no necesariamente relacionados con fines educativos (por ejemplo chatear). Además, el resultado del primer capítulo podría explicarse también porque no todos los usos de las TIC con fines educativos repercutan del mismo modo en el rendimiento académico. En este sentido, podría ocurrir que usar las TIC para resolver ejercicios o trabajos sea beneficioso para el rendimiento, tal y como evidencia el capítulo 2, pero por ejemplo usarlas como un instrumento para visualizar el material o comunicarse con el docente sea perjudicial como consecuencia de una incorrecta implementación de estas herramientas. En cualquier caso, a falta de confirmar la explicación de las relaciones causales encontradas, estos resultados ponen de manifiesto la relevancia de continuar investigando sobre los distintos tipos de uso de las TIC en las escuelas para poder orientar de forma idónea la incorporación de estas herramientas en la docencia.

Recomendaciones para responsables políticos

Teniendo en cuenta los resultados obtenidos en esta tesis, resulta de especial interés elaborar recomendaciones para responsables políticos a nivel nacional y regional en relación a la promoción del uso de las TIC en los hogares y en las escuelas. En este sentido - tal y como se ha discutido en la subsección precedente - es importante recordar que esta tesis evidencia que no todos los tipos de uso de las TIC repercuten de la misma manera sobre el rendimiento académico. Por tanto, no se trata únicamente de incrementar la dotación de recursos TIC en los hogares y las escuelas y fomentar su uso, sino de promover un uso adecuado de estas herramientas que derive en efectos positivos sobre el aprendizaje.

En primer lugar, se señalan recomendaciones para responsables políticos por lo que respecta a la disponibilidad y uso de las TIC en los hogares. En esta tesis se ha evidenciado que iniciarse tempranamente en el uso de las TIC se asocia con mayores niveles de rendimiento académico, por lo que parece propicio garantizar que todos los niños tengan a su alcance recursos TIC desde pequeños. Según datos del Instituto Nacional de Estadística (INE, 2021), en los últimos diez años el porcentaje de hogares españoles sin acceso a internet ha bajado del 40% al 5% y el porcentaje de hogares sin ordenador disponible ha disminuido del 30% al 19%. Estos datos son positivos, pero ponen de manifiesto que todavía existe una *brecha digital* en España y que parte de la población se enfrenta a barreras de acceso al uso de las TIC en el hogar. En este sentido, el cierre de las escuelas en marzo de 2020 como consecuencia de la crisis sanitaria de la COVID-19, evidenció la desigualdad entre aquellos estudiantes que podían utilizar las TIC e internet en sus hogares y los que no. Concretamente, en el caso de España, el 9% de los hogares con niños carece de acceso a internet (INE, 2021), lo que permite estimar que alrededor de 100.000 hogares con niños no disponían de conectividad durante la etapa de confinamiento domiciliario, convirtiendo por tanto la brecha digital en una brecha educativa. Por tanto, teniendo en cuenta estos datos y los resultados de esta tesis, parece necesario continuar desarrollando políticas públicas orientadas a reducir la brecha digital y lograr la inclusión digital, bien sea mediante ayudas económicas en los casos de brecha digital por asequibilidad, o mediante la mejora de conectividad en zonas rurales o áreas marginadas que se enfrentan a una brecha digital de ubicación.

Paralelamente a la implementación de medidas orientadas a mejorar la disponibilidad de recursos TIC en los hogares, resulta crucial desarrollar políticas encaminadas a garantizar un correcto uso de las TIC por parte de niños y adolescentes. Los resultados de esta investigación muestran que el uso de las TIC con fines de entretenimiento y el grado de interés por las TIC se relacionan positivamente con el rendimiento académico. Sin embargo, el grado de importancia que se les da a las TIC en las interacciones sociales se relaciona negativamente con el rendimiento. Teniendo en cuenta estos resultados, una buena política podría ser promover campañas de concienciación social orientadas a dar a conocer entre niños y, especialmente entre jóvenes, todas las posibilidades de uso que presentan los recursos TIC con fines de entretenimiento, más allá de sus usos relacionados meramente con la interacción social: blogs, periódicos, libros, series y películas, *webinars*, cursos, juegos, música, etc.

Por lo que se refiere al uso de las TIC en el contexto escolar, los resultados del capítulo 2 ponen de manifiesto que el uso de las TIC para realizar tareas y ejercicios en las escuelas tiene efectos positivos sobre el rendimiento académico. Además, en el capítulo 3 se demuestra que cuantos más recursos TIC existen en la escuela, más propicios son los docentes al uso de estas herramientas en las aulas, por lo que si se quiere promover su uso resulta clave incrementar la dotación de recursos TIC en los centros educativos. Sin embargo, es importante recalcar que la inversión en recursos TIC no es una condición suficiente. Esta debe ir acompañada de medidas paralelas que garanticen un uso adecuado de estas herramientas por parte de alumnos y profesores. En este sentido, resulta crucial acompañar la inversión en recursos TIC de medidas orientadas a la formación del profesorado y del alumnado en el uso de estas herramientas. Los ordenadores, las tablets o las pizarras digitales no garantizan per se una mejora del rendimiento académico y su presencia podría ser incluso perjudicial para este según muestran los resultados del capítulo 1. La clave parece ser acompañar la inversión en recursos TIC de medidas orientadas a la formación del profesorado en el uso de estas herramientas, de forma que puedan ser incorporados adecuadamente a la docencia para la realización de tareas y permitan una mejora del rendimiento académico, tal y como evidencia el capítulo 2. Además, teniendo en cuenta que en el capítulo 3 tanto la formación en TIC por parte del profesorado, como el grado de familiarización de los estudiantes en el uso de las TIC, resultan ser factores determinantes a la hora de decidir usar estas herramientas en las clases, queda más que evidenciado que si se quiere promover el uso de las TIC resulta indispensable ofrecer formación específica a docentes y mejorar la familiarización de los estudiantes con estas herramientas.

Por último, considerando los resultados obtenidos en las regresiones cuantílicas, resulta también de interés recalcar la relevancia de las TIC como un elemento más a ser considerado en la lucha contra el fracaso escolar. España es el segundo país de la UE con peores cifras de abandono escolar prematuro (Eurostat, 2021): el 16% de los jóvenes no finalizan educación secundaria. Esta cifra sitúa al país muy lejos de los objetivos marcados por la Unión Europea. Considerando este escenario y los resultados del capítulo 1, parece interesante considerar las TIC como un factor adicional a tener en cuenta en la lucha contra el abandono escolar. En base a los resultados obtenidos, fomentar el inicio en el uso de las TIC desde una edad temprana, el uso de las TIC en el hogar con fines de entretenimiento y el interés en general por estas herramientas, sería especialmente beneficioso para los estudiantes con peor rendimiento y por tanto los responsables políticos deberían tener en cuenta las herramientas TIC a la hora de elaborar políticas educativas orientadas a reducir los niveles de fracaso escolar. Sin embargo, en el caso del uso de estas herramientas en las escuelas, los resultados del capítulo 2 muestran que dependiendo de la asignatura se ven más beneficiados los estudiantes situados en la parte alta o baja de la distribución del rendimiento académico. Por tanto, en este tipo de uso concreto sería necesario estudiar más a fondo su efecto en los estudiantes con peor rendimiento para considerar su inclusión o no como un elemento clave en la lucha contra el fracaso escolar.

En resumen, las recomendaciones para responsables políticos van en la dirección de: (1) incrementar la disponibilidad de recursos TIC en los hogares para lograr reducir la brecha digital; (2) complementar la medida anterior con campañas orientadas a dar a conocer los distintos usos de las TIC con fines de entretenimiento, más allá de las redes sociales; (3) incrementar la disponibilidad de recursos TIC en las escuelas; (4) complementar la medida anterior con programas de formación específicos para el profesorado sobre el uso de las TIC como una herramienta docente y con programas orientados a mejorar la familiarización de los estudiantes con estas herramientas; y (5) considerar las TIC como un elemento adicional en la lucha contra el fracaso escolar.

Recomendaciones para docentes y directores de centros educativos

Las recomendaciones sugeridas para responsables políticos deben complementarse necesariamente con recomendaciones directamente sugeridas a los centros educativos. En este sentido, más allá de las medidas que requieran la intervención de las Administraciones Públicas, existen una serie de medidas que podrían ser directamente aplicadas por directores de centros educativos y docentes en base a los resultados obtenidos en esta tesis.

Un resultado muy relevante de esta tesis es la identificación en el capítulo 1 de una relación negativa entre el uso de las TIC en el hogar para realizar tareas escolares y el rendimiento académico. Este resultado evidencia que los docentes deben prestar especial atención a los materiales y herramientas que se facilitan a los estudiantes para la realización de deberes usando las TIC. Por ello, es muy importante que se aseguren, antes de mandar estos deberes, de que los estudiantes van a ser capaces de emplear de forma autónoma las TIC para realizar las actividades que se les solicitan. Parece relevante por ejemplo que los alumnos hayan trabajado previamente con estas herramientas en el aula y que no se enfrenten por primera vez a su uso en el hogar. Adicionalmente, también sería recomendable que al mandar este tipo de actividades se tenga especialmente en cuenta la posibilidad de que los estudiantes al no estar supervisados por el profesor acaben utilizando los recursos TIC para fines distintos a la realización de los deberes (juegos, chatear, etc.). En este sentido, la recomendación sería fomentar la relación entre la familia y el centro educativo, de forma que los docentes expliquen a los padres la importancia de supervisar a sus hijos mientras utilizan recursos TIC para realizar tareas escolares para poder garantizar un uso correcto de estos recursos. Por supuesto, se recomienda a los docentes que se aseguren de que las actividades a realizar con recursos TIC estén adecuadamente planteadas y contribuyan positivamente al aprendizaje. No se trata únicamente de pedir a los alumnos que usen el ordenador para realizar la tarea, sino que es clave plantear la actividad de forma que se aprovechen las potenciales ventajas de las TIC.

En relación al uso de las TIC en la escuela, considerando que se encuentra un efecto positivo del uso de estas herramientas para realizar tareas y ejercicios en clase sobre el rendimiento académico, sería recomendable que desde la dirección de los centros educativos se recalcaran al personal docente las potenciales ventajas del uso de estas herramientas en las aulas. Por supuesto, esta recomendación de uso debe ir acompañada de formación específica que, paralelamente a la que se reciba por parte de las Administraciones Públicas, puede ser mejorada con medidas de formación internas por parte de los centros educativos. En este sentido, resulta también crucial que el personal docente sea consciente de la necesidad de prestar especial atención a las actividades a realizar con recursos TIC y garantizar que estas complementan adecuadamente al resto de métodos de docencia empleados en las aulas. Adicionalmente, teniendo en cuenta que se trata de recursos novedosos y que evolucionan a gran velocidad, fomentar dinámicas de grupo con regularidad entre los distintos docentes del centro educativo sería recomendable para poder mejorar el uso de las TIC en el aula a partir de la puesta en común de las experiencias de los distintos profesores. Por último, teniendo en cuenta los resultados de las regresiones cuantílicas, también parece relevante recomendar a los docentes que tengan en cuenta que las TIC pueden afectar desigualmente a los distintos alumnos de la clase. En este sentido, deberían prestar atención cuando usen estas herramientas para garantizar que todos los estudiantes siguen el hilo de la clase y aprovechan al máximo estos recursos.

En resumen, las recomendaciones para directores de centros educativos van en la dirección de: (1) fomentar una adecuada relación entre familias y centros educativos para garantizar el correcto uso de las TIC en el hogar; (2) recalcar al equipo docente la relevancia de implementar las TIC en las aulas; (3) organizar cursos de formación interna en relación al uso de las TIC con fines educativos; y (4) fomentar dinámicas de grupo entre docentes para debatir sobre el uso de las TIC en el aula. Por lo que respecta a los docentes, las recomendaciones serían: (1) asegurar la adecuación de los deberes escolares a realizar con TIC en el hogar (experiencia previa con las TIC en el aula); (2) garantizar una adecuada relación familia-profesor para certificar el correcto uso de las TIC en el hogar; (3) acudir a cursos de formación sobre el uso de las TIC en docencia; (4) incorporar las TIC como un recurso docente adicional asegurándose de que complementa adecuadamente al resto de métodos de docencia; (5) participar en dinámicas de grupo con otros docentes del centro para extraer conclusiones sobre cómo mejorar el uso de las TIC en el aula; y (6) prestar atención en la práctica a las diferencias que puedan observarse en el uso de los recursos TIC según el nivel de rendimiento del alumno, al objeto de garantizar que todos los estudiantes sacan provecho del uso de estas herramientas.

Futuras líneas de investigación

Teniendo en cuenta la evidencia empírica obtenida en los tres capítulos de esta tesis doctoral, se señalan a continuación futuras líneas de investigación que permitirían complementar los resultados aquí obtenidos y corroborar su validez externa.

En primer lugar, sería interesante replicar estas investigaciones con datos más actualizados. En el capítulo 1 se trabaja con datos de PISA 2015 (los datos disponibles más actualizados en el momento que se inició la investigación), pero la replicación del análisis con los datos de PISA 2018 permitiría valorar si las asociaciones que se encuentran en este primer capítulo se mantienen o se han visto modificadas con el tiempo. Teniendo en cuenta el ritmo al que evolucionan las TIC en el contexto actual, resulta especialmente de interés poder efectuar análisis lo más actualizados posible. En el caso del capítulo 2, se utilizan datos del curso 2016-2017 (los datos más recientes disponibles en el momento de inicio de la investigación). Una de las futuras líneas de investigación es replicar el análisis empírico de este capítulo utilizando los datos de las evaluaciones individualizadas del curso 2018-2019, los empleados en el capítulo 3. Sin embargo, no es posible trabajar con datos de estas evaluaciones individualizadas más actualizados que los que empleados en el capítulo 3, dado que estas pruebas han dejado de realizarse desde el año 2020 y en el curso 2019-2020 no se realizaron como consecuencia de la crisis sanitaria de la COVID-19. Precisamente por este motivo, otra de las futuras líneas de investigación es replicar estos análisis con otras bases de datos actualizadas a nivel internacional, estatal o de comunidad autónoma, que contengan información relacionada con el uso de las TIC en las escuelas y permitan continuar la investigación en esta línea.

En segundo lugar, tal y como se ha mencionado al explicar los principales resultados del capítulo 2, una futura línea de investigación sería replicar el análisis del capítulo 1 sobre el impacto de distintos tipos de uso de las TIC en el hogar y en la escuela, pero empleando metodologías cuasiexperimentales. En este sentido, una opción sería emplear el método de variables instrumentales e instrumentar algunas de las variables TIC utilizadas en este capítulo para las que sí se observan instrumentos potencialmente apropiados en la base de datos de PISA 2018. Un ejemplo de ello sería la utilización de la información disponible en el cuestionario TIC realizado a los alumnos sobre el uso de las TIC en las clases de las distintas asignaturas. Esta información no estaba disponible en PISA 2015, pero sí se incluye en PISA 2018. Siguiendo la metodología del capítulo 2, la información disponible permitiría instrumentar la variable que refleja el uso de las TIC en cada asignatura, mediante los valores de esa misma variable en el resto de las asignaturas, permitiendo así aproximar la *cultura* de uso de las TIC que existe en el centro educativo. No existe sin embargo posibilidad de asociar a profesores y alumnos - contrariamente a lo que permiten las evaluaciones individualizadas del capítulo 2 - y por tanto, pese a sí incluirse como novedad en PISA 2018 información detallada sobre la formación en TIC por parte de los docentes no sería posible la utilización del otro instrumento utilizado en el capítulo 2: el nivel de formación en TIC del profesorado. Con respecto al resto de variable analizadas en el capítulo 1, se requeriría un estudio pormenorizado de potenciales instrumentos en base a la nueva información disponible en los datos más actualizados de PISA.

En tercer lugar, sería interesante ampliar el análisis sobre el impacto de las TIC en el rendimiento académico a otros niveles educativos distintos a educación secundaria. En este sentido, resultaría de interés por ejemplo explorar el uso de bases de datos que centran la atención en educación primaria a nivel internacional (PIRLS o TIMSS) y nivel estatal (evaluaciones individualizadas del curso 2018-2019 o futuras pruebas que se realicen). El uso de las TIC en el contexto de estudiantes de educación primaria es muy distinto al de estudiantes de educación secundaria y precisamente por ello esta línea de investigación resulta muy interesante y puede ayudar a elaborar recomendaciones en materia de política educativa adaptadas a cada nivel educativo en particular.

Adicionalmente, también sería interesante analizar el impacto del uso de las TIC en otros países. Esto permitiría contextualizar los resultados obtenidos para España y, en el caso de que se observen efectos diferentes según el país, poder indagar sobre las potenciales explicaciones teniendo en cuenta el contexto social y cultural de cada país.

Por último, tal y como se ha señalado en las reflexiones de los distintos capítulos, este tema de investigación requiere ser complementado con investigaciones cualitativas que brinden información detallada necesaria para comprender la evidencia empírica obtenida en esa tesis. Conocer por ejemplo las impresiones, opiniones y perspectivas de estudiantes, profesores y directos de centros educativos en relación a las TIC, permitiría aportar a los distintos capítulos de esta tesis un conocimiento más profundo sobre cómo se están implementando las TIC en el contexto social y educativo. En este sentido, una posible línea de investigación futura sería acompañar los análisis estadísticos de estas y futuras investigaciones, de información obtenida en cuestionarios cualitativos.

En un momento de revolución digital en las escuelas como consecuencia del periodo de cierre de escuelas experimentado tras la crisis sanitaria originada por la COVID-19, es importante situar los resultados obtenidos en esta tesis e indicar lo que estos aportan al debate actual sobre el papel de la enseñanza a distancia y el uso de las TIC en las escuelas. Para ello, en primer lugar, es necesario recordar que los resultados mostrados en esta tesis se obtienen utilizando datos del periodo *prepandemia*, por lo que se puede esperar que algunas de las conclusiones obtenidas puedan verse alteradas como consecuencia del impacto de la crisis sanitaria por la COVID-19 en el uso de las TIC en el contexto educativo. En este sentido, sería especialmente relevante replicar los análisis de esta tesis cuando se publiquen bases de datos nacionales e internacionales con información sobre el uso de las TIC tras la vuelta a las aulas de forma presencial (por ejemplo, datos de PISA 2022).

Hasta el momento, la evidencia científica sugiere que el paso de la docencia presencial a online en la etapa de confinamiento tuvo consecuencias negativas sobre el nivel de aprendizaje del alumnado (Donnelly y Patrinos, 2021; Reimers, 2022). Sin embargo, es importante matizar que de este resultado no debe concluirse que el uso de las TIC para enseñar sea negativo, sino más bien que muchas familias y docentes no estaban preparados para un cambio tan profundo e inesperado. No obstante, pese a este impacto negativo, se puede prever que el aprendizaje forzado al que se enfrentaron los docentes en marzo de 2020 haya impulsado el nivel de formación en TIC del profesorado. Considerando los resultados del capítulo 3, este mayor nivel de formación en TIC debería traducirse en un mayor uso de las TIC en las aulas en la actualidad y en el futuro. De hecho, el reciente estudio de BlinkLearning (2021) muestra que, tras el confinamiento y la vuelta a las aulas de forma presencial, el porcentaje de docentes españoles encuestados que declaró utilizar las TIC diariamente en las aulas creció del 58% al 83%. Esta evidencia sugiere que la pandemia parece haber impulsado una reforma educativa en lo que al uso de las TIC se refiere.

En este contexto de mayor protagonismo de las TIC en las escuelas, esta tesis aporta evidencia sobre el potencial impacto positivo sobre el rendimiento académico que tiene el empleo de estas tecnologías en las aulas con fines educativos. No obstante, los resultados de la tesis ponen de manifiesto la importancia de implementar las TIC adecuadamente y de ser conscientes de que los efectos de estas herramientas difieren por asignaturas, perfil del alumnado (nivel de rendimiento académico) y tipología de uso (en el aula vs para realizar tareas en el hogar). Por ello, todas las recomendaciones enunciadas a raíz de los resultados de esta tesis deberían ser tenidas en cuenta en el mundo *postpandemia* para garantizar que el mayor protagonismo de las TIC en las escuelas se traduce en mejoras del rendimiento académico.

A modo de conclusión general, los resultados obtenidos en esta tesis ponen de manifiesto la importancia de las TIC como un factor más a ser considerado cuando se analizan los factores determinantes del rendimiento académico. El sistema educativo debe tener en cuenta que estas herramientas presentan potenciales ventajas y que correctamente implementadas pueden ayudar a mejorar el proceso de adquisición de competencias de los escolares. Por ello, como se ha ido señalando en los distintos capítulos y en esta sección final de conclusiones, las políticas educativas deben tener en cuenta las TIC como una herramienta docente más y deberían promover un uso frecuente y adecuado de estas herramientas en las aulas y en los hogares.

CONCLUSIONS

En aquesta secció, es presenten unes conclusions generals d'aquesta tesi doctoral que permeten interpretar de manera conjunta l'evidència empírica obtinguda en les tres investigacions que componen aquest document. Addicionalment, tenint en compte els resultats obtinguts, s'assenyalen futures línies d'investigació que permetrien complementar les anàlisis presentades en aquesta tesi i es reflexiona sobre possibles recomanacions en matèria de política educativa, així com per a docents i directors de centres educatius.

Aquesta secció de conclusions s'estructura al seu torn en diferents subseccions: (1) resum i reflexió sobre els principals resultats obtinguts en els diferents capítols; (2) discussió sobre els efectes diferencials (negatius o positius sobre el rendiment acadèmic) segons la mena d'ús de les TIC; (3) implicacions dels resultats de la tesi per a responsables polítics; (4) implicacions per a professors i directors de centres educatius; i (5) futures línies d'investigació.

Principals resultats dels tres capítols de la tesi

En el capítol 1, l'anàlisi de les dades de PISA 2015 mitjançant l'estimació de models multinivell i regressions quantíliques suggereix que les TIC guarden relació amb el rendiment acadèmic en les competències en comprensió lectora, ciències i matemàtiques dels estudiants de 15 anys. Una de les grans novetats i aportacions d'aquesta investigació és que se centra en analitzar un conjunt de variables TIC relacionades amb la presència i l'ús d'aquestes eines tant en l'entorn social, com en l'entorn educatiu dels estudiants. En aquest sentit, els resultats d'aquest primer capítol mostren que no es pot parlar d'un impacte general de les TIC sobre el rendiment acadèmic, sinó que la influència de les TIC en el rendiment depén de la variable TIC concreta que estiguem analitzant. Així mateix, les regressions quantíliques mostren que les associacions trobades en aquest capítol són especialment rellevants per a aquells estudiants que es troben en la part baixa de la distribució de les puntuacions obtingudes a PISA. Aquest últim resultat suposa una important aportació a la literatura científica atés que no existeixen estudis previs que hagen centrat l'atenció a analitzar la relació entre els tipus d'ús de les TIC estudiats en el capítol 1 i el rendiment acadèmic distingint pel percentil de rendiment de l'alumnat.

En concret, en el capítol 1 es troba que l'ús de les TIC s'associa amb majors nivells de rendiment acadèmic si es realitza amb finalitats d'entreteniment en la llar. És a dir, es conclou que major freqüència d'ús de les TIC en la llar per a realitzar activitats com jugar, xatejar, veure pel·lícules o escoltar música, s'associa amb millors nivells de rendiment acadèmic. Contràriament, s'observa una relació negativa entre una major freqüència d'ús de les TIC en la llar per a fer tasques escolars i el rendiment acadèmic dels estudiants. Aquests resultats sobre l'impacte de l'ús de les TIC en la llar sobre el rendiment acadèmic estan en línia amb els trobats en investigacions prèvies (Biagi i Loi, 2013; Mediavilla i Escardíbul, 2015; Agasisti et al., 2020). No obstant això, el capítol 1 d'aquesta tesi aporta nova evidència empírica a la literatura científica atés que els estudis prèviament esmentats es basaven en dades de rondes de PISA (PISA 2009 i PISA 2012) prèvies a la utilitzada en aquesta tesi (PISA 2015). Per tant, els resultats actualitzats d'aquesta tesi considerant la informació disponible a PISA 2015 confirmen que la finalitat de l'ús de les TIC en la llar continua sent clau a l'hora d'explicar l'efecte de l'ús de la tecnologia sobre el rendiment acadèmic.

Respecte a les actituds dels estudiants cap a les TIC, els resultats evidencien que aquells que s'inicien més primerencament en l'ús d'aquestes tecnologies presenten majors nivells de rendiment acadèmic, en línia amb el suggerit per Mediavilla i Escardíbul (2015) i Escardíbul i Mediavilla (2016). Addicionalment, s'observa que els estudiants amb major grau d'interés per les TIC mostren també un millor rendiment acadèmic, mentre que, contràriament, aquells que concedeixen més importància a les TIC en les seues interaccions socials, presenten menors nivells de rendiment acadèmic en comprensió lectora. Aquests dos últims resultats són nous atés que no existeixen investigacions prèvies que hagen avaluat aquestes relacions i per tant constitueixen una important aportació al debat científic sobre l'impacte de l'ús de les TIC en el rendiment acadèmic.

Quan se centra l'anàlisi en el context escolar, els resultats suggereixen que una major freqüència d'ús de les TIC a l'escola s'associa amb pitjors nivells de rendiment acadèmic, mentre que un major nombre d'ordinadors per estudiants en el centre educatiu s'associa amb millors nivells de rendiment acadèmic. Aquesta associació negativa entre la freqüència d'ús de les TIC a l'escola i el rendiment acadèmic està en línia amb els resultats trobats en investigacions prèvies que també utilitzen com a variable independent l'índex d'ús de les TIC a l'escola proporcionat per PISA (Gumus i Atalmis, 2011; Biagi i Loi, 2013; Skryabin et al., 2015; Mediavilla i Escardíbul, 2015; Escardíbul i Mediavilla, 2016; Petko et al., 2017; Hu et al., 2018; Gorjón et al., 2021). No obstant això, és important assenyalar que l'índex de PISA que mesura l'ús de les TIC a l'escola en el capítol 1 engloba diferents tipus d'ús, alguns amb finalitats educatius i altres no. Per això, aquesta associació negativa ha de ser explorada en major profunditat per a poder determinar l'efecte sobre el rendiment acadèmic de cadascun dels diferents tipus d'ús de les TIC a les escoles. En la subsegüent subsecció, s'assenyalen potencials raons que podrien explicar aquesta relació negativa. En resum, els resultats obtinguts en el capítol 1 que assenyalen una associació negativa entre l'ús de les TIC a les escoles i el rendiment acadèmic, fan necessari ampliar la investigació referent a això per a tractar de donar resposta a com s'han d'utilitzar les TIC en els centres educatius.

Tenint en compte el resultat sobre l'ús de les TIC a les escoles trobat en el capítol 1, en el capítol 2 d'aquesta tesi se centra l'atenció en l'ús de les TIC a les escoles exclusivament amb finalitats educatius utilitzant dades de les avaluacions individualitzades realitzades en la

Comunitat de Madrid. L'objectiu és discernir si la relació negativa que es troba en el primer article es pot atribuir a la incorporació d'aquestes eines en la docència. Aplicant les tècniques de variables instrumentals i d'aparellament per puntuació de propensió, els resultats evidencien que l'ús de les TIC a l'aula per a fer tasques o fer exercicis (és a dir, amb finalitats exclusivament educatius) té un impacte positiu sobre el rendiment acadèmic en anglés, competència social i cívica i matemàtiques acadèmiques en quart curs d'educació secundària.

Els resultats dels models de variables instrumentals del capítol 2 es complementen amb les regressions quantíliques amb variables instrumentals que mostren que l'impacte positiu d'usar les TIC a l'aula és especialment rellevant per als estudiants que es troben en l'extrem inferior de la distribució de les puntuacions en anglés, i per als estudiants que es troben en els percentils mitjà i superior del rendiment acadèmic en competència lingüística en espanyol, competència social i cívica i matemàtiques acadèmiques. Igual que en el capítol 1, aquesta anàlisi per percentils de rendiment és nova i suposa una rellevant aportació a la literatura prèvia.

És important assenyalar que una de les principals fortaleses del capítol 2 és la utilització de tècniques quasi-experimentals (variables instrumentals i regressions quantíliques amb variables instrumentals), la qual cosa permet superar les limitacions de les tècniques de regressió (anàlisi multinivell i regressió quantílica) empleades en el capítol 1. La no utilització de tècniques de variables instrumentals en el primer capítol es fonamenta principalment en la dificultat per a trobar instruments convincents per al conjunt de variables TIC analitzades. En aquest sentit, cal assenyalar que després d'una anàlisi detallada de les diferents variables incloses en la base de dades de PISA 2015, no es van trobar instruments sòlids per a cap de les variables. Una explicació d'això radica per exemple en el fet que, en comparació a les dades del capítol 2, a PISA 2015 no hi ha informació sobre l'ús de les TIC en cadascuna de les assignatures, sinó que simplement se'ls preguntava als alumnes per l'ús general de les TIC a l'escola i a més no és possible vincular a estudiants i professors. Aquests dos fets impedeixen per exemple la utilització dels instruments emprats en el capítol 2. No obstant això, les dades de PISA 2018 sí que aporten com a novetat informació més detallada sobre l'ús de les TIC – desagregant el nivell d'ús per assignatures – pel que una nova línia d'investigació seria replicar l'anàlisi del capítol 1 usant dades de PISA 2018 i emprant la tècnica de variables instrumentals per a l'anàlisi d'algunes de les variables TIC d'aquest capítol, tal com es concreta en la subsecció de futures línies d'investigació.

Del capítol 2 s'extrau per tant la conclusió que usar les TIC com una eina docent a l'aula és positiu per al rendiment dels estudiants. No obstant això, de nou cal assenyalar que ens estem referint a un ús concret - per a realitzar projectes o exercicis - i s'estan excloent per tant altres tipus d'ús de les TIC que també es poden fer amb finalitats educatius, com ara usar les TIC per a visualitzar el material docent o comunicar-se via e-mail amb el professor.

En aquest sentit, tal com s'assenyala en les reflexions del capítol 2, és necessari complementar els resultats d'aquesta investigació amb futures investigacions que permeten conèixer amb més detall l'ús de les TIC que es realitza a les escoles per a poder així estudiar l'impacte dels diferents tipus d'ús sobre el rendiment acadèmic.

Considerant que, sobre la base dels resultats del capítol 2, una major freqüència d'ús de les TIC a l'aula per a realitzar projectes i exercicis té un impacte positiu en el rendiment acadèmic en determinades competències, en el capítol 3 se centra l'atenció en els factors que porten als professors a emprar sovint les TIC en les seues classes com una eina docent. Els resultats de les regressions logístiques multinivell mostren que la decisió d'implementar les TIC per part dels docents ve motivada per una sèrie de característiques personals, dels seus estudiants i del centre educatiu en el qual imparteixen docència. Concretament, s'observa que aquells docents amb majors nivells de satisfacció amb la professió i aquells que han participat en els últims 12 mesos en cursos de formació en l'ús de les TIC, són més propicis a utilitzar aquestes eines a l'aula. La relació positiva entre satisfacció amb la professió i freqüència d'ús de les TIC estan en línia amb l'estudi previ de Sang et al. (2011). Pel que respecta a la formació en TIC, el resultat obtingut coincideix també amb els obtinguts per estudis previs (Inan i Lowther, 2010; Shin, 2015; Gerick et al., 2017) i evidència la importància que els docents reben formació en l'ús de les TIC. A més, l'entorn importa. Aquells docents que fan classe a un grup d'estudiants que es comporta adequadament a l'aula i que usa sovint les TIC en la llar, presenten també una major probabilitat d'utilitzar les TIC en les seues classes. Pel que respecta al centre educatiu, els resultats evidencien que la disponibilitat de dispositius digitals és un factor clau si es pretén incrementar la freqüència d'ús d'aquestes eines per part dels docents, en línia amb el suggerit per Eickelmann et al. (2017) i Petko et al. (2018). Els resultats d'aquesta investigació són nous atés que, tal com s'ha explicat detalladament en el capítol 3, existeixen molt pocs estudis que hagen analitzat aquesta temàtica. A més aquesta tesi presenta un estudi detallat per nivells educatius i inclou variables que no havien sigut prèviament explorades en la literatura prèvia. Per tot això, els resultats aconseguits suposen una interessant aportació al debat científic sobre l'ús de les TIC per part dels docents en els centres educatius.

Efectes positius versus efectes negatius de l'ús de les TIC sobre el rendiment acadèmic

Els resultats d'aquesta tesi mostren que depenent de la mena d'ús de les TIC, el seu efecte sobre el rendiment acadèmic difereix. Aquest resultat és molt interessant i mereix l'atenció suficient com per a dedicar una subsecció exclusivament per a en anàlisi de la naturalesa d'aquests diferents resultats.

En primer lloc, es procedeix a analitzar les diferències en l'ús de les TIC en la llar. Aquestes diferències són analitzades en el capítol 1, en el qual es conclou que depenent de la finalitat de l'ús de les TIC, la relació amb el rendiment acadèmic pot ser negativa o positiva.

Concretament, es conclou que l'ús de les TIC en la llar amb finalitats d'entreteniment s'associa amb majors nivells de rendiment acadèmic, mentre que l'ús de les TIC en la llar per a fer tasques escolars s'associa amb pitjors nivells de rendiment acadèmic. Si bé les anàlisis d'aquesta tesi no poden determinar la relació causal entre l'ús de les TIC i el rendiment acadèmic, a continuació s'assenyalen possibles hipòtesis sobre aquest tema. No obstant això, per a confirmar com s'expliquen aquestes relacions causals, serien necessàries investigacions complementàries. Una possible explicació a aquest resultat podria ser que l'ús de les TIC amb finalitats d'entreteniment ocasionara que, involuntàriament, els estudiants desenvolupen les seues habilitats de lectura i pensament crític en navegar per internet, xatejar amb amics o jugar amb els ordinadors. Això podria traduir-se com a conseqüència en millores del rendiment acadèmic. Addicionalment, l'ús de les TIC per a entretindre's pot associar-se amb un augment de la motivació i l'interès general per l'ús de la tecnologia. Això pot propiciar que aquells que usen sovint les TIC per a entretindre's també decidisquen usar-les voluntàriament amb finalitats educatius (per exemple per a buscar informació addicional sobre conceptes explicats a l'aula) i d'aquesta manera vegen millorat el seu rendiment acadèmic. No obstant això, un resultat molt nou i interessant d'aquesta tesi és que el nivell d'importància que es concedeix a les TIC en les interaccions socials s'associa negativament amb el rendiment acadèmic. Entre la informació que se sol·licita per a reflectir aquest grau d'importància s'inclouen preguntes relacionades amb l'interès per reunir-se amb amics per a jugar a videojocs. Aquest resultat sembla apuntar al fet que és necessari diversificar els usos de les TIC per part de xiquets i adolescents. Sembla que una importància excessiva a l'ús amb finalitats d'interacció social repercuteix negativament en el rendiment. Això podria explicar-se perquè aquesta importància s'associe amb períodes de temps excessius usant aquestes tecnologies per a realitzar activitats que no contribueixen a l'aprenentatge (videojocs no educatius) i per tant amb menor temps per a altres tipus d'ús de les TIC que sí que contribueixen a l'aprenentatge i, en general, amb menor temps per a la realització de tasques escolars en la llar.

D'altra banda, que l'ús de les TIC en la llar per a fer tasques escolars s'associe amb pitjors nivells de rendiment acadèmic, sembla suggerir que les TIC no s'estan implementant adequadament en el context educatiu i que els docents han de millorar l'assignació de tasques a realitzar amb aquestes tecnologies. Això podria explicar-se per diferents motius, com ara que: (i) els alumnes no estan prou familiaritzats amb l'ús especifique de les TIC per a fer tasques escolars; (ii) en emprar recursos TIC, per exemple un ordinador o una tauleta, podrien evadir-se fàcilment i acabar consultant recursos que no contribueixen a l'aprenentatge; i (iii) podria ser que les tasques no estiguen adequadament plantejades per part del professorat i no contribuïsquen a l'aprenentatge. En la subsecció de recomanacions a docents d'aquesta secció de conclusions, es plantegen propostes de millora per a tractar d'invertir aquesta relació negativa trobada entre l'ús de les TIC per a fer tasques escolars i el rendiment acadèmic.

En relació a l'ús de les TIC a les escoles, tal com s'ha comentat en la subsecció de principals resultats, encara que a priori els resultats del capítol 1 i 2 puguen semblar contradictoris, la potencial explicació estaria en la varietat d'usos de les TIC que es pot donar a les escoles. En aquest sentit, és important assenyalar que l'índex que mesura la freqüència d'ús de les TIC a l'escola en el capítol 1 engloba diferents tipus d'ús, alguns amb finalitats educatius i altres no. No obstant això, en el capítol 2, la variable utilitzada per a mesurar l'ús de les TIC a les escoles se centra únicament en l'ús per a la realització de tasques i exercicis a l'aula. Tenint en compte la naturalesa de les variables emprades en els capítols 1 i 2 per a mesurar la freqüència d'ús de les TIC en els centres educatius, del resultat del capítol 1 no pot concloure's que usar les TIC amb finalitats educatius (per exemple per a fer tasques i exercicis) s'associe amb un pitjor rendiment, atés que darrere d'aquesta variable també s'inclouen usos no necessàriament relacionats amb finalitats educatius (per exemple xatejar). A més, el resultat del primer capítol podria explicar-se també perquè no tots els usos de les TIC amb finalitats educatius repercutisquen de la mateixa manera en el rendiment acadèmic. En aquest sentit, podria ocórrer que usar les TIC per a resoldre exercicis o treballs siga beneficiós per al rendiment, tal com evidencia el capítol 2, però per exemple usar-les com un instrument per a visualitzar el material o comunicar-se amb el docent siga perjudicial a conseqüència d'una incorrecta implementació d'aquestes eines. En qualsevol cas, mancant confirmar l'explicació de les relacions causals trobades, aquests resultats posen de manifest la rellevància de continuar investigant sobre els diferents tipus d'ús de les TIC a les escoles per a poder orientar de manera idònia la incorporació d'aquestes eines en la docència.

Recomanacions per a responsables polítics

Tenint en compte els resultats obtinguts en aquesta tesi, resulta d'especial interès elaborar recomanacions per a responsables polítics a nivell nacional i regional en relació a la promoció de l'ús de les TIC en les llars i a les escoles. En aquest sentit - tal com s'ha discutit en la subsecció precedent - és important recordar que aquesta tesi evidencia que no tots els tipus d'ús de les TIC repercuteixen de la mateixa manera sobre el rendiment acadèmic. Per tant, no es tracta únicament d'incrementar la dotació de recursos TIC en les llars i les escoles i fomentar el seu ús, sinó de promoure un ús adequat d'aquestes eines que derive en efectes positius sobre l'aprenentatge.

En primer lloc, s'assenyalen recomanacions per a responsables polítics pel que respecta a la disponibilitat i ús de les TIC en les llars. En aquesta tesi s'ha evidenciat que iniciar-se primerencament en l'ús de les TIC s'associa amb majors nivells de rendiment acadèmic, per la qual cosa sembla propici garantir que tots els xiquets tinguen al seu abast recursos TIC des de xicotets. Segons dades de l'Institut Nacional d'Estadística (INE, 2021), en els últims deu anys el percentatge de llars espanyoles sense accés a internet ha baixat del 40% al 5% i el percentatge de llars sense ordinador disponible ha disminuït del 30% al 19%. Aquestes dades són positives, però posen de manifest que encara existeix una bretxa digital a Espanya i que parteix de la població s'enfronta a barreres d'accés a l'ús de les TIC en la llar. En aquest sentit, el tancament de les escoles al març de 2020 a conseqüència de la crisi sanitària de la COVID-19, va evidenciar la desigualtat entre aquells estudiants que podien utilitzar les TIC i internet en les seues llars i els que no. Concretament, en el cas d'Espanya, el 9% de les llars amb xiquets manca d'accés a internet (INE, 2021), la qual cosa permet estimar que al voltant de 100.000 llars amb xiquets no disposaven de connectivitat durant l'etapa de confinament domiciliari, convertint per tant la bretxa digital en una bretxa educativa. Per tant, tenint en compte aquestes dades i els resultats d'aquesta tesi, sembla necessari continuar desenvolupant polítiques públiques orientades a reduir la bretxa digital i aconseguir la inclusió digital, bé siga mitjançant ajudes econòmiques en els casos de bretxa digital per assequibilitat, o mitjançant la millora de connectivitat en zones rurals o àrees marginades que s'enfronten a una bretxa digital d'ubicació.

Paral·lelament a la implementació de mesures orientades a millorar la disponibilitat de recursos TIC en les llars, resulta crucial desenvolupar polítiques encaminades a garantir un correcte ús de les TIC per part de xiquets i adolescents. Els resultats d'aquesta investigació mostren que l'ús de les TIC amb finalitats d'entreteniment i el grau d'interés per les TIC es relacionen positivament amb el rendiment acadèmic. No obstant això, el grau d'importància que se'ls dona a les TIC en les interaccions socials es relaciona negativament amb el rendiment. Tenint en compte aquests resultats, una bona política podria ser promoure campanyes de conscienciació social orientades a donar a conèixer entre xiquets i, especialment entre joves, totes les possibilitats d'ús que presenten els recursos TIC amb finalitats d'entreteniment, més enllà dels seus usos relacionats merament amb la interacció social: blogs, periòdics, llibres, sèries i pel·lícules, *webinars*, cursos, jocs, música, etc.

Pel que fa a l'ús de les TIC en el context escolar, els resultats del capítol 2 posen de manifest que l'ús de les TIC per a fer tasques i exercicis a les escoles té efectes positius sobre el rendiment acadèmic. A més, en el capítol 3 es demostra que quants més recursos TIC existeixen a l'escola, més propicis són els docents a l'ús d'aquestes eines a les aules, per la qual cosa si es vol promoure el seu ús resulta clau incrementar la dotació de recursos TIC en els centres educatius. No obstant això, és important recalcar que la inversió en recursos TIC no és una condició suficient. Aquesta ha d'anar acompanyada de mesures paral·leles que garantisquen un ús adequat d'aquestes eines per part d'alumnes i professors. En aquest sentit, resulta crucial acompanyar la inversió en recursos TIC de mesures orientades a la formació del professorat i de l'alumnat en l'ús d'aquestes eines. Els ordinadors, les *tablets* o les pissarres digitals no garanteixen per se una millora del rendiment acadèmic i la seua presència podria ser fins i tot perjudicial per a aquest segons mostren els resultats del capítol 1. La clau sembla ser acompanyar la inversió en recursos TIC de mesures orientades a la formació del professorat en l'ús d'aquestes eines, de manera que puguen ser incorporats adequadament a la docència per a la realització de tasques i permeten una millora del rendiment acadèmic, tal com evidencia el capítol 2. A més, tenint en compte que en el capítol 3 tant la formació en TIC per part del professorat, com el grau de familiarització dels estudiants en l'ús de les TIC, resulten ser factors determinants a l'hora de decidir usar aquestes eines en les classes, queda més que evidenciat que si es vol promoure l'ús de les TIC resulta indispensable oferir formació específica a docents i millorar la familiarització dels estudiants amb aquestes eines.

Finalment, considerant els resultats obtinguts en les regressions quantíliques resulta també d'interés recalcar la rellevància de les TIC com un element més a ser considerat en la lluita contra el fracàs escolar. Espanya és el segon país de la UE amb pitjors xifres d'abandó escolar prematur (Eurostat, 2021): el 16% dels joves no finalitzen educació secundària. Aquesta xifra situa al país molt lluny dels objectius marcats per la Unió Europea. Considerant aquest escenari i els resultats del capítol 1, sembla interessant considerar les TIC com un factor addicional a tindre en compte en la lluita contra l'abandó escolar. Sobre la base dels resultats obtinguts, fomentar l'inici en l'ús de les TIC des d'una edat primerenca, l'ús de les TIC en la llar amb finalitats d'entreteniment i l'interès en general per aquestes eines, seria especialment beneficiós per als estudiants amb pitjor rendiment i per tant els responsables polítics haurien de tindre en compte les eines TIC a l'hora d'elaborar polítiques educatives orientades a reduir els nivells de fracàs escolar. No obstant això, en el cas de l'ús d'aquestes eines a les escoles, els resultats del capítol 2 mostren que depenent de l'assignatura es veuen més beneficiats els estudiants situats en la part alta o baixa de la distribució del rendiment acadèmic. Per tant, en aquesta mena d'ús concret seria necessari estudiar més a fons el seu efecte en els estudiants amb pitjor rendiment per a considerar la seua inclusió o no com un element clau en la lluita contra el fracàs escolar.

En resum, les recomanacions per a responsables polítics van en la direcció de: (1) incrementar la disponibilitat de recursos TIC en les llars per a aconseguir reduir la bretxa digital; (2) complementar la mesura anterior amb campanyes orientades a donar a conèixer els diferents usos de les TIC amb finalitats d'entreteniment, més enllà de les xarxes socials; (3) incrementar la disponibilitat de recursos TIC a les escoles; (4) complementar la mesura anterior amb programes de formació específics per al professorat sobre l'ús de les TIC com una eina docent i amb programes orientats a millorar la familiarització dels estudiants amb aquestes eines; i (5) considerar les TIC com un element addicional en la lluita contra el fracàs escolar.

Recomanacions per a docents i directors de centres educatius

Les recomanacions suggerides per a responsables polítics han de complementar-se necessàriament amb recomanacions directament suggerides als centres educatius. En aquest sentit, més enllà de les mesures que requerisquen la intervenció de les Administracions Públiques, existeixen una sèrie de mesures que podrien ser directament aplicades per directors de centres educatius i docents sobre la base dels resultats obtinguts en aquesta tesi.

Un resultat molt rellevant d'aquesta tesi és la identificació en el capítol 1 d'una relació negativa entre l'ús de les TIC en la llar per a fer tasques escolars i el rendiment acadèmic. Aquest resultat evidencia que els docents han de prestar especial atenció als materials i eines que es faciliten als estudiants per a la realització de deures usant les TIC. Per això, és molt important que s'asseguren, abans de manar aquests deures, que els estudiants seran capaços d'emprar de manera autònoma les TIC per a realitzar les activitats que se'ls sol·liciten. Sembla rellevant per exemple que els alumnes hagen treballat prèviament amb aquestes eines a l'aula i que no s'enfronten per primera vegada al seu ús en la llar. Addicionalment, també seria recomanable que en manar aquest tipus d'activitats es tinga especialment en compte la possibilitat que els estudiants al no estar supervisats pel professor acaben utilitzant els recursos TIC per a fins diferents a la realització dels deures (jocs, xatejar, etc.). En aquest sentit, la recomanació seria fomentar la relació entre la família i el centre educatiu, de manera que els docents expliquen als pares la importància de supervisar als seus fills mentre utilitzen recursos TIC per a fer tasques escolars per a poder garantir un ús correcte d'aquests recursos. Per descomptat, es recomana als docents que s'asseguren que les activitats a realitzar amb recursos TIC estiguen adequadament plantejades i contribuïsquen positivament a l'aprenentatge. No es tracta únicament de demanar als alumnes que usen l'ordinador per a fer la tasca, si no que és clau plantejar l'activitat de manera que s'aprofiten els potencials avantatges de les TIC.

En relació a l'ús de les TIC a l'escola, considerant que es troba un efecte positiu de l'ús d'aquestes eines per a fer tasques i exercicis en classe sobre el rendiment acadèmic, seria recomanable que des de la direcció dels centres educatius es recalcaren al personal docent els potencials avantatges de l'ús d'aquestes eines a les aules. Per descomptat, aquesta recomanació d'ús ha d'anar acompanyada de formació específica que, paral·lelament a la qual es reba per part de les Administracions Públiques, pot ser millorada amb mesures de formació internes per part dels centres educatius. En aquest sentit, resulta també crucial que el personal docent siga conscient de la necessitat de prestar especial atenció a les activitats a realitzar amb recursos TIC i garantir que aquestes complementen adequadament a la resta de mètodes de docència emprats a les aules. Addicionalment, tenint en compte que es tracta de recursos nous i que evolucionen a gran velocitat, fomentar dinàmiques de grup amb regularitat entre els diferents docents del centre educatiu seria recomanable per a poder millorar l'ús de les TIC a l'aula a partir de la posada en comú de les experiències dels diferents professors. Finalment, tenint en compte els resultats de les regressions quantíliques, també sembla rellevant recomanar als docents que tinguen en compte que les TIC poden afectar desigualment els diferents alumnes de la classe. En aquest sentit, haurien de parar atenció quan usen aquestes eines per a garantir que tots els estudiants segueixen el fil de la classe i aprofiten al màxim aquests recursos.

En resum, les recomanacions per a directors de centres educatius van en la direcció de: (1) fomentar una adequada relació entre famílies i centres educatius per a garantir el correcte ús de les TIC en la llar; (2) recalcar a l'equip docent la rellevància d'implementar les TIC a les aules; (3) organitzar cursos de formació interna en relació a l'ús de les TIC amb finalitats educatius; i (4) fomentar dinàmiques de grup entre docents per a debatre sobre l'ús de les TIC a l'aula. Pel que respecta als docents, les recomanacions serien: (1) assegurar l'adequació dels deures escolars a realitzar amb TIC en la llar (experiència prèvia amb les TIC a l'aula); (2) garantir una adequada relació família-professor per a certificar el correcte ús de les TIC en la llar; (3) acudir a cursos de formació sobre l'ús de les TIC en docència; (4) incorporar les TIC com un recurs docent addicional assegurant-se que complementa adequadament a la resta de mètodes de docència; (5) participar en dinàmiques de grup amb altres docents del centre per a extraure conclusions sobre com millorar l'ús de les TIC a l'aula; i (6) parar atenció en la pràctica a les diferències que puguen observar-se en l'ús dels recursos TIC segons el nivell de rendiment de l'alumne, a fi de garantir que tots els estudiants trauen profit de l'ús d'aquestes eines.

Futures línies d'investigació

Tenint en compte l'evidència empírica obtinguda en els tres capítols d'aquesta tesi doctoral, s'assenyalen a continuació futures línies d'investigació que permetrien complementar els resultats ací obtinguts i corroborar la seua validesa externa.

En primer lloc, seria interessant replicar aquestes investigacions amb dades més actualitzades. En el capítol 1 es treballa amb dades de PISA 2015 (les dades disponibles més actualitzades en el moment que es va iniciar la investigació), però la replicació de l'anàlisi amb les dades de PISA 2018 permetria valorar si les associacions que es troben en aquest primer capítol es mantenen o s'han vist modificades amb el temps. Tenint en compte el ritme al qual evolucionen les TIC en el context actual, resulta especialment de interès poder efectuar anàlisi el més actualitzats possible. En el cas del capítol 2, s'utilitzen dades del curs 2016-2017 (les dades més recents disponibles en el moment d'inici de la investigació). Una de les futures línies d'investigació és replicar l'anàlisi empírica d'aquest capítol utilitzant les dades de les avaluacions individualitzades del curs 2018-2019, els empleats en el capítol 3. No obstant això, no és possible treballar amb dades d'aquestes avaluacions individualitzades més actualitzats que els que emprats en el capítol 3, atès que aquestes proves han deixat de realitzar-se des de l'any 2020 i en el curs 2019-2020 no es van realitzar a conseqüència de la crisi sanitària de la COVID-19. Precisament per aquest motiu, una altra de les futures línies d'investigació és replicar aquestes anàlisis amb altres bases de dades actualitzades a nivell internacional, estatal o de comunitat autònoma, que continguen informació relacionada amb l'ús de les TIC a les escoles i permeten continuar la investigació en aquesta línia.

En segon lloc, tal com s'ha esmentat en explicar els principals resultats del capítol 2, una futura línia d'investigació seria replicar l'anàlisi del capítol 1 sobre l'impacte de diferents tipus d'ús de les TIC en la llar i a l'escola, però emprant metodologies quasi-experimentals. En aquest sentit, una opció seria emprar el mètode de variables instrumentals i instrumentar algunes de les variables TIC utilitzades en aquest capítol per a les quals sí que s'observen instruments potencialment apropiats en la base de dades de PISA 2018. Un exemple d'això seria la utilització de la informació disponible en el qüestionari TIC realitzat als alumnes sobre l'ús de les TIC en les classes de les diferents assignatures. Aquesta informació no estava disponible a PISA 2015, però sí que s'inclou en PISA 2018. Seguint la metodologia del capítol 2, la informació disponible permetria instrumentar la variable que reflecteix l'ús de les TIC en cada assignatura, mitjançant els valors d'aqueixa mateixa variable en la resta de les assignatures, permetent així aproximar la cultura d'ús de les TIC que existeix en el centre educatiu. No existeix no obstant això possibilitat d'associar a professors i alumnes - contràriament al que permeten les avaluacions individualitzades del capítol 2 - i per tant, malgrat si incloure's com a novetat a PISA 2018 informació detallada sobre la formació en TIC per part dels docents no seria possible la utilització de l'altre instrument utilitzat en el capítol 2: el nivell de formació en TIC del professorat. Respecte a la resta de variable analitzades en el capítol 1, es requeriria un estudi detallat de potencials instruments sobre la base de la nova informació disponible en les dades més actualitzades de PISA.

En tercer lloc, seria interessant ampliar l'anàlisi sobre l'impacte de les TIC en el rendiment acadèmic a altres nivells educatius diferents a educació secundària. En aquest sentit, resultaria de interès, per exemple, explorar l'ús de bases de dades que centren l'atenció en educació primària a nivell internacional (PIRLS o TIMSS) i nivell estatal (avaluacions individualitzades del curs 2018-2019 o futures proves que es realitzen). L'ús de les TIC en el context d'estudiants d'educació primària és molt diferent al d'estudiants d'educació secundària i precisament per això aquesta línia d'investigació resulta molt interessant i pot ajudar a elaborar recomanacions en matèria de política educativa adaptades a cada nivell educatiu en particular. Addicionalment, també seria interessant analitzar l'impacte de l'ús de les TIC en altres països. Això permetria contextualitzar els resultats obtinguts per a Espanya i, en el cas que s'observen efectes diferents segons el país, poder indagar sobre les potencials explicacions tenint en compte el context social i cultural de cada país.

Finalment, tal com s'ha assenyalat en les reflexions dels diferents capítols, aquest tema d'investigació requereix ser complementat amb investigacions qualitatives que brinden informació detallada necessària per a comprendre l'evidència empírica obtinguda en aqueixa tesi. Conèixer per exemple les impressions, opinions i perspectives d'estudiants, professors i directes de centres educatius en relació a les TIC, permetria aportar als diferents capítols d'aquesta tesi un coneixement més profund sobre com s'estan implementant les TIC en el context social i educatiu. En aquest sentit, una possible línia d'investigació futura seria acompanyar les anàlisis estadístiques d'aquestes i futures investigacions, d'informació obtinguda en qüestionaris qualitatius.

En un moment de revolució digital a les escoles a conseqüència del període de tancament d'escoles experimentat després de la crisi sanitària originada per la COVID-19, és important situar els resultats obtinguts en aquesta tesi i indicar el que aquests aporten al debat actual sobre el paper de l'ensenyament a distància i l'ús de les TIC a les escoles. Per a això, en primer lloc, és necessari recordar que els resultats mostrats en aquesta tesi s'obtenen utilitzant dades del període prepandèmia, per la qual cosa es pot esperar que algunes de les conclusions obtingudes puguen veure's alterades a conseqüència de l'impacte de la crisi sanitària per la COVID-19 en l'ús de les TIC en el context educatiu. En aquest sentit, seria especialment rellevant replicar les anàlisis d'aquesta tesi quan es publiquen bases de dades nacionals i internacionals amb informació sobre l'ús de les TIC després de la volta a les aules de manera presencial (per exemple, dades de PISA 2022).

Fins al moment, l'evidència científica suggereix que el pas de la docència presencial a en línia en l'etapa de confinament va tindre conseqüències negatives sobre el nivell d'aprenentatge de l'alumnat (Donnelly i Patrinos, 2021; Reimers, 2022). No obstant això, és important matisar que d'aquest resultat no ha de concloure's que l'ús de les TIC per a ensenyar siga negatiu, sinó més aviat que moltes famílies i docents no estaven preparats per a un canvi tan profund i inesperat. No obstant això, malgrat aquest impacte negatiu, es pot preveure que l'aprenentatge forçat al qual es van enfrontar els docents al març de 2020 haja impulsat el nivell de formació en TIC del professorat. Considerant els resultats del capítol 3, aquest major nivell de formació en TIC hauria de traduir-se en un major ús de les TIC a les aules en l'actualitat i en el futur. De fet, el recent estudi de BlinkLearning (2021) mostra que, després del confinament i la volta a les aules de manera presencial, el percentatge de docents espanyols enquestats que va declarar utilitzar les TIC diàriament a les aules va créixer del 58% al 83%. Aquesta evidència suggereix que la pandèmia sembla haver impulsat una reforma educativa en el que a l'ús de les TIC es refereix.

En aquest context de major protagonisme de les TIC a les escoles, aquesta tesi aporta evidència sobre el potencial impacte positiu sobre el rendiment acadèmic que té l'ús d'aquestes tecnologies a les aules amb finalitats educatius. No obstant això, els resultats de la tesi posen de manifest la importància d'implementar les TIC adequadament i de ser conscients que els efectes d'aquestes eines difereixen per assignatures, perfil de l'alumnat (nivell de rendiment acadèmic) i tipologia d'ús (a l'aula versus per a fer tasques en la llar). Per això, totes les recomanacions enunciades arran dels resultats d'aquesta tesi haurien de ser tingudes en compte en el món post pandèmia per a garantir que el major protagonisme de les TIC a les escoles es tradueix en millores del rendiment acadèmic.

A manera de conclusió general, els resultats obtinguts en aquesta tesi posen de manifest la importància de les TIC com un factor més a ser considerat quan s'analitzen els factors determinants del rendiment acadèmic. El sistema educatiu ha de tindre en compte que aquestes eines presenten potencials avantatges i que correctament implementades poden ajudar a millorar el procés d'adquisició de competències dels escolars. Per això, com s'ha anat assenyalant en els diferents capítols, les polítiques educatives han de tindre en compte les TIC com una eina docent més i haurien de promoure un ús freqüent i adequat d'aquestes eines a les aules i en les llars.

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