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Does ICT matter for effectiveness and efficiency in mathematics education?

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A B S T R A C T

ICT infrastructure investments in educational institutions have been one of the key priorities of education policy during the last decade. Despite the attention, research on the effectiveness and efficiency of ICT is inconclusive. This is mainly due to small-scale research with weak identification strategies which lack a proper control group. Using the 2011 'Trends in International Mathematics and Science Study' (TIMSS) data, we define by a Mahalanobis matching a control group with similar student, teacher, school and regional characteristics. The results indicate that accounting or not accounting for these characteristics, may considerably alter the estimated impact of ICT. This suggests that a correction for characteristics related to the student population, teaching staff, administrative personnel and school management is warranted in the evaluation of the impact of ICT.

1. Introduction

1.1. ICT and education

ICT infrastructure investments in educational institutions (i.e., primary schools, secondary schools, colleges and universities) have been one of the key priorities of education policy during the last decade. Most countries have invested (and still are investing) considerable amounts of public resources in ICT equipment such as computers, whiteboards, connectivity, software, etc. An example of such a country is the Netherlands. In the last three decades, in the Netherlands, large amounts of public resources have been invested in the implementation of ICT infrastructure in primary and secondary education (Haelermans & De Witte, 2012). In a policy document published in 2008 for the parliament, the Education Council recognized that as a result of these investments, most schools have computers, internet connection and educational software at their disposal (Onderwijsraad, 2008). With enormous amounts of public resources being invested in educational technology, an important question is whether this investment has paid off in terms of higher efficiency and effectiveness in school administration, teaching and learning.

More precisely, policy makers and stakeholders in the Netherlands (however, the same question frequently pops up in other countries) ask themselves (1) how the schools are currently doing in terms of implementing the ICT infrastructure in the daily organization (e.g., school management and administration), (2) the implementation of ICT in teaching and (3) whether or not ICT has positively impacted the effectiveness and efficiency of education (see European Schoolnet (2006) for a similar discussion). While effectiveness denotes the extent to which ICT can improve education outcomes, efficiency refers to the extent to which ICT can replace traditional instruction methods (e.g., reduce teaching and administrative time).

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First, concerning the impact of technology in school administration and organization, there seems to be a consensus among practitioners and scholars that ICT has benefited efficiency and effectiveness of daily organization. More and more schools use ICT-infrastructure (such as intranets and digital learning environments) to support the administrative personnel in performing administrative tasks (e.g., financial management) and the daily organization of the school (e.g., planning of the rooms). For example, schools use ICT applications to collect pupil test scores, monitor progress in pupils' scholastic achievements, report the pupil education outcomes to the parents, share information among the teaching staff, etc. The belief is that all of these applications have benefited the efficiency and the effectiveness of administrative personnel.

Second, the implementation of ICT in education is visualized in Fig. 1, which indicates the reported computer shortage by grade 4 math teachers in the Netherlands between 2003 and 2011. Being one of the stakeholders most involved in the school and the classroom, we believe that teachers are well-placed to indicate whether or not the considerable investments in ICT implementation in schools have actually resulted in more ICT infrastructure (both hardware and software) being present in the school, in general, and the classrooms, in particular. While the ICT shortage reported by math teachers is only a proxy for general ICT shortage, it is one of the only indicators for ICT implementation. Whereas in 2003 about 39% of the Dutch math teachers reported in the Timms (Trends in International Mathematics and Science Study) 'a lot' or 'some' shortage, only 14% of the teachers reported 'a lot' or 'some' shortage in 2011. Moreover, an increasing share of teachers did not observe any computer shortage between 2003 and 2011 (from 34% in 2003 to 51% in 2011). Other measures of ICT infrastructure confirm this trend (e.g., number of computers available at the school/in the classroom, number of internet connections, presence of WIFI). Similar trends are observed in the OECD Pisa data (Fig. 1b). As computer shortage is nowadays less an issue, for a large majority of the schools, the use of ICT has become a relatively routine part of the everyday practice. Next to using ICT for the more "traditional purposes" as a management and administration tool, it is also increasingly used in the classroom as a supplement or as an alternative to the more conventional teaching methods. Fig. 2 shows the use of computer in Dutch classrooms to discuss math principles. Between 2003 and 2011 we observe in the Dutch TIMSS data an increase of 21 percentage points of the teachers who use computers in about half of the lessons to discuss math principles. However, notwithstanding this positive trend in ICT-usage, recent reports of the European Commission (e.g., European Schoolnet, 2006) show that the heterogeneity in the availability of ICT-infrastructure is still considerable, with large differences between countries and regions as well as between schools within countries and regions.

The third question, concerning the impact of ICT on the effectiveness and efficiency, attracted the attention of (international) public institutions and scholars. Broadly speaking there are two opposite findings in the literature. One group of researchers and teachers advocates the use of ICT in teaching and learning thereby referring to studies that found a positive impact of ICT on teaching effectiveness and pupil learning. They typically reason that the use of ICT in teaching and learning both enhances the educational outcomes of pupils and reduces the educational costs (particularly in the long run). Additional benefits discussed by advocates are, among other things, a greater flexibility and autonomy for pupils in their learning and an increase in the learning attitudes and experiences of pupils. Next to the group of believers, there is also the group of scholars and practitioners who are more critical to the use of technology in teaching and learning. They believe that the return of using ICT in teaching and learning in terms of increasing pupil performances is not significantly positive. Some of the disbelievers even warn that the impact of more ICT in education may very well be negative with the use of ICT-tools in the classroom being more a distraction to pupils than anything else or teachers and/or pupils not having the necessary skills to use computers most effectively in their teaching and learning (see a discussion in van Braak, 2001). To buttress their viewpoint, they refer to the findings of an insignificant impact of ICT on pupil educational achievement reported by (predominantly quantitative) studies.

The paper is organized as follows. The next subsection gives an overview of the literature on the impact of ICT on education. The focus is on the findings of how ICT impacts efficiency and/or effectiveness in school management and organization, teaching and learning. The third subsection discusses the limitations of earlier work, some of which this paper aims to overcome. Section 2 presents the matching procedure employed to study the impact of ICT, while Section 3 describes the TIMSS data and results. The paper concludes with a section which briefly summarizes the main conclusions. It also discusses some limitations of this study and presents some interesting avenues for future research.

1.2. Literature

The study of the impact of ICT use in primary and secondary schools has gained interest in the academic literature during the last two decades. This resulted in a considerable expansion of the number of studies on this topic. In this section, a review of the previous impact

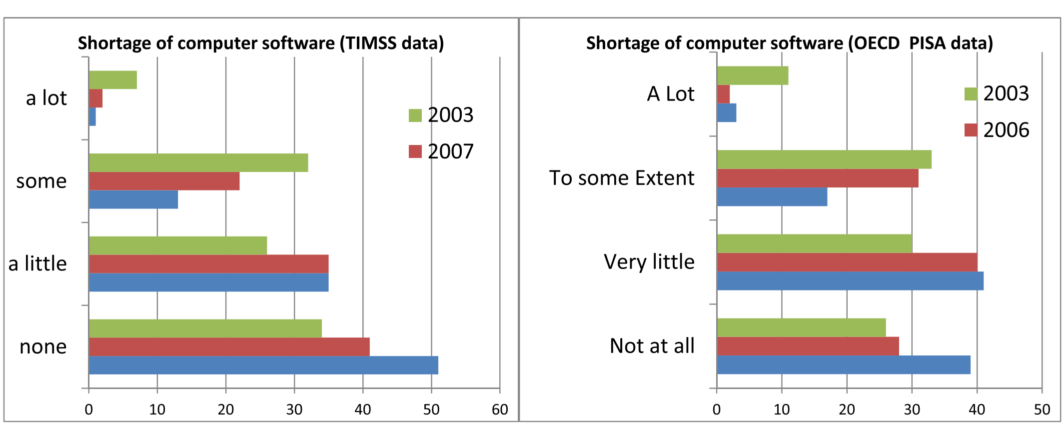

Fig. 1. Experienced shortage of computer software by grade 4 math teachers in the Netherlands between 2003 and 2011, expressed in % (source: left hand side: own calculations based on TIMSS 2003–2007–2011; right hand side: own calculations based on PISA 2003–2006–2009).

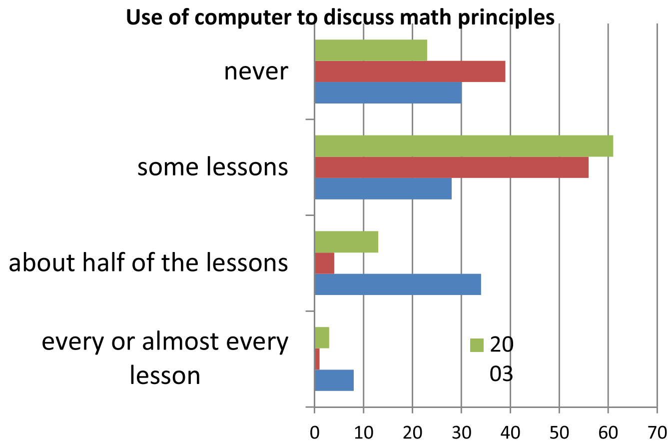

Fig. 2. Use of computers to discuss math principles by grade 4 math teachers in the Netherlands between 2003 and 2011, expressed in % (source: own calculations based on TIMSS 2003–2007–2011).

studies and surveys is presented. In the selection of the studies that qualify for the review, the first inclusion criterion is to describe the main findings of the review studies that appeared in the literature since the 1990s. Second, concerning the case studies considered for review, we included the findings of the most recent case studies because findings from earlier case studies have been included in previous review studies (see above). As a third inclusion criterion, given the large popularity of the topic of ICT in education and, as a result, the large number of case studies recently published in the literature, the choice was to consider relevant papers which investigated the impact of ICT on learning in mathematics and science in primary and secondary education.[1] To enhance the comparability, we excluded studies from developing countries. As a final criterion for inclusion, we have pragmatically restricted the literature search to English language literature.

To this end we have used the search engines ERIC (Educational Resources Information Center), ScienceDirect and Google Scholar. Given the review's emphasis, the keywords "ICT", "secondary education" and "math" have been used in search for abstracts. Using these keywords, Google Scholar yielded the highest number of hits (over thousands), whereas ERIC only provided us with 15 abstracts. To limit the total number of hits in Google Scholar, we also have included the keywords "review" and "computer-assisted". ERIC then excluded all abstracts from the hit list, while in Google Scholar, we still retained a few thousands abstracts.

There are several ways to structure the literature review. One way is to look at the methodologies used in the case studies and distinguish between the quantitative and qualitative studies. Another way to organize the review is looking at the particular relation examined in the study: i.e., ICT and pupil learning effectiveness, ICT and efficiency of the educational process, ICT and other educational outcomes (e.g., pupil attitudes towards school and learning).

1.2.1. Methodological distinctions

The quantitative studies typically use statistical techniques to examine the impact of ICT-use in the school and the classrooms. Some quantitative studies focused on the relationship between ICT-use in the classroom and teaching. There are also quantitative studies which examined the relationship between ICT-use in the school and school administration (and/or organization). Other studies scrutinized the relationship between ICT-use in the classroom (or/and at home) and student learning. Different statistical techniques have been applied by previous studies. Examples of applied statistical techniques include simple correlation analysis (Mcalister, Dunn, & Quinn, 2005), multivariate regression techniques (Angrist & Lavy, 2002), (M)AN(C)OVA (Chang, 2003; Shieh, 2012; Pilli & Aksu, 2013), randomized control trail designs (Çepni, Taş, & Köse, 2006; Papastergiou, 2009; Shieh, 2012), a pretest-posttest control-group design (e.g., Chang, 2001, 2002) and meta-analysis techniques (Cheung & Slavin, 2013; Christmann & Badgett, 1997; Kulik & Kulik, 1991). Traditional indicators to assess the availability and/or the use of ICT in schools and classrooms include the number of computers and/of software packages, the pupil-to-computer ratio (Aristovnik, 2012), the amount of money spent in total or per pupil on ICT-equipment and/or software (Barrow, Markman, & Rouse, 2008; Leuven, Lindahl, Oosterbeek, & Webbink, 2004; Machin, McNally, & Silva, 2007). The outcomes in teaching and learning are predominantly measured by the pupils' achievements in one or more subjects (Haelermans & Blank, 2012; Papastergiou, 2009; Pilli & Aksu, 2013) or by changes in the pupils' test scores (Shieh, 2012).

The qualitative studies frequently use semi-structured, in-depth interviews or other formats of interviews/surveys (e.g., face-to-face interviews, focus group discussions, observations) to collect information about the perceptions, attitudes, or opinions of the different stakeholders (teachers, pupils, parents, school director, educational experts, etc.). Examples of such studies include Cuckle and Clarke (2003), Galanouli, Murphy and Gardner (2003), Hennessy, Ruthven, and Brindley (2005), Mcalister et al. (2005), Smeets (2005), Yurt and Cevher-Kalburan (2011), Ozyurt, Ozyurt, Baki, and Güven (2013), Gurkaynak and Gulcu (2012), and Kennedy-Clark (1991). The studies can also be further subdivided according to the level at which the studies are carried out (international-, national-, regional-, school-level). The studies which use international, national and regional-level data can be considered as large-scale studies (Biagi & Loi, 2013; Rouse & Krueger, 2004; Spiezia, V., 2010). Small-scale studies are particularly carried out at the school and class-level (Muir-Herzig, 2004; Ruthven, Hennessy, & Deaney, 2005). It is also important to note that whereas some studies looked at the impact of ICT in general (Luu & Freeman, 2011; Robertson, Grady, Fluck, & Webb, 2006), other studies focused on the impact of specific ICT-tools (e.g., Baki & Güveli,

[1] Note, however, the review is not exhaustive. In particular, it does not provide a summary of everything that has been written on the topic (given that as a term ICT is a very broad). Examples of ICT-instruments not considered in the review are learning games and mobile technology.

2008; Clements, 2000; Pilli & Aksu, 2013; Shieh, 2012). The former studies mainly concern large-scale studies whilst the latter studies are predominantly small-scale.

1.2.2. Influence on effectiveness

A first stream of earlier research concentrated on the question: 'does the use of ICT results in better educational outcomes?'. Kulik and Kulik (1991), Cox et al. (2003), Rutten, van Joolingen, and van der Veen (2012), Cuban and Kirkpatrick (1998) and Cheung and Slavin (2013) provide some interesting meta-analyses summarizing the results. The meta-analysis of Kulik and Kulik (1991) analyzed the results from 254 controlled evaluation studies (covering learners of all age levels). They found that computer-based instruction usually impacts the pupil outcomes positively with computer-based teaching raising the pupils' examination scores moderately yet significantly. Moreover, it helped pupils in acquiring a more in depth understanding of subject material, challenge pupils' thinking and understanding, and improve the pupils' problem-solving skills.

Cox et al. (2003) found evidence of a statistically significant and positive impact of ICT on pupil attainment in a lot of the course subjects. The evidence of a positive effect of ICT on the pupils' attainments appeared to be particularly robust in the core subjects in the curriculum, e.g., mathematics, science and languages. However, regarding the impact of ICT on the pupils' attainment in the other course subjects, Cox et al. (2003) concluded that the evidence is much less consistent with the results depending on the subject area and the technological instrument being investigated. Nevertheless, they emphasized that a crucial factor is the manner in which ICT is applied by the teachers. More specifically, the impact of ICT in pupil attainment depends to a considerable extent on which technologies are selected for use and on how they are deployed in the classroom.

The review study of Cuban and Kirkpatrick (1998) and by Becta (2007) provided mixed results and concluded that there is no conclusive evidence on the effectiveness of ICT in education. This contrasts to Cheung and Slavin (2013) who found that ICT applications produce modest but positive effects on mathematics achievements in comparison to traditional methods.

Several studies have also examined the impact of ICT in the classroom in the education of specific groups of pupils. For instance, Seo and Woo (2010) examined the effects of a new computer-assisted instruction program (i.e., Math Explorer) that is developed specifically to remediate mathematics skills (e.g., addition and subtraction) for pupils with learning disabilities. They found that the computed-assisted instruction program may be an effective tool for helping pupils with learning disabilities mastering particular mathematical concepts more easily.. Similar small-scale studies confirming the effectiveness in mathematics and science instruction include, among others, Serin (2011), Aqda, Hamidi, and Rahimi (2011), Zengin, Furkan, and Kutluca (2012), Craig et al. (2013), and Garcia and Pacheco (2013). Other small-scale studies focusing on the impact of ICT on learning outcomes of pupils with special educational needs (e.g., at-risk pupils, etc.) include Seo and Bryant (2009), Räsänen, Salminen, Wilson, Aunio, and Dehaene (2009), and Muir-Herzig (2004).

1.2.3. Influence on efficiency

Second, ICT might improve the efficiency of the educational process. This can be observed in (a) reducing the time needed for instruction, and (b) more efficient administrative processes.

Regarding the use of ICT in schools' management and organization, it is indicated (Becta, 2007; Goolsbee & Guryan, 2006; Muir-Herzig, 2004; Zain, Atan, & Idrus, 2004) that more and more secondary schools use intranets to support the administrative personnel in performing administrative tasks (e.g., financial management) as well as the daily organization of the school (e.g., planning of the rooms). Other potential applications of ICT in the schools' management and organization tasks reported by studies include the collection of pupil test scores, the reporting of the pupils' school outcomes to the parents, the sharing of information among the teaching staff, the development of tests and assignments, and the monitoring of progress in pupils' scholastic achievements (Becta, 2007; PricewaterhouseCooper, 2004). The latter is enhanced by the popularity of 'data driven teaching'.

It is believed that all of these potential applications should benefit the efficiency of the school (administrative and teaching) personnel. This intuition was confirmed in two studies, namely the study of Selwood and Pilkington (2005) and the study of PricewaterhouseCooper (2004). In both studies, the findings suggested that ICT does help address workload issues for some teachers, particularly those who are confident in its use. There is also some evidence that the use of ICT in administration allows schools to become better in communicating with the pupils, the parents, and others within the local community. In addition, some findings show that ICT enables school administration to collect a lot of data which are useful for strategic, self-evaluation and monitoring purposes.

Aristovnik (2012) examined at a country level ICT efficiency and the impact of ICT on educational outcomes using a production frontier approach (i.e., Data Envelopment Analysis). Using input and output/outcome data on a sample 27 EU-countries and some OECD countries, Aristovnik (2012) found that the efficiency of ICT differs significantly across the great majority of EU and OECD-countries. The efficient countries include Belgium, Korea, Finland and Norway. The inefficient countries are found to have considerable room for improvements. Aristovnik (2012), however, warns that one should look at more than just the efficiency in ICT use. For instance, in their study, Slovakia and Poland are found to be relatively efficient in their ICT-use which at first sight appears to be a good performance. However, a detailed analysis of the input and output/outcome data of these two countries shows that this relatively high efficiency is mainly due to the low input levels. Thus, in spite of a high efficiency in ICT use, a significant increase in ICT expenditures is needed in those countries.

1.2.4. Influence on other outcomes

Third, the literature discussed various other potential advantages of ICT use in teaching and learning. They include (for references, see Papastergiou, 2009; Zain et al., 2004; Kulik & Kulik, 1991; Means, Roschelle, Penuel, Sabelli, & Haertel, 2003; and the Becta, 2007-report):

- enabling opportunities that benefit pupils' reflection and analysis;
- making it possible for pupils to work more at their own pace;
- allowing a more immediate and personalized feedback based on a given pupil's learning progress and conditions;
- helping the schools and the teachers in bridging the gap between pupils' in-school and out-of-school learning;
- improving the pupils' attitudes toward teaching and ICT.

Obviously, as indicated by the review studies, the more specific benefits of ICT use in teaching and learning depend on the course subject and the willingness of teachers to innovate (van Braak, 2001; Sagrà and Gonzalez-Sannamed, 2010). For instance, specific benefits of ICT in teaching and learning of mathematics are helping pupils in developing problem-solving skills, practicing number skills and exploring patterns and relationships, for instance, by visualizing difficult and complex structures, challenging pupils' thinking and understanding, and illustrating graphically how misconceptions can be minimized.

The Becta (2007) report also lists some studies which found that when used properly and effectively ICT positively impacts pupil motivation, engagement and concentration both during the courses as well as when doing homework (Condie, Munro, Muir, & Collins, 2005; Ofsted, 2004; Passey, Rogers, Machell, & McHugh, 2004; Valentine, Marsh, & Pattie, 2005). Passey et al. (2004) is one of the most significant studies to date that has focused on the impact of ICT use on pupil motivation. It found that working with ICT in the classroom positively affected the pupils' high levels of learning motivation (both towards realizing more personal learning and obtaining positive feedback on the own competence). Ofsted (2004) even noted that this impact was strongest for pupils who had a high access to ICT. Valentine et al. (2005) found in their qualitative study that both pupils and parents share the belief that more and proper use of ICT in schools has the potential to increase pupil motivation and confidence as well as make schoolwork more pleasant for the pupils. Other studies that found that more and better use of ICT benefits or could benefit the pupils' interest in the course subject as well as the pupils' learning attitudes include Hennessy et al. (2005) and Oblinger (2004).

1.2.5. Disadvantages of ICT

While much has been written about the potential advantages of using ICT in schools and in teaching and learning more in particular, there are relatively few studies that discuss potential disadvantages of using ICT in the classroom. An exception is Condie et al. (2005), who remarked that some researchers expressed concerns that more use of computers, internet and other ICT-tools tends to benefit primarily the development of ICT skills rather than the other knowledge and skills. Another concern frequently raised by teachers and researchers is that using technology in teaching could undermine the teacher–pupil relationship (Condie et al., 2005). Other examples of studies mentioning potential disadvantages of ICT use include Angrist and Lavy (2002), Hennessy et al. (2005), and Zain et al. (2004). The latter two papers, for instance, discussed that the implementation of ICT has also resulted in some negative perceptions among the schools' stakeholders (e.g., increase in maintenance costs, decrease in the human interaction, etc.). Hennessy et al. (2005) found that some teachers (but also some pupils) were concerned that (over-)use of ICT may distract the pupils from learning.

1.2.6. Summary

In sum, it is very difficult to generalize the findings from previous qualitative and quantitative studies. The findings seem to suggest that there may be a positive impact of ICT on pupil attainment where ICT is an integral part of the day-to-day learning experiences of pupils and used for teaching and learning high-order skills. Nevertheless, as noted by several studies, the volume and the consistency of the evidence are insufficient to draw firm conclusions.

Important key findings of quantitative studies include, among other things, that (1) length of time in ICT use may be moderately related to the pupils' educational achievements particularly in the subjects mathematics, science, history, modern foreign languages, and geography, (2) pupils in schools which are better equipped in terms of ICT infrastructure realize, on average, higher achievements, (3) schools with more proper use of ICT in teaching (i.e., teaching high-order skills instead of drilling practice) display on average higher pupil test scores compared to schools with lower levels of ICT use in teaching or with improper use of ICT in teaching, and (4) the impact of ICT on the pupils' achievements are typically more profound in schools with an organization and culture that enables a more effective use of ICT in teaching and the daily organization (for more findings, see European Schoolnet, 2006).

Concerning the qualitative studies on the impact of ICT usage on student outcomes, the following findings are worth mentioning. Firstly, pupils and teachers believe that the ICT in the classroom benefits the learning experience, motivation and engagement of the pupils. Secondly, according to teachers, the pupils' subject-related performance and basic skills (calculation, reading and writing) improve with ICT. Thirdly, teachers are increasingly convinced that the educational achievements of pupils improve through the use of ICT. Fourthly, academically strong students benefit more from ICT use, but ICT serves also weak students. Several qualitative studies emphasized that the effectiveness/efficiency of the use of ICT in the classroom depended considerably on the skills of the teachers. Only when used properly can ICT positively influence pupil learning experiences and outcomes. In that perspective, it is important to note that several surveys found that ICT is typically used for drilling and practice purposes and not for more effective purposes such as helping students in developing higher-order skills (e.g., Clements, 2000; European Schoolnet, 2006). Moreover, several surveys found that some teachers are still quite resistant to using technology in teaching (e.g., Barton & Haydn, 2006). Typically there is also a generation gap between the older and younger teachers (although some studies (e.g., Galanouli et al., 2003) found that differences between younger and older teacher may disappear with adequate ICT-training). Being more acquainted with ICT, younger teachers are more open to the use of computers and other technology in their teaching. For the older generation of teachers it is in general more difficult to use technology in education (at least it requires more effort for them). This particularly holds for the use of recent technological innovations.

1.3. Limitations of earlier work

A large majority of previous studies suffer from several methodological limitations, which limit the reliability and hence the usefulness of these studies' results in the debate on the impact of ICT on education (Becta, 2007; Cheung & Slavin, 2013; Cox & Marshall, 2007; European Schoolnet, 2006; Kulik & Kulik, 1991). To set the scene for our own application, this section briefly discusses several of these limitations and argues how we circumvent them. In particular, we discuss the issues of the small scales, the limited time horizons, the indicators used, and the limitations of employed methodologies.

Regarding the first issue of the scale of the studies, there are only few studies which examined the association between ICT and educational achievements on a large-scale (i.e., on a national or international scale) and across a wide range of settings. The majority of the previous studies consist of small-scale studies on class-level, school-level or regional-level. As noted in Becta (2007) as well as in Cox and Marshall (2007), this paucity of large-scale research makes the external validity low, i.e. it is difficult to draw firm conclusions or to generalize the findings of the studies to other contexts. By making use of the Trends in International Mathematics and Science Study (TIMSS) data, we obtain a representative large-scale dataset. Note, however, that also large-scale studies may suffer from potential issues. An example of such an issue is that it becomes much more difficult to determine the beginning and the end of the evaluation of ICT impact. That is, whereas in small-scale studies, it is usually clear what marks the beginning and the end of the ICT project so as to evaluate its impact on student achievement (using for instance a difference-in-differences approach), the definition of a clear start and ending point is much more arduous in studies that use large-scale data.

A second limitation of most previous studies is the limited time horizon. Typically, studies measure the impact of ICT use on the short term thereby using cross-section data from one period. There are several potential issues with such a short term perspective. Firstly, as noted by a recent report of the European Commission (European Schoolnet, 2006), most of the schools are still in the early phase of implementing ICT in teaching and the daily organization (administration, etc.). This makes the availability as well as the use of the ICT infrastructure quite patchy and uncoordinated in many schools. More in particular, the use of ICT is very likely characterized by learning effects in the sense that it may take some time for the teachers to strike the right balance between traditional teaching and the use of ICT in the classroom. As a result, the real impact of ICT use in teaching and learning may only become apparent in the long term. Given this observation, it may very well be that the results of past studies may be understating the true impact of ICT. A second potential issue with the short term perspective of most studies is that the impact of ICT may differ depending on the stage of the development in which it is measured. Stated differently, ICT probably benefits pupil attainment differently at different stages in the pupils' development.

A third issue with most previous studies is that they use poor measures of ICT use. Traditional indicators used by studies to assess the availability of ICT in schools include the number of computers and/of software packages, the pupil-to-computer ratio, and the amount of money spent in total or per pupil on ICT-equipment and/or software. The problem of these measures is that they provide an incomplete picture of the ICT use. In the words of Wenglinsky (1998, p. 8), "no matter how many computers are available in the classroom, if teachers are unwilling to use them for instruction [or for the most effective purposes such as teaching high-order skills], that are unlikely to have much impact on students". Therefore, an adequate indicator of ICT use should measure the actual use of ICT in teaching. In that perspective, the frequency of computer use by pupils is a better indicator. We will use this indicator in Section 2. However, also this indicator is not without limitations. To get a complete picture of the effectiveness ICT in increasing pupil outcomes, an indicator should comprise not only the quantity aspect but also the quality aspect of computer use in the classroom.

A fourth criticism raised against previous studies is that only a small number of them meet a satisfactory methodological standard. Particularly economists (e.g., Rouse & Krueger, 2004) noted that many studies suffer from one or multiple methodological shortcomings which makes that it is difficult to conclude that their findings are reliable representations of the relationship between ICT use and pupil educational outcomes. For instance, a majority of the qualitative studies base their conclusions on impressions from educational stakeholders such as teachers and pupils without looking at the impressions in a comparison group. Also quite some quantitative studies suffer from methodological shortcomings. An example of a methodological shortcoming frequently observed is the confusion between correlation and causation. The non-randomness manner by which most studies select pupils for the treatment and comparison group makes that one should be very cautious in interpreting the findings of these studies. For instance, it may very well be that schools with pupil populations above average in terms of pupil attainment invest more in the use of ICT in teaching and learning. Obviously, when not accounting for this impact, resulting estimates of the covariation between ICT use and pupil attainment may provide a distorted picture of the exact relationship (i.e., the relationship may be just because of an unobserved factor which drives both ICT use and pupil outcomes). The measurement of the causal impact of ICT on the effectiveness and/or efficiency in teaching and learning (as measured by, for instance, changes in pupil test scores) requires techniques such as randomized controlled experiments or matching procedures. Section 4 outlines a matching strategy which allows us to create a control and treatment group based on observed student, teacher, school and regional variation.

1.3.1. Research questions of the paper

Given the state-of-the-art and the limitations of earlier work, this paper has the following objectives:

First, this paper contributes to the literature by explicitly tackling conceptual and methodological issues raised in recent research. In particular, disbelievers often point to conceptual and methodological concerns about the validity of most of the past research (see discussions in Angrist & Lavy, 2002; Barrow et al., 2008; Becta, 2007; Cheung & Slavin, 2013; Machin et al., 2007; Rouse & Krueger, 2004). It is argued that quite some previous research suffers from some common problems. Examples of methodological problems frequently observed include the lack of a control group, brief duration of interventions, no initial equivalence of the experimental and control group, and cherry-picking evidence. We might add to this range of problems that earlier research focused on small-scale implementations (in line with Wenglinsky, 1998). While this results in high internal validity of the results, it has only little external validity.

The objective of this paper is to examine the effects of ICT on pupil test scores by using large-scale data with initial equivalence of the experimental and control group.

To do so, we advocate the use of a Mahalanobis matching procedure. The main advantage of the matching procedure is that it allows mimicking a random assignment in the definition of the control and experimental group by using a selection procedure that is based on a set of criteria of similarity. The control group has, by construction, initial equivalence with the treatment group on the (wide range of) observed characteristics. It thus accounts for several exogenous pupil-, teacher-, and school-related characteristics (e.g., sex of pupil, age of pupil, sex of teacher, age of teacher, teacher experience with ICT, number of computed present in the classrooms, etc.) and therefore yields estimates of the value added by ICT use in teaching beyond teacher, pupil, and class characteristics. To study the impact of ICT in education on a large scale and without suffering from some brief duration of an intervention, we use data from the rich and large TIMSS sample for the Netherlands. We focus on the fourth grade students in Dutch schools.

2. Methodology

By applying a matching approach in the study of the relationship between ICT use and secondary school pupils' educational outcomes, one effectively controls for a group of environmental characteristics which may impact this relationship and therefore should be corrected for. Stated differently, by matching the data one is able to estimate the value added by ICT for comparable groups of secondary school pupils with comparable teachers teaching in classes of comparable sizes in comparable schools and regions.

In line with the potential outcome model there are two potential outcomes for each student *i*. As a first outcome, y_{1i} represents the math score (i.e., our outcome variable; see below) when the student is part of the treatment group, while y_{0i} denotes the outcome if the student is assigned to the control group. As both outcomes cannot be observed simultaneously, the outcome that we do not observe is generally referred to as the counterfactual outcome. The average treatment effect (ATE) is the difference in outcome between the control and treatment group (i.e., $E(y_{1i} - y_{0i})$). The ATE is a biased outcome if student, teacher, school and regional characteristics differ. Therefore, we rather estimate the average treatment effect on the treated (ATT).

Denote by I a discrete treatment variable equal to 1 for students in the treatment group and 0 for students in the control group. The ATE can be written as:

$$E(y_{1i}|I = 1) - E(y_{0i}|I = 0) = E(y_{1i} - y_{0i}|I = 1) + \{E(y_{0i}|I = 1) - E(y_{0i}|I = 0)\}. \quad (1)$$

While $E(y_{1i} - y_{0i}|I = 1)$ is the average treatment effect on the treated, the last term in braces of equation (1) represents a ‘bias’. The unbiased average treatment effect on the treated requires that $E(y_{0i}|I = 1) = E(y_{0i}|I = 0)$, which is unlikely if there is selection on observables and unobservables. Therefore, we control for relevant characteristics X_i at student, teacher, school and regional level.[2] Minimizing the Mahalanobis distance, the matching procedure searches for every teacher who does not experience ICT shortage, the best look-alike teacher who experienced a little or some ICT shortage. The matching approach assigns weights to the *j*-th observation, that could serve as a potential match for the *i*-th observation. The weight-function is denoted by $w(i,j)$ with $\sum_j w(i,j) = 1$. The matching estimator of the average treatment effect on the treated (ATT) is then:

$$\Delta = \frac{1}{N_M} \sum_{i \in I=1} \left[y_{1,i} - \sum_j w(i,j) \cdot y_{0,j} \right], \quad (2)$$

Where $w(i,j) = 1$, $I = 1$ is the set of teachers without ICT shortage and j is a teacher with ICT shortage; and N_C and N_E denote the number of teachers in the control and experimental group, respectively.

2.1. Data and results

2.1.1. TIMSS data

This paper contrasts to earlier work by using a large-scale data set in a matching design with comprehensive outcomes. This meets the critiques of earlier literature. We use the 2011 ‘Trend in International Mathematics and Science Study’ (TIMSS) data, which is a survey in 63 countries on the mathematics and science achievement of fourth and eighth grade. As noted in the introduction, in this paper, we focus on the fourth grade students in Dutch schools. The Netherlands makes an interesting case study as significant resources are currently spend on ICT (Haelermans & De Witte, 2012).

While there are various data sources with small-scale ICT applications, large-scale data on the use of ICT are scarce. The TIMSS data set is an exception and contains data on the access to and use of ICT in education. More precisely, in the TIMMS-survey teachers were explicitly asked about the availability (or, stated otherwise, the shortage) of ICT at their school. In particular, the data include questions on how many computers are available for instruction, how the computers are used (e.g., for preparation, administration, instruction, exploring concepts, or looking up ideas), the shortage of computers for instruct, and the shortage of computer software for reading and science. As a disadvantage, it lacks information on the quality of the ICT use.

It appears that the inequality in technology in secondary education lies both in the distribution of the ICT-equipment and the use of this equipment. This is visualized in Figs. 3 and 4. These figures present the reported shortage of computers for instruction and the use of computers in school, respectively. Both variables are reported by teachers. The large range of observed values of availability and shortage of ICT-infrastructure, for instance, indicates that there are still schools which do not succeed in providing a sufficient ICT infrastructure. In addition, the data on the use of ICT shows that there is still considerable variation when it comes to regular access to ICT-infrastructure across schools. Even for schools which are reasonably well accommodated with ICT infrastructure, however, there seems to be a large difference in how this ICT equipment is used in teaching. Some teachers reported that they only use ICT sporadically in the classroom whereas others indicated that they strongly integrate ICT in their teaching. While Hermans, Tondeur, van Braak, and Valcke (2008) show that teachers’ beliefs are significant determinants in explaining why teachers adopt computers in the classroom, we observe a low, though significant, correlation of 0.11 between shortage of ICT and use of ICT.

2.2. Control and treatment group

Given that we are interested in the causal influence of ICT on student performance and educational efficiency, we construct an artificial control and experimental group. The reported shortage of computers for instruction is clearly a qualitative indicator on the ‘perceived’ ICT shortage, while the use of the computer is a qualitative indicator on the ‘intensity’ of ICT use. It should be noted that the shortage is reported by Dutch math teachers. We exploit this variation in the perceived (Fig. 3) ICT shortage and the intensity of ICT use (Fig. 4) to determine the treatment and control group in two different and complementing ways.

First, we consider the construction of control and treatment group along the perceived ICT shortage. More in particular, if teachers report that there is little or some shortage of computers to instruct, we consider these teachers as working in a school with insufficient ICT facilities ($n = 1214$). As this hinders them from teaching in an ICT intensive way, we consider these teachers as working in a control group. On the

[2] An extensive discussion of the matching procedure can be found in AUTHOR BLINDED FOR REVIEW and Cameron and Trivedi (2005).

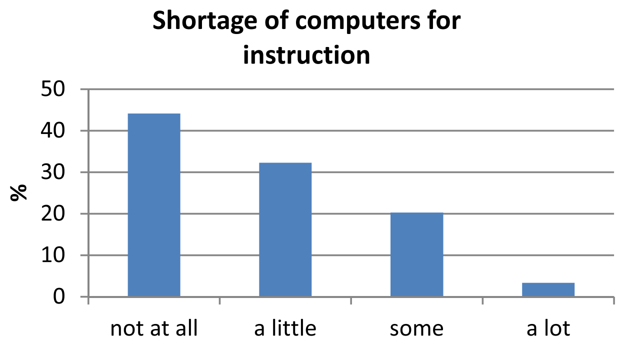

Fig. 3. Perceived ICT shortage as measured by the reported ICT shortage for instruction. Source: own calculations on TIMSS 2011.

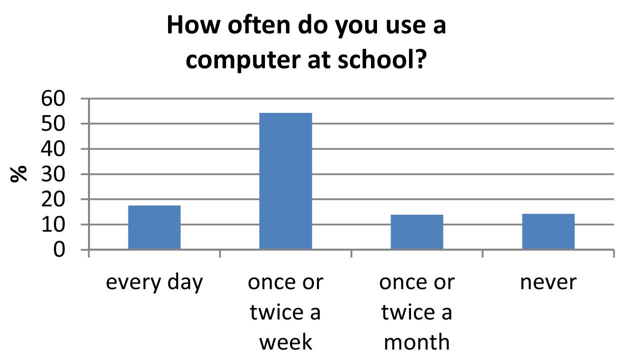

Fig. 4. Use of computers in Dutch schools. Source: own calculations on TIMSS 2011.

other hand, about an equal sized group of teachers ($n = 1105$) report that they are working in schools without any shortage of computers for instruction. These teachers can teach in an ICT intensive way, such that they are considered as the treatment group. We exclude teachers ($n = 83$) who state that they are working in a school with ‘a lot’ shortage of computers. The latter group might have different characteristics or expectations what explains their rather dramatic answer (robustness tests, which include the latter group, point to similar outcomes as the reported ones below).

Second, consider the construction of the control and treatment group along the frequency of ICT use. We assign students to the control group if they never use computer at school or only once or twice a month ($n = 441$). Students are assigned to the treatment group if they use every day, or at least once or twice a week a computer at school ($n = 1327$).

Obviously, we have to make sure that underlying (un)observed teacher characteristics do not matter for their statement on computer shortage. It might well be that precisely innovative and motivated teachers mention ICT shortage, whereas unmotivated teachers who are not willing to apply ICT in their class state that they do not experience ICT shortage. The existence of this source of endogeneity makes a secondary level argument for the use of matching. In the matching analysis we include various characteristics at student, teacher, school and region level. Moreover, auxiliary regressions on various other questionnaire items indicate that there are no observed differences between the teacher characteristics in the control and experimental group.

As outcome variable we use the average math score on the five plausible values available in the data. Nevertheless, all reported results in the paper have been separately tested for the five plausible values. These outcomes delivered similar results and are available upon request.

2.3. Matching variables

We distinguish four types of matching variables: student, teacher, school and region (for the complete list, see Table 1). First consider the variables at student level. They include indicators for the socio-economic situation of the student, such as ‘possession of an own room’ (yes; no), ‘how often do your parents ask about school’ (every day; once or twice a week; once or twice a month; never), and ‘amount of books at home’. Other student level observed variation deals with students’ motivation: ‘I like being in school’ (agree a lot; agree a little; disagree a little; disagree a lot) and ability as measured by the average plausible values on geometry and data display.

The variables at teacher level consist of the teacher’s gender, age, and level of formal education. In addition, we use a proxy of the motivation of the teacher as measured by survey questions ‘I am satisfied as a teacher’ (agree a lot; agree a little; disagree a little), ‘I think my work is important’ (agree a lot; agree a little), and ‘I am frustrated in my job’ (agree a little; disagree a little; disagree a lot). Finally, we measure the technological skills of the teacher. As noted previously, such skills are important determinants of how ICT can be used in teaching. Teachers who have more ICT skills (for instance, because of having followed professional training of computer use in teaching) typically are more likely to use ICT for higher-order skills teaching activities. As a proxy for the technological skills we use the survey questions ‘I use computers to prepare my teaching’ (yes; no) and ‘I feel comfortable with pc use’ (agree a lot; agree a little; disagree a little).

Concerning the observed variation at school level, we match on the number of students in the evaluated math class, the total enrollment of students in the school, and the percentage of students in the school coming from an economic affluence and disadvantaged background (0–10%; 11–25%; 26–50%; more than 50%).

Table 1
Descriptive statistics of the matching variables before the matching.

Variable	Control group (i.e., with ICT shortage)					Treatment group (i.e., without ICT shortage)					Difference	
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	*p*-value	
gen\home possess\own room	1301	1.075	0.263	1	2	1092	1.091	0.287	1	2	0.153	
gen\how often\home\parents ask learning	1293	1.642	0.944	1	4	1083	1.691	0.991	1	4	0.221	
gen\agree\being in school	1275	1.678	0.742	1	4	1075	1.673	0.750	1	4	0.893	
gen\amount of books in your home	1287	2.875	1.053	1	5	1082	2.968	1.037	1	5	0.032	**
Ability	1314	525.198	44.671	385	666	1105	528.597	45.856	361	667	0.066	*
ability_data	1314	560.246	55.653	349	736	1105	563.099	58.623	371	716	0.220	
gen\sex of teacher	1131	1.227	0.419	1	2	912	1.294	0.456	1	2	0.001	***
gen\age of teacher	1131	3.454	1.322	1	6	912	3.477	1.518	1	6	0.720	
gen\level of formal education completed	1131	5.007	0.084	5	6	912	5.013	0.114	5	6	0.165	
gen\pc use\use computers teach\prepare	1131	1.080	0.272	1	2	935	1.084	0.278	1	2	0.740	
gen\pc use\comfortable	1131	1.643	0.639	1	4	905	1.516	0.617	1	3	0.000	***
gen\agreement\satisfied teacher	1131	1.659	0.633	1	4	923	1.387	0.577	1	4	0.000	***
gen\agreement\work importance	1131	1.233	0.423	1	2	935	1.185	0.420	1	3	0.010	***
gen\agreement\level of frustration	1131	2.985	0.866	2	4	935	3.314	0.840	1	4	0.000	***
gen\number of students in the class	1131	24.443	7.148	6	36	931	23.904	7.446	6	60	0.095	*
gen\total enrolment of students	1243	300.053	165.523	73	794	1092	285.950	130.885	38	640	0.024	**
gen\students background\economic disadva	1246	1.451	0.847	1	4	1105	1.406	0.764	1	4	0.181	
gen\students background\economic affluen	1269	3.020	1.131	1	4	1062	3.060	1.005	1	4	0.374	
gen\how many people live in area	1314	3.200	1.183	1	6	1105	3.927	0.979	1	6	0.000	***
gen\average income level of area	1235	2.017	0.423	1	3	1081	1.891	0.474	1	3	0.000	***

Finally, the included regional characteristics consist of the number of people living in the area (we distinguish 6 groups) and the average income level of the area (high; medium; low).

2.4. Results

2.4.1. Descriptive statistics before and after the matching

Descriptive statistics on the raw data –without matching- are presented in Table 1. Rather than discussing all variables, we focus on the variables which differ significantly between the control and treatment group. It seems that there is both selection from students in the treatment group, as well as differences in satisfaction among teachers. Students in the treatment group have significantly more books at home and a higher ability. Concerning the teacher characteristics, the treatment group counts significantly more males, teachers feel less comfortable in pc use, are less satisfied with their work and experience a higher level of frustration. Teachers without reported ICT shortage have significantly fewer students in their class and operate in smaller schools. They live in higher populated areas with a lower income level.

Given the significant differences, it is clear that there might arise endogeneity issues from selection bias. Teachers who report teacher shortage have significantly different characteristics from teachers who do feel that they operate in an environment without teacher shortage. A matching procedure, which constructs a more appropriate control group is therefore a necessary condition for unbiased estimations.

Comparing Tables 1 and 2 provides information on the student, teacher, school and region characteristics that reduce differences in test outcomes between pupils in schools with and without ICT shortage. Examples of characteristics that considerably alter the estimated impact

Table 2
Descriptive statistics after the matching.

Variable	Control group (i.e., with ICT shortage)					Treatment group (i.e., without ICT shortage)					Difference	
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	*p*-value	
gen\home possess\own room	348	1.075	0.263	1	2	750	1.071	0.256	1	2	0.810	
gen\how often\home\parents ask learning	348	1.698	1.006	1	4	750	1.681	1.000	1	4	0.794	
gen\agree\being in school	348	1.652	0.718	1	4	750	1.675	0.760	1	4	0.644	
gen\amount of books in your home	348	2.874	0.955	1	5	750	2.967	1.015	1	5	0.150	
Ability	348	525.545	40.308	420	642	750	528.221	45.408	361	667	0.347	
ability_data	348	560.783	50.236	406	695	750	564.459	58.841	371	716	0.314	
gen\sex of teacher	348	1.287	0.453	1	2	750	1.317	0.466	1	2	0.317	
gen\age of teacher	348	3.333	1.223	1	5	750	3.461	1.527	1	6	0.170	
gen\level of formal education completed	348	5.011	0.107	5	6	750	5.011	0.103	5	6	0.902	
gen\pc use\use computers teach\prepare	348	1.089	0.285	1	2	750	1.068	0.252	1	2	0.217	
gen\pc use\comfortable	348	1.546	0.527	1	3	750	1.491	0.634	1	3	0.157	
gen\agreement\satisfied teacher	348	1.589	0.598	1	3	750	1.349	0.530	1	3	0.000	***
gen\agreement\work importance	348	1.158	0.365	1	2	750	1.156	0.363	1	2	0.931	
gen\agreement\level of frustration	348	3.057	0.850	2	4	750	3.359	0.791	2	4	0.000	***
gen\number of students in the class	348	24.132	6.693	8	36	750	23.839	7.614	6	60	0.537	
gen\total enrollment of students	348	286.853	147.236	73	794	750	301.009	135.015	38	640	0.117	
gen\students background\economic disadva	348	1.307	0.626	1	4	750	1.316	0.684	1	4	0.844	
gen\students background\economic affluen	348	3.193	1.024	1	4	750	3.133	1.020	1	4	0.372	
gen\how many people live in area	348	3.428	1.197	1	6	750	4.017	0.919	1	5	0.000	***
gen\average income level of area	348	1.968	0.397	1	3	750	1.855	0.508	1	3	0.000	***

of ICT include the amount of books at home, the sex of the teacher, a proxy of the motivation of the teacher (as measured by survey questions 'I am satisfied as a teacher'), a variable indicating whether the teacher is comfortable with the use of computers (the survey question 'I feel comfortable with pc use"), the number of students in the evaluated classes, the total enrolment of students in the schools, and the average income level of the region.

After applying the matching procedure, only four observed differences remain. Teachers in the matched treatment group are less satisfied and more frustrated than teachers in the matched control group. Moreover, they teach in more urban areas with a lower average income level. Despite the significant differences on the four (out of 20) variables, the matching procedure was successful. This is confirmed in the analysis of the bias which is for the majority of the covariates lower than 5% (detailed results available upon request). This indicates that the covariates are well balanced in the control and treatment group.

2.4.2. Matching outcomes

First, consider the construction of the control and experimental group along the shortage of ICT as perceived by the teacher. The results are reported in the upper half of Table 3. For the unmatched sample, the math scores differ significantly between the treatment and the control group. For the treated students (i.e., students from teachers who do not experience a shortage of ICT), the average score amounts to 544, while for the control group students (i.e., students with teachers who experience an ICT shortage) the average math score equals 540 points. This difference of about 3.7 points is significantly different from 0 (at 0.05%-level).

Question is to which extent this significant difference can be attributed to student, teacher, school, and region specific variation. The outcomes of the ATT after the matching provide some insights in the latter question. After the matching, the ATT increases in the control group to 544 as well. The difference in educational outcomes of students working in favorable conditions is not significantly different from the educational outcomes of students working in unfavorable conditions. In other words, if students would work under the same conditions, they would not have significantly different outcomes. This suggests that differences in student outcomes are predominantly driven by student, teacher, school and region characteristics, rather than the availability of ICT.

Second, consider the frequency of ICT use to determine the control and treatment group. The results are presented in the lower half of Table 3. For the unmatched sample, the math outcomes for the students in the control group are 3.8 points lower than the math outcomes for the students in the treatment group (significant at 0.068%). Controlling for student, teacher, school and regional characteristics reduces the gap in test scores between the treated and control students. While students with a low frequency of ICT use have still lower test scores (i.e., a difference of 3.0), it is no longer significantly different from 0.

3. Conclusion and discussion

With enormous amounts of public resources being invested in educational technology, policy makers, school directors and other school stakeholders (e.g., parents) are increasingly interested in evaluating whether this investment has paid off in terms of increased efficiency and/or effectiveness in school administration and organization as well as in teaching and learning. While we observe initial differences in the test outcomes between pupils in schools with and without ICT shortage and students who are frequently or not using ICT, this paper found that these differences may vanish if one accounts for student, teacher, school and regional characteristics. This suggests that an evaluation of the impact of ICT on efficiency and effectiveness in school administration, teaching and learning warrants a proper consideration of characteristics related to the student population, teaching staff, administrative personnel and school management.

The results reported in this paper should, however, be interpreted with some caution. In spite of addressing some of the shortcomings of past research, this study still suffers from some limitations. First of all, while using a matching approach our study starts from employing a proper control group, it does not account for all characteristics that may impact the return of ICT. For instance, given the central role that the teachers play in the use of ICT in teaching (both in terms of the frequency as well as the purpose of the use), it would be of interest to also include information on the teachers' beliefs towards the use of ICT in teaching. Similar information is unavailable yet. Another shortcoming of the current study is that, due to data issues, it does not distinguish between the different types of ICT use and the subject areas. A final limitation is related to the TIMSS data. Even though this dataset is unique in the sense that it contains data on the use of ICT at a large scale, the data on the use is mainly derived from the perceptions of the teachers. This raises the potential issue that the perceptions of teachers may not accurately reflect how ICT is actually used in the classroom. For instance, teachers could have the perception that they are using the computer sufficiently frequently and for the right purposes whereas in reality this is not completely the case. Another option would be to survey among pupils. However, this would not solve the problem as also their perceptions are probably not accurate (as there may be a discrepancy between what pupils believe is good use of ICT and what is actually effective use of ICT).

We see multiple avenues for follow-up research. Firstly, further research is needed to analyze the other effects that ICT may have on pupils. For instance, as remarked in Becta (2007), one facet of the digital technology that has remained largely ignored in the academic studies is the impact that an increased ICT use may have on the pupils' creativity. For instance, it may very well be that more use of ICT enables pupils to develop new insights concerning the course material which is not reflected in their grades. A second possible direction for future research consists of examining the potential applications of more recent technologies such as media players, tablets, mobile phones, personal laptops, e-readers, etc. Mobile technologies and computer games for example are gaining in popularity among pupils and some schools have been developing educational initiatives to gradually introduce such technologies into the classrooms. Whilst some recent

Table 3
Math scores for the unmatched and matched sample.

Treatment group by	Sample	Treated	Controls	Difference	S.E.	*T*-stat	*p*-Value
Perceived ICT shortage	Unmatched	544.382	540.662	3.720	2.317	1.610	0.054
	ATT	544.382	544.389	−0.006	3.588	0.000	0.500
Frequency ICT use	Unmatched	543.395	539.512	3.882	2.606	1.490	0.068
	ATT	543.395	540.345	3.049	3.908	0.780	0.218

studies (e.g., Ke, 2008; Kebritch, Hirumi, & Bai, 2010; Papastergiou, 2009) found that the use of mobile technologies in the classrooms may have some benefits such as supporting learning for disaffected and 'hard to reach' pupils, further research would definitely yield additional insights.

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Appendix. Label of the variables

Variable	Label	Value	Variable	Label	Value
gen\home possess\own room	Yes	1	gen\agreement\satisfied teacher	Agree a lot	1
	No	2		Agree a little	2
gen\how often\home\parents ask learning	Every day	1		Disagree a little	3
	Once or twice a week	2		Disagree a lot	4
	Once or twice a month	3	gen\agreement\work importance	Very high	1
	Never	4		High	2
gen\agree\being in school	Agree a lot	1		Medium	3
	Agree a little	2		Low	4
	Disagree a little	3	gen\agreement\level of frustration	Agree a lot	1
	Disagree a lot	4		Agree a little	2
gen\amount of books in your home	0–10	1		Disagree a little	3
	11–25.	2		Disagree a lot	4
	26–100	3	gen\students background\economic disadvantage	0–10%	1
	16–100	4		11–25%	2
	101–200	5		25–50%	3
	200+	6		>50%	4
gen\sex of teacher	Female	1	gen\students background\economic affluent homes	0–10%	1
	Male	2		11–25%	2
gen\level of formal education completed	Not completed isced 3	1		26–50%	3
	isced level 3	2		>50%	4
	isced level 4	3	gen\how many people live in area	>500,000 people	1
	isced level 5b	4		100,001–500,000 people	2
	isced level 5a, first	5		50,001–100,000 people	3
	isced level 5a, second	6		15,001–50,000 people	4
gen\pc use\use computers teach\prepare	Yes	1		3001–15,000 people	5
	No	2		<3000 People	6
gen\pc use\comfortable	Agree a lot	1	gen\average income level of area	High	1
	Agree a little	2		Medium	2
	Disagree a little	3		Low	3
	Disagree a lot	4			

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