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Abstract

This paper combines data from a government programme providing broadband access to primary schools in Ireland with survey microdata on schools', teachers' and pupils use of the internet to examine the links between public subsidies, classroom use of the internet and educational performance. Provision of broadband service under a government scheme was associated with more than a doubling of teachers' use of the internet in class after about a two year lag. Better computing facilities in schools were also associated with higher internet use, but advertised download speed was not statistically significant. A second set of models show that use of the internet in class was associated with significantly higher average mathematics scores on standardised tests. There was also a less robust positive association with reading scores. A set of confounding factors is included, with results broadly in line with previous literature.

Key words: internet use, primary education, academic performance
JEL codes: H52, L86

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1. Introduction

The connection of schools and other educational institutions to the internet and, more recently, specifically to the broadband network continues to be high on the agenda of politicians and policymakers around the world. This paper combines data from a government programme providing broadband access to primary schools in Ireland with survey microdata on schools', teachers' and pupils' use of the internet. In a fortunate coincidence, the implementation of Ireland's "Broadband for Schools" programme overlapped with the collection of data on a large sample of primary school children. We exploit this coincidence to examine the links between public subsidies, classroom use of the internet and educational performance. Having access to matched microdata on the timing and quality of schools broadband connectivity and on many likely influences on students' educational outcomes allows us to control for many confounding factors. However, we do not have control of the "experiment" on which the study is based, so we cannot make strong causal claims.

The next section of the paper considers why broadband access might affect educational outcomes and briefly reviews some of the existing evidence on use of the internet in schools and its association with student academic performance. Section 3 sets out our methodological approach and the data we use, Section 4 gives our results and the last section sets out some conclusions.

1. Evidence on access to the internet in schools and the effects of internet use on student performance

1.1 The policy background

The European Commission has adopted a range of policies that aim to promote the adoption of broadband technology; the *e*Europe Action Plan stated that by the end of 2005 all member states should have all schools and universities connected to the broadband network (Underwood *et al*., 2005). In 2005 the *e*Europe Action Plan was replaced by the i2010 Strategy, which in turn was replaced by the Digital Agenda in 2010. Through its "TeLearn" project (European Commission, 2012) the European Commission is researching ways in which communication and information technologies can be used to enhance teaching and learning.

In 2004, Ireland's Department of Education and Science and the Department of Communications, Marine and Natural Resources jointly launched the Broadband for Schools Programme. This project, which was jointly funded by the government and the telecommunications sector, aimed to ensure that every primary and secondary school in Ireland had access to broadband technology by the end of 2005. Government ministers at the time stressed the positive role broadband would play in education; that it would "significantly enhance the potential of ICT in teaching and learning" and would "pay dividends in years to come" (DCMNR, 2004). The contracts for delivering broadband to schools were in place by mid-2005 which ensured that 841 schools would be connected to the broadband network via DSL (fixed line), 1507 by wireless and 1577 by satellite technology (DCMNR, 2005). The cost of the programme, including set-up and running costs for about three years, was about €30 million (Department of Education and Science, 2008).

The role of ICT in education was also emphasised by the report of the Next Generation Broadband Taskforce published by the Department of Communications, Energy and Natural Resources (DCENR, 2012a), which recommended that the government continue to invest in broadband for schools and that "digital skills should be a fundamental part of the school curriculum".

Political support for the use of ICT, and specifically for broadband access in the classroom, is based on a view that, through numerous channels, it will have a positive effect on student outcomes. The UK's Broadband Stakeholders Group (BSG, 2001) highlight five channels through which they believe broadband can positively impact education. The first is by "enhancing the learning experience"; allowing schools to access innovative educational content, which would not be accessible through a narrower bandwidth, should motivate students' desire to learn. Evidence of the positive impact of ICT on students' motivation is provided by Passey *et al.* (2003), who conducted case studies of the use of ICT in schools; the authors do note, however, that the way in which ICT was used affected pupils' motivation. The second channel is through improved cooperation between educational institutions; for example, videoconferencing can be used in order to share scarce teacher resources. The third channel is by delivering "new potentialities", by which the BSG are referring to innovations on a larger scale such as using the internet in language classes to connect with native speakers. The fourth channel is by improving efficiencies from an administrative point of view; enabling schools to streamline reporting, collation of performance data and other administrative tasks. The fifth and final channel proposed by the BSG is "widening access to education"; the report refers specifically to the ability of broadband to widen access to educational material from external sources such as libraries and museums, and also to widen access in a geographical sense.

Similar themes are mentioned in the US context. The National Broadband Plan (FCC, 2010) outlines the role that ICT can play in broadening the array of material available to students, facilitating teaching that is increasingly tailored to students' individual needs. The National Broadband Plan also notes that barriers, such as a lack of adequate infrastructure, may prevent schools from successfully embracing online learning. Such benefits are also mentioned in the European Commission's Digital Agenda, with a further emphasis placed on the ability of ICT to promote pupil engagement in science, technology and mathematics. The ability of online materials to accommodate different learning styles is frequently cited as a benefit.
Despite the near consensus among policymakers internationally in favour of extending the use of the internet and other forms of ICT in schools, the empirical evidence is not one-sided. Indeed, Livingstone (2012) notes that the lack of conclusive evidence of the positive effects of ICT on education may provide an explanation as to why schools have been reluctant to change traditional teaching practices to accommodate new technologies. In the next sub-section we review some of the existing evidence.

1.2 Empirical evidence

Early studies of the effects of ICT on educational outcomes found mixed evidence, and many suffered from serious methodological shortcomings, e.g. small sample sizes, failing to control for important confounding factors or lacking a control group (Kirkpatrick and Cuban, 1998). More recently, studies have been carried out using more robust approaches to account for omitted variables and possible endogeneity; these have measured the effect of ICT on education by using methods such as randomized control trials or natural experiments exploiting rule changes and discontinuity in rules. A great deal of research has been carried out on ICT effects, and although the findings are extremely varied and dependent upon specific circumstances of programmes and affected groups, there is evidence of that these investments can have a positive effect. A second-level meta analysis by Tamim *et al.* (2011) finds statistically significant low to moderate positive mean effects of ICT on achievement, using a dataset made up of 25 meta analyses that refer to 1,055 primary studies.

Of course, while ICT generally may have benefits for teaching and learning, that does not mean every possible ICT investment is worthwhile. In this paper we focus on broadband connectivity: a technology that is currently being highlighted by policymakers and which is receiving significant investment in many countries. For broadband use *per se*, the evidence of positive effects on educational outcomes remains equivocal.

Goolsbee and Guryan (2006) looked at the effect of the E-Rate programme on internet connectivity and student outcomes in California public schools. The E-Rate programme provides subsidies to schools and libraries to gain access to internet and communication technologies; the subsidies range from 20%-90% of the cost depending on the characteristics of the school. The authors used a regression discontinuity design (RDD) to examine the effects of the subsidy on the level of internet connectivity for schools which were just above and just below the cut-off point for the subsidy, and OLS regression to test the effect of subsidies on ICT investment, and the effect of this investment on student performance,[1] in all schools in the dataset. The authors found that while the subsidies led to a strong and statistically significant increase in the number of schools with internet access, this did not lead to an increase in pupil performance.

A more recent study by Belo *et al.* (2011) looked specifically at the effects of broadband access on educational outcomes. Following a 2004 initiative by the Portuguese government to connect all schools to the broadband network, the authors used distance between the school and the broadband provider's central office as an instrument for broadband connection quality (and thus quantity of broadband used) and found that the effects of internet usage on educational outcomes were negative for both male and female pupils. Furthermore they found that the negative effect was stronger in schools where pupils were allowed to access websites such as YouTube. However, they did find that the effect was stronger in the 2005-2008 period compared to the 2005-2009 period which, the authors note, may indicate that the negative effects fade over time. Where empirical evidence suggests a negative effect of technology on educational outcomes (as opposed to ineffectivness), this raises the question of whether ICT-aided educational techniques are less effective than traditional teaching methods or whether, as suggested by Underwood *et al.* (2005), the traditional assessment techniques in use are unable to capture the progress made by ICT use in the classroom.

Some studies have shown more positive (or at least mixed) results, however. Underwood *et al.* (2005) found that broadband access had a positive impact on the

[1] Performance was measured by standardised test scores; the percentage of pupils taking more advanced courses; the proportion of pupils progressing to a system with higher standards; and the drop-out rate

examination outcomes of second-level pupils but that for primary school pupils ("Key Stage 2") there was no effect. Sprietsma (2012) examines the effect of computer and internet usage, and the availability of designated computer labs, on the test scores of 15-year-old students in Brazil, using a pseudo-panel approach. Results from this analysis found that use of the internet *by the teacher* had a positive impact on test scores in both reading and maths, and use of a computer by students had a positive effect on maths scores only. Conversely, access to a computer lab had a significant, negative effect on test scores in both subjects; the author hypothesises that this may be due limited resources, and thus investing in a computer lab means that investments in other resources cannot be made.

To our knowledge, the associations between broadband provision, classroom internet use and educational performance of primary school children have not been studied in Ireland before. There is evidence that home use of computers and some internet applications in Ireland are associated positively with primary school test scores. Casey *et al*. (2012) find that moderate use of computers by children in the home had a significant positive association with mathematics and reading test performance. This paper also examined this association at the level of particular computer applications and found that some were positive and others negative. Computer use in class may also interact in complex ways with its use in the home: McCoy, *et al.* (2012a) find that primary school students with internet access in school tend to use ICT more outside school, particularly for social networking purposes. This group of students also achieved among the highest scores for reading and mathematics, suggesting the use of ICT reinforces literacy and other skills.

2. Methodology and data

This section first sets out our approach to the analysis and then discusses the data employed.

2.1 Analytic Strategy

Ultimately, we are interested in whether the BFS programme led to improved educational outcomes. Connection of a school to the internet should not, of itself, have any direct effect on educational outcomes. Instead, the introduction of better internet access may affect teaching practices and other school activities, and through these channels have an impact on the educational performance of pupils. A range of complementary infrastructures are likely to be essential intermediating factors, e.g. availability of computers in the school or classroom through which the internet may be used, rules or filtering software governing its use, and the way in which teachers use the internet in the classroom. An additional complementary factor is whether or not computer usage in the classroom promotes computer usage in the home, dependent on economic factors.

Due to data limitations, we cannot model the chain of causation explicitly. Only cross-sectional information is currently available on pupil characteristics and outcomes (although this will change when the next wave of GUI becomes available) and we do not know whether individual schools had broadband access *per se*, just when they received service under the BFS programme. Schools may have purchased broadband service outside the programme or might have taken it up if the programme did not exist.

Nevertheless, we can cast some light on one channel that we think might be important, the association between BFS and internet use in the classroom, and try to control for as many other possible confounding factors. Although we will not be able to prove causation with the data available, we can see whether the data are consistent with two hypotheses:

> H1: Ireland's Broadband for Schools Programme helped increase use of the internet in primary school classrooms.
> H2: Use of the internet in class led to better educational performance for children in Ireland's primary schools.

If significant associations are found, this should help indicate directions for future research.

To examine H1, we estimate a regression model of whether the internet was used in each classroom in the GUI study.[2] We express the use of the internet in class or not as a 1/0 variable (*U*) and use a logit estimator. This regression is estimated at the classroom level, as summarised in Equation 1 below (coefficients omitted for brevity):

$$\Pr\left(U_i = 1\right) = f\left(\alpha + \mathbf{A}_j + \mathbf{E}_j + \mathbf{S}_j + \mathbf{F}_j + \mathbf{D}_j + \mathbf{B}_i + T_i + \varepsilon_i\right) \qquad (1)$$

where f is the cumulative logistic function and teacher *i* is in school *j*. Vectors of explanatory variables are included for the time elapsed since the Broadband for Schools programme was made available to the school (A), the nature of service supplied (E), advertised download speed of service (S), other complementary facilities such as computers in the school and classroom (F), demographics of the area served by the school (D), the teacher's experience and teaching style (B) and a proxy for how early in the GUI study the teacher was surveyed (*T*). ε is an error term.

Two separate econometric models are estimated to test H2 using both OLS and two stage least squares (2SLS) estimators. These are estimated at child level and the dependent variables are measures of children's performance on standardised reading and mathematics tests given to nine year-olds. The OLS specification is summarised in Equation 2 below:

$$P_k = \alpha + \mathbf{S}_j + \mathbf{F}_j + \mathbf{D}_j + \mathbf{B}_i + \mathbf{G}_k + \mathbf{A}_k + \mathbf{E}_k + \mathbf{C}_k + \mathbf{H}_k + Y_k + T_k + \varepsilon_k \qquad (2)$$

where teacher *i* is in school *j*. *P* represents either reading or maths test performance, depending on the model being estimated. Vectors of explanatory variables are included for advertised download speed of Broadband for Schools service (S), other complementary facilities such as computers in the school and classroom (F), demographics of the area served by the school (D), the teacher's experience and teaching style (B), study child gender (G), indicators of the child's home activity profile (A), parents' levels of educational attainment (E), household social class (C), indicators of the child's health (H), family income (*Y*) and a proxy for how early in the GUI study the child's household was surveyed (*T*). ε is again an error term.

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[2] All regressions were estimated using Stata® v.12.

An alternative 2SLS estimation is performed on each of these models to try to assess their robustness. One concern we have in estimating these models with OLS is that there might well be unobserved factors affecting both a teacher's propensity to use the internet in class and a pupil's results on standardised tests. In other words, the use of the internet in class may not be exogenous in the reading and maths test models. In an attempt to allow for this possibility, we use the predicted probability of a child's teacher using the internet in class (taken from the stage 1 model) in place of the actual use variable. The time since enabling of BFS and a dummy variable for schools that were not enabled by the time they were surveyed act as instrumental variables in these models.

Details of the variables used are provided in the next sub-section.

2.2 Data

This paper uses data from the newly-extended Research Microdata File for the nine year-old cohort of the Growing Up in Ireland national longitudinal study of children (GUI).[3] Only the first wave of the study is currently available, so the file is cross-sectional in structure. In addition, a set of variables has been added to GUI indicating when participants' schools received broadband service under the Irish government's Broadband for Schools programme and some details about the nature of services received (i.e. advertised download speed and technology used to supply broadband for each school). This additional information was provided by the Department for Education and Skills. Further details of the GUI study, with specific reference to research about influences on learning, are given in McCoy *et al.* (2012a, b).

In this section we discuss the variables included in our models, starting with the dependent variables (use of the internet in the classroom and educational test scores).

2.2.1 Use of the Internet in the Classroom

The Teacher's questionnaire includes a yes/no question on use of the internet: "Do the children in the study child's class use a computer to access the internet?" For 56.9% of study teachers, the answer was yes, for the remainder it was no. We use the answer to this question as a dependent variable when we estimate Equation 1 and an explanatory variable in the other models.

2.2.2 Educational Test Scores

We estimate two models based on Equation 2: one explaining pupils' mathematics test scores and the other explaining reading scores. We use the logit scores for the vocabulary component of the *Drumcondra Primary Reading Test - Revised* and part 1 of the *Drumcondra Primary Mathematics Test - Revised*, which were collected as part of the Growing Up in Ireland Study. Further details of these variables are given in Casey, *et al.* (2012).

[3] © Department of Health and Children

2.2.3 Data on the Broadband for Schools Programme

Our main interest in estimating Equation 1 is whether the Broadband for Schools Programme was associated with increased or accelerated adoption of the internet in classrooms. We can look at this because we know the timing of programme implementation relative to the timing of the survey. Figure 1 compares the time pattern of broadband installation under Broadband for Schools (bars with dark shading) with the time pattern of surveying in the GUI study (light shading). There is a small overlap between the survey period and installation period, but most of the variation in our sample comes from the lag since installation experienced by different schools. Although our data only capture when each child's household questionnaire was completed, not the teacher's questionnaire, we construct a proxy for when the teacher was surveyed by assigning each teacher the earliest survey date reported for any of his or her students. Because teachers' surveys were distributed ahead of those of their students, we consider that this to be a reasonable proxy for when teachers' surveys might have been completed.

Figure 2 shows how this lag is distributed. Almost 80% of classrooms in our sample were in schools that received BFS service at least 800 days before the GUI survey was administered to their teachers. 37 classes were in schools that did not receive service under the scheme, either at all or by the time they were surveyed. Observations where no service was received are shown with a zero value.

We have no prior expectation about how time elapsed since service provision might affect school practices or outcomes, so we try two functional forms. The first approach includes a continuous variable for the time lag since installation, implying that this factor has a linear effect. The other treats the time lag as categorical, allowing for a more flexible relationship. Categories are chosen to allow a broadly similar number of samples in each category: 1-599 days, 600-699 days, 700-799 days, and 800+ days. Both approaches include a dummy variable for being in a school that did not receive service under the scheme.

This set of explanatory variables is included only in the internet use models; we have no reason to think that broadband provision *per se* should affect academic performance of children; its effects on such outcomes should be indirect as an enabling technology facilitating the use of computers and the internet.

2.2.4 Other Control Variables Included in Both the Internet Use and Academic Performance Models

The advertised broadband download speed for the service provided to each school by the BFS (for those that received service) is available as a categorical variable. There are many categories in the original dataset, some of which overlap. We have aggregated them into the following set: '<=0.5 MBit/s', '<=1 MBit/s', '<=2 MBit/s', '<=3 MBit/s', '<=5 MBit/s', and 'other'. The '<=5 MBit/s' category includes 'Up to 4 MBit/s', and 'Up to 5 MBit/s', while the 'other' category includes '>2 MBit/s' and '> 8MBit/s'. Each of the remaining categories are made up of two bands from the original dataset: one giving an exact estimate of the speed and the other having an upper bound at the same point; for example, our '<=2 MBit/s' band includes the original categories '2 Mbit/s' and 'Up to 2 Mbit/s'. We have no information on the extent to which the advertised speed is reflected in actual speed for each school.

We also know what technology was used to deliver broadband to each school in the scheme. This may capture some unobserved element of service quality. We have consolidated the original data into three categories:

- Fixed line: fixed line broadband connections delivered using existing copper local phone circuits (digital subscriber lines or unbundled local loops) and partial private circuits (leased lines). This incorporates five categories from the original dataset: ‘dsl’, ‘ull’, ‘ppc’, ‘DSL WAS SAT’ and ‘Pure ULL’.
- Wireless: Fixed wireless broadband service where data is transmitted to fixed locations over a terrestrial radio network.
- Satellite: Fixed wireless broadband service where data is transmitted to fixed locations over a satellite-based radio network.
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The extent of complementary facilities is accessible through four variables. We can compute the number of computers per pupil in the school using two fields in the principal’s questionnaire: the number of computers available to pupils and the number of pupils. Also on that questionnaire, there is a subjective categorical statement about the quality of computer facilities in the school, coded as ‘poor’, ‘fair’, ‘good’ or ‘excellent’. From the Principal’s questionnaire we know whether there is a computer room in the school, and from the Teacher’s questionnaire we know whether computers were available in the classroom. Better quality facilities should be associated with more extensive use of the internet (although the causation may run both ways) and could lead to improved academic performance if the facilities offer significant benefits for teaching and learning processes.

In line with previous research, we include a proxy for the social mix in each school. The Delivery of Equality of Opportunity in Schools (DEIS) programme provides additional supports to about 21% of Irish primary schools that are deemed to experience high concentrations of disadvantage. Schools are selected for the programme based on a set of indicators including local unemployment rates, the prevalence of public housing, and the share of children eligible for the free book grants scheme. We use a four level DEIS status indicator, which distinguishes between Urban band 1 (most disadvantaged), Urban band 2 (disadvantaged), Rural DEIS (disadvantaged) and a fourth category denoting ‘Not disadvantaged’. There are at least two channels of influence that might be important for this factor in the present study. DEIS Urban Band 1 and Rural DEIS schools seem to use computers more often in class than other schools (McCoy *et al.,*2012b), and past research has shown that pupils in disadvantaged (particularly urban DEIS) schools tend to suffer reduced performance on standardised tests (McCoy *et al.*, 2010).

We include controls for the number of years’ teaching experience possessed by each study child’s teacher and the active teaching index introduced in McCoy *et al*. (2012b). It is possible that more experienced teachers are more or less likely to introduce innovative technologies and associated teaching methods, so this factor could have either a positive or negative partial effect in the internet use models. Teacher experience is expected to have a positive effect on test performance. Similarly, use of active teaching methods (e.g. hands-on activities, pair work and group work) might have a direct effect on outcomes inasmuch as it leads to greater engagement and more effective learning by pupils, but we also want to rule it out as a possible confounding factor for the effects of internet use. It may be that teachers adopting active teaching methods are also more open to using the internet in class, so omitting this factor could lead to bias on the internet use coefficient in the academic performance models.

Finally, we include a time index (in days) for the time elapsed between the date a given observation was surveyed and the date the earliest survey was completed (i.e. the earliest completion date =1), allowing us to control for unobserved effects that might vary with calendar time. When we are estimating the probability of classroom internet use this variable is based on the earliest survey completion in a given classroom; in the models of exam performance it is based on when each child's household was surveyed.

2.2.5 Other Control Variables – Academic Performance Models only

A range of child-level characteristics are included, again drawn from previous research into the determinants of children's educational performance. These include the child's gender, a dummy variable for chronic illness or disability as reported by the mother and a dummy variable for learning disability as reported by the class teacher. Children with learning disabilities or chronic health problems are likely to have lower test scores on average. Parental education is often found to have an important (positive) influence on educational performance, so we include categorical variables for the highest level of education attained by the primary carer (almost invariably the mother) and the secondary carer (father). The categories are lower secondary, higher secondary, post secondary and third level (the reference category). For fathers we also include categories for 'no secondary carer' and 'not reported'. A categorical variable for the social class of the study child's household and the log of equivalised net household income are also included, in the expectation that higher social class and income will be associated with higher average test performance.

There is evidence that a child's profile of activities undertaken out of school may affect educational performance. McCoy *et al.* (2012a) carry out a cluster analysis of Irish children's out-of-school activities, and we include the five clusters identified in their paper as explanatory variables here to allow for possible confounding effects from this source. McCoy *et al.* refer to these clusters as 'TV and sports', 'social networkers', 'sports and computer games', 'cultural activities' and 'busy lives', although obviously such shorthand descriptions provide only an indicative sense of the activities undertaken and more detail is given in the paper.

Table 1 lists the sample shares for each of the categorical variables discussed above and Table 2 shows sample means for the continuous variables.

3. Results

We first discuss the results for use of the internet in the classroom, followed by those for pupils' reading and mathematics test performance.

4.1 Modelling the Effect of the Broadband for Schools Programme on Use of the Internet in Class

We first estimated two logit regressions with a dependent variable indicating whether the internet was used in class or not. The first model includes a linear variable for the number of days since service was provided under the BFS programme. The other uses a categorical representation of this variable.

The time since BFS service was provided had a positive and significant association with internet use in the linear model. Using the categorical form of this variable, coefficients suggest a positive association but it is only significant in the case of classrooms that received service at least 800 days before they were surveyed (relative to the reference case where service was provided 1-599 days ago). Such classrooms were over twice as likely to use broadband as those in the reference group. There was also a marginally significant negative association for cases where broadband was not provided under the programme by the time they were surveyed. This result is consistent with the hypothesis that BFS encouraged classroom internet use, but implies that it took about two years to have a measurable impact in the average school. It is plausible that incorporating use of the internet in classroom activities would take time, e.g. for adaptation of lesson plans, acquisition of complementary equipment, etc.

Indeed, as expected we also found strong positive associations between some relevant facilities and classroom internet use. Having computers available in the classroom or (to a lesser extent) a computer room in the school had large and significant effects. Teachers in schools where principals reported that computer facilities were fair rather than good were much less likely to use the internet in class.

Other possible factors, including download speed, BFS technology, computers per pupil, teacher experience, the active teaching index and DEIS status were not statistically significant in these models.

4.2 Modelling the Effect of Internet Use in Class on Students' Reading Test Performance

Table 4 shows results for OLS and 2SLS models of children's reading test results. Being in a classroom where the internet is used was associated with about a marginally significant 0.06 points higher reading test logit score in the OLS version, but this variable is not significant in the 2SLS version.

It is not immediately obvious which of these coefficients is more reliable. Although the 2SLS model tries to correct for potential endogeneity of internet use in class, the instruments employed are likely to be rather weak for reasons discussed earlier. There is also a question as to whether this variable is in fact endogenous and thus whether a 2SLS estimator is necessary. We estimated a simpler model assuming linearity at both stages of the 2SLS and tested for exogeneity of internet use;[4] this was not rejected.

[4] The endog option in Stata's ivreg2 command was employed. This test is based on the difference between the Sargan-Hansen statistics for the equation estimate with an without the regressor being treated as endogenous.

Many other factors were significant in these models, with most results following the expected pattern. Positive associations were found for children with a more highly educated primary or secondary carer and those from a household with a higher social class or higher income. Negative associations were found for those with an intellectual disability or attending urban schools classified as disadvantaged.

We found similar results for out of school activities as those reported in McCoy *et al.* (2012a): children assigned to the clusters styled 'social networkers', 'sports and computer games' and 'cultural activities' had higher average scores than the reference group 'TV and sports'. Separately, we tested whether there might be an interaction between the effect of classroom internet use on academic performance and that of out of school activity variables or an alternative variable capturing the intensity of ICT outside school. For example, using the internet at school might prime children to use it more effectively at home, or vice versa. Taking the variables for out of school activities or home internet use in and out of the model has little impact on the classroom internet use coefficients (detailed results available on request from the authors).

We found little evidence that the broadband speed or principal-reported quality of school computer facilities had a direct effect on reading test results. Other insignificant factors included the child having a chronic illness or disability (although this was negative and marginally significant in the 2SLS version), the density of computers in the school, reported frequency of computer use in class, teacher experience and the active teaching index. The time index shows a very small negative trend during the sample period.

4.3 Modelling the Effect of Internet Use in Class on Students' Maths Test Performance

In Table 5, we turn to the models of mathematics test results. The OLS results are qualitatively similar to those for reading tests, but there are some interesting differences. Internet use in class is again positive but in this case is highly significant, associated with 0.12 points higher maths test logit scores. However, in contrast to the reading test model, this coefficient remains positive and marginally significant when we use a 2SLS estimator for maths test results. Indeed, the absolute magnitude of the internet in class coefficient is larger (0.28) when instrumental variables are employed.

We find no significant effects from broadband speed, frequency of computer use in class, quality of school computing facilities, computers/pupil, or the active teaching index.

Being in an Urban Band 1 disadvantaged school had a negative association with maths results, but Urban Band 2 was not significant (in contrast to the reading models where it was). Two other differences from the reading models is that teacher experience and being male had positive and significant associations with mathematics test scores, whereas having a chronic illness or disability has a highly significant negative association in this case.

Again, intellectual disability, social class, income, parental education and activity clusters had the expected associations with maths test results. The time index again shows a very small negative trend during the sample period.

4.4 Another exogeneity check: did schools in better- or worse-off areas get BFS service first?

An additional potential source of endogeneity might be that schools prone to better academic performance (e.g. those in better off areas or with a stronger set of internal institutions) might have been able to gain earlier access to the Broadband for Schools programme. Although we included controls for disadvantaged schools in all models, some of this variation might still be omitted and be picked up erroneously by the coefficients on the Broadband for Schools variables.

As a cross-check, we estimated models of the time it took for schools to be given service under BFS, including only those schools (most) that were served within the sample period. Both OLS and count data (negative binomial) estimators were used. We found no evidence that region or social class mix of the local area systematically affected whether schools received service earlier. Urban DEIS Band 2 schools received service about 6-7 weeks earlier on average than non-disadvantaged schools, but other disadvantaged schools did not. Larger schools had service for slightly longer: on average, having 100 more pupils in a school was associated with getting service about 8-9 days earlier. This might suggest larger schools are slightly better placed to manage the liaison with suppliers during the installation process, perhaps because they are more likely to have designated ICT coordinators. The detailed results are available on request from the authors.

4. Discussion and Conclusions

BFS provision was associated with more than a doubling in the average teacher's probability of using the internet in class after about a two year lag. Not surprisingly, having better computer-related facilities in a school also showed a positive relationship with internet use. However, advertised connection speed showed no significant effects.

Given that we have only cross-sectional survey data and some important variables are omitted, we cannot conclude with certainty that the BFS programme caused higher internet adoption. In particular, the lack of information on whether individual schools had broadband access (apart from BFS-provided services) is an important data gap. However, the direction, timing and scale of the effect seem consistent with the expectation that public supports for broadband supply to schools would lead to more use of the internet.

Our second set of models shows that use of the internet in class was associated with significantly higher average mathematics scores. There was also a smaller significant positive association with reading scores in the OLS specification, but significance was lost when 2SLS was employed. These models control for many factors thought to affect pupils' exam performances, and the observed associations with confounding factors such as income, social class, parental education, intellectual disability and out of school activities are broadly consistent with theory and previous research.

To get a sense of the size of these effects, note that the internet use coefficient in the OLS mathematics model is similar to the partial effect of a child's mother having completed a third level education rather than upper secondary.

The existence and strength of this association suggests that further research to establish causation and to further explore the mechanisms through which school broadband subsidies affect outcomes might be worthwhile. We found no evidence for Ireland of the negative effects of broadband in schools reported by Belo *et al.* (2011) for Portugal, which might be due to different limits placed on internet use or the sites to which access is typically permitted in the two cases. In Ireland the filtering system in place can mean that only a limited number of websites can be accessed via the school's internet connection; access restrictions are dependent on the level of filtering for which schools have signed up.[5] The data available to us does not permit deeper investigation of this dimension. Our findings also contrast with the insignificant effects observed by Underwood *et al.* (2005) in UK primary schools.

Our work suffers by some limitations that could be addressed in future with better data. One inevitable concern in this sort of research is possible omitted variables. For example, maybe the most advanced teachers are more effective than their peers in a range of domains but also use the internet more. Perhaps richer schools (or schools in richer areas, with more scope for fund raising) adopted the internet earlier outside BFS and thus gained an advantage not captured in our data. We tried to control for both of these phenomena, but it is hard to be certain that no relevant unobserved heterogeneity remains.

Fortunately, there is potential for future research. One obvious extension would be to examine the speed and nature of internet adoption in classrooms following enabling of broadband or supply of complementary infrastructure in individual schools. In addition, the next wave of the GUI study covers the same pupils at age 13, so longitudinal analysis and examination of broadband use early in the secondary school years should be possible. In 2012 the Irish government announced it was to ensure that all secondary schools would be connected to high speed broadband (100Mbps) by 2014 (DCENR, 2012b). The capital costs of this project, estimated to be in the order of €11 million, will be funded by the Department of Communications, Energy and Natural Resources who will also provide funding to cover current costs up to €10 million for the years 2013-2015; the remainder of the current costs up to 2015 are expected to be approximately €20 million, and will be funded by the Department of Education and Skills (Department of Education and Skills, 2012). With suitable access to data, these investments might be evaluated and help provide guidance to future policymakers.

[5] http://www.ncte.ie/Technology/SchoolsBroadband/FAQs/#Q15

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Figure 1: Sample frequency distributions of dates that survey was administered and broadband was supplied under the BFS scheme (unit of analysis: classrooms)

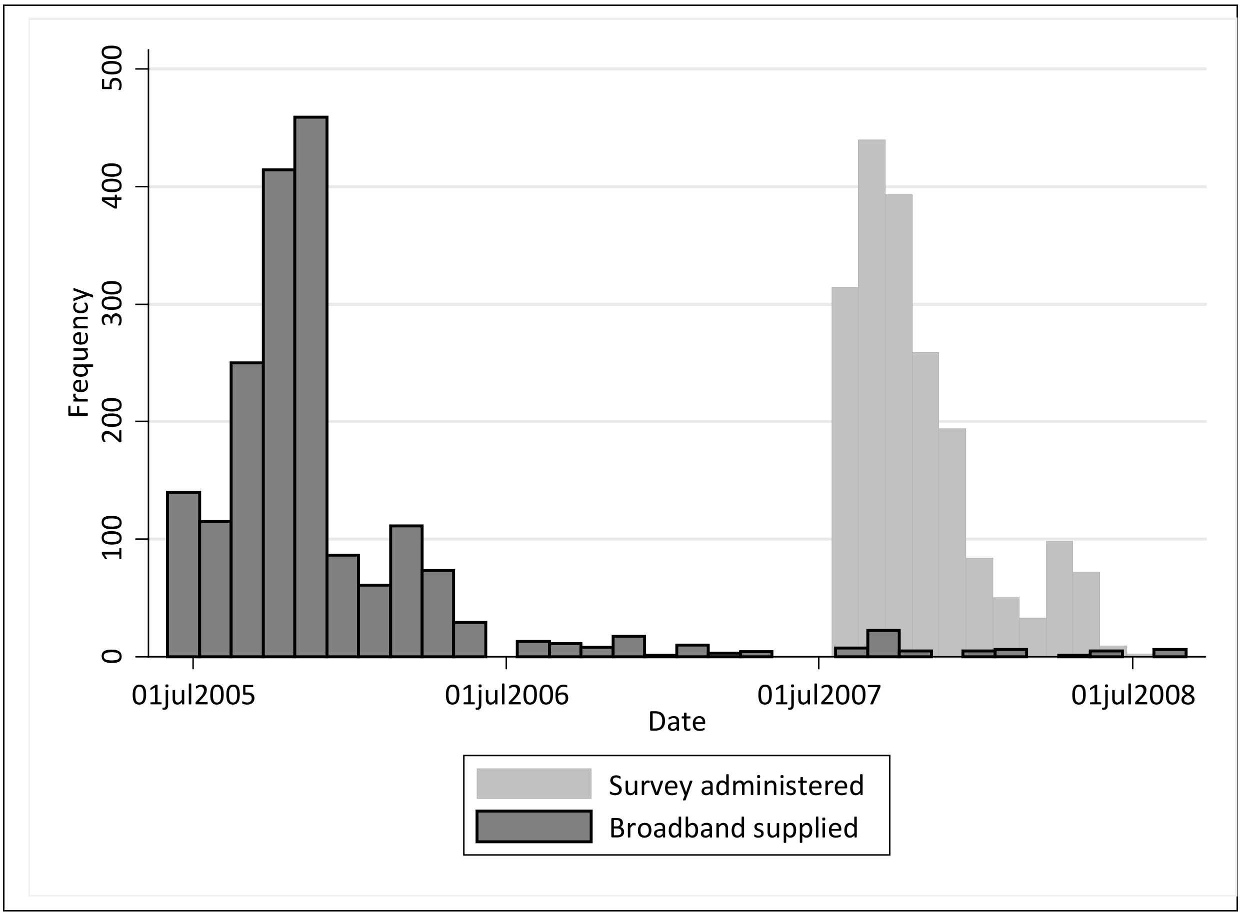

Figure 2: Sample frequency distribution of time between broadband installation and survey completion (unit of analysis: classrooms)

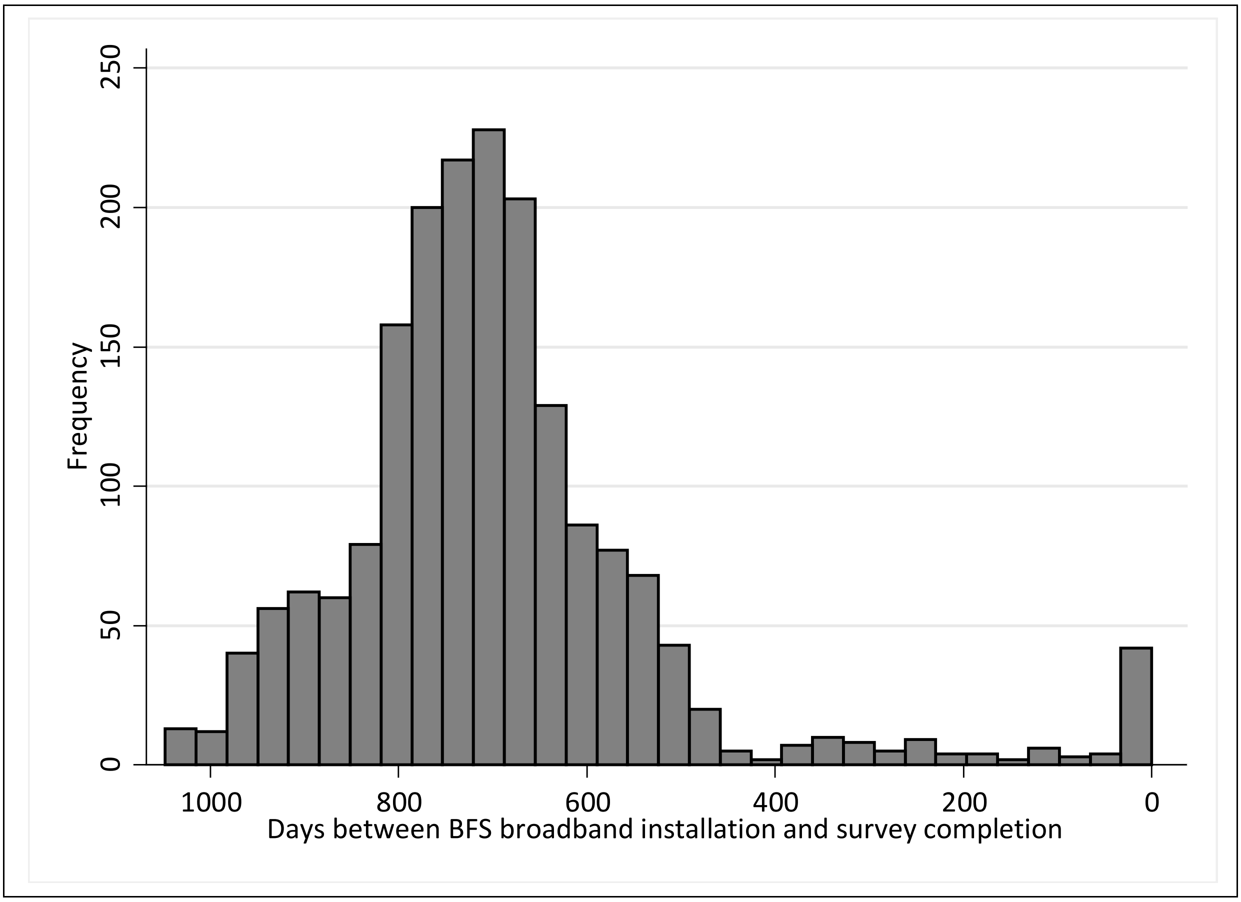

Table 1: Survey shares for categorical variables (survey weights applied at each level)

	Sample share (%)
SCHOOL LEVEL(s) & TEACHER LEVEL(t)	
BFS broadband installed[t]	
No broadband under BFS	2.15
1-599 days before survey	16.2
600-699 days before survey	25.7
700-799 days before survey	34.8
800+ days before survey	21.3
BFS technology[s]	
Fixed line	25.5
Satellite broadband	41.0
Wireless broadband	31.3
Broadband speed[s]	
<=0.5 MBit/s	32.3
<=1 MBit/s	24.2
<=2 MBit/s	25.1
<=3 MBit/s	5.86
<=5 MBit/s	8.97
Other	1.44
School computer facilities[s]	
poor	15.4
fair	31.3
good	37.8
excellent	15.5
Computer/internet use & availability	
Computer room in school[s]	39.7
Internet used in class[t]	56.9
Computers available in class[t]	81.5
School DEIS status[s]	
Urban band 1	6.59
Urban band 2	5.32
Rural DEIS	6.71
Non-disadvantaged	81.4

	Sample share (%)
CHILD LEVEL	
Gender of children	
Male	49.1
Female	50.9
Activity clusters of children	
Busy lives	14.4
Social networkers	16.3
TV and sports	26.7
Sports and computer games	21.5
Cultural activities	21.2
Mother's Education	
Lower secondary	30.3
Higher secondary	36.4
Post secondary	15.7
Third level	17.6
Father's Education	
Lower secondary	26.3
Higher secondary	22.2
Post secondary	11.4
Third level	16.3
No secondary carer	18.5
Not reported	5.4
Social Class of Household	
Professional managers	8.32
Managerial & technical	33.1
Non manual	19.0
Skilled manual	16.3
Semi skilled	9.24
Unskilled	1.76
Unclassified	12.3
Learning disability	10.6
Chronic illness or disability	10.9

Table 2: Mean values of continuous variables in survey (survey weights applied at each level)

		Mean
School level	Days since broadband provided under BFS	671
	Computers/pupil in school	0.105
Teacher level	Teaching experience of teacher (years)	12.7
	Active teaching index of teacher	2.74
	Time index of survey, teacher level (days)	100
Child level	Time index of survey, child level (days)	117
	Reading test logit score	0.00708
	Maths test logit score	-0.764
	Equivalised household annual income (€)	19,008

Table 3: Results from logit regressions on internet use in the classroom for teachers in the GUI dataset

DV: "Do the children in the study child's class use a computer to access the internet?" [1/0]	Linear BFS effect model		Categorical BFS effect model	
Variables	Odds ratio	S.E.	Odds ratio	S.E.
Days since broadband provided under BFS	1.00196	0.000611***		
No broadband under BFS	1.125	0.785	0.335	0.198*
BFS broadband inst. 1-599 days ago			REF	
BFS broadband inst. 600-699 days ago			1.0936	0.229
BFS broadband inst. 700-799 days ago			1.143	0.23
BFS broadband inst. 800+ days ago			2.31	0.652***
BFS provided DSL or ULL broadband	0.840	0.219	0.659	0.186
BFS provided satellite broadband	1.0788	0.258	0.988	0.243
BFS provided wireless broadband	REF		REF	
Broadband speed <=0.5 MBit/s	REF		REF	
Broadband speed <=1 MBit/s	1.224	0.345	1.155	0.336
Broadband speed <=2 MBit/s	1.0103	0.207	1.0989	0.227
Broadband speed <=3 MBit/s	1.354	0.478	1.573	0.563
Broadband speed <=5 MBit/s	1.276	0.458	1.543	0.569
Broadband speed other	1.831	1.29	2.06	1.37
Computers/pupil in school	5.10	6.5	7.06	9.12
School computer facilities: poor	0.741	0.155	0.76	0.158
School computer facilities: fair	0.653	0.111**	0.662	0.113**
School computer facilities: good	REF		REF	
School computer facilities: excellent	0.988	0.195	0.952	0.192
Computer room in school	1.466	0.236**	1.454	0.234**
Computers available in class	3.12	0.516***	3.16	0.523***
Constant	0.111	0.065	0.384	0.187**
Teacher experience	Not significant		Not significant	
Teacher active teaching index	Not significant		Not significant	
School DEIS status	Not significant		Not significant	
Time index of survey, teacher level	Not significant		Not significant	
N	1,430		1,430	
Pseudo R^2	0.0662		0.0661	
Hosmer & Lemeshow goodness of fit test	$X^2(1408)=1430$ [P=0.322]		$X^2(1406)=1425$ [P=0.356]	

Notes: Standard errors are robust to clustering at school level and survey weights are used, averaged at teacher level. REF = the reference category for each factor variable. The single, double and triple asterisks represent the 1%, 5%, and 10% levels of significance respectively.

Table 4: Results from regressions on reading test performance

DV: Reading test logit score	OLS model		2SLS model	
Variables	β	S.E.	β	S.E.
Internet used in class	0.0772	0.036**	-0.00506	0.172
Broadband speed <=0.5 MBit/s	REF		REF	
Broadband speed <=1 MBit/s	0.0719	0.0652	0.0786	0.0691
Broadband speed <=2 MBit/s	0.0114	0.0546	0.0153	0.0564
Broadband speed <=3 MBit/s	-0.0514	0.0876	-0.0397	0.0897
Broadband speed <=5 MBit/s	0.0662	0.0717	0.0783	0.0736
Broadband speed other	0.186	0.105*	0.119	0.136
Computers/pupil in school	-0.293	0.45	-0.401	0.492
School DEIS Urban Band 1	-0.175	0.0854**	-0.168	0.0881*
School DEIS Urban Band 2	-0.221	0.0715***	-0.213	0.0779***
School DEIS Rural DEIS	0.0385	0.107	0.0341	0.103
School non-disadvantaged	REF		REF	
Teacher experience	0.00235	0.00158	0.00208	0.00161
Teacher active teaching index	-0.0461	0.0331	-0.0493	0.0338
Activity cluster: busy lives	-0.0184	0.0467	-0.0138	0.0471
Activity cluster: social networkers	0.187	0.0475***	0.195	0.0479***
Activity cluster: TV and sports	REF		REF	
Activity cluster: sports and computer games	0.100	0.0436**	0.111	0.044**
Activity cluster: cultural activities	0.167	0.041***	0.184	0.042***
Boy	-0.0617	0.0313**	-0.0567	0.0317*
Girl	REF		REF	
Primary carer edu lower secondary	-0.376	0.0482***	-0.372	0.0489***
Primary carer edu higher secondary	-0.212	0.04***	-0.208	0.0405***
Primary carer edu post-secondary	-0.165	0.0455***	-0.174	0.0459***
Primary carer edu third level	REF		REF	
Second. carer edu lower secondary	-0.315	0.0503***	-0.302	0.0511***
Second. carer edu higher secondary	-0.118	0.0464**	-0.114	0.0473**
Second. carer edu post-secondary	-0.212	0.0497***	-0.194	0.0503***
Second. carer edu third level	REF		REF	
No Secondary carer	-0.188	0.065***	-0.156	0.0664**
Second. carer edu not reported	-0.316	0.0757***	-0.313	0.0784***
SC Professional workers	REF		REF	
SC Managerial & technical	-0.0279	0.0453	-0.0374	0.0462
SC Non-manual	-0.11	0.0538**	-0.137	0.0546**
SC Skilled manual	-0.21	0.0613***	-0.236	0.0627***
SC Semi skilled	-0.0639	0.0669	-0.0811	0.0679
SC Unskilled	-0.172	0.109	-0.161	0.116
SC Unclassified	-0.125	0.0884	-0.154	0.0902*
(Log) HH Net Equivalent Income	0.124	0.0373***	0.122	0.0376***
Intellectual disability	-1.04	0.0477***	-1.04	0.0478***
Chronic illness or disability	-0.0741	0.0487	-0.0818	0.0488*
Time index of survey, child level	-0.000507	0.000247**	-0.00045	0.00025*
Constant	-0.581	0.409	-0.493	0.403
Frequency of computer use in class	Not significant		Not significant	
Quality of school computer facilities	Not significant		Not significant	
N	5,720		5,591	
R^2	0.248		0.248	

Notes: Standard errors are robust to clustering at teacher level, and survey weights are used. REF = the reference category for each factor variable. The single, double and triple asterisks represent the 1%, 5%, and 10% levels of significance respectively.

Table 5: Results from regressions on mathematics test performance

DV: Maths test logit score	OLS model		2SLS model	
Variables	β	S.E.	β	S.E.
Internet used in class	0.134	0.0375***	0.280	0.169*
Broadband speed <=0.5 MBit/s	REF		REF	
Broadband speed <=1 MBit/s	-0.0171	0.0568	-0.0303	0.0615
Broadband speed <=2 MBit/s	0.0624	0.053	0.0499	0.0547
Broadband speed <=3 MBit/s	0.00411	0.0839	0.019	0.0828
Broadband speed <=5 MBit/s	-0.00177	0.072	-0.0213	0.0724
Broadband speed other	0.245	0.13*	0.119	0.143
Computers/pupil in school	0.0332	0.397	-0.334	0.404
School DEIS Urban Band 1	-0.150	0.0791*	-0.129	0.0775*
School DEIS Urban Band 2	-0.0590	0.0754	-0.0807	0.0801
School DEIS Rural DEIS	-0.0654	0.0823	-0.0741	0.0832
School non-disadvantaged	REF		REF	
Teacher experience	0.00425	0.00157***	0.00432	0.0016***
Teacher active teaching index	-0.0331	0.0353	-0.0366	0.0356
Activity cluster: busy lives	0.0353	0.0469	0.0507	0.0464
Activity cluster: social networkers	0.150	0.0439***	0.169	0.0445***
Activity cluster: TV and sports	REF		REF	
Activity cluster: sports and computer games	0.0657	0.0418	0.0857	0.0413**
Activity cluster: cultural activities	0.138	0.0403***	0.161	0.0407***
Boy	0.0677	0.0327**	0.0680	0.033**
Girl	REF		REF	
Primary carer edu lower secondary	-0.361	0.0492***	-0.351	0.0492***
Primary carer edu higher secondary	-0.117	0.0402***	-0.111	0.0406***
Primary carer edu post-secondary	-0.0773	0.0424*	-0.0828	0.0415**
Primary carer edu third level	REF		REF	
Second. carer edu lower secondary	-0.215	0.0489***	-0.211	0.0491***
Second. carer edu higher secondary	-0.0669	0.0455	-0.0694	0.0459
Second. carer edu post-secondary	-0.145	0.0515***	-0.136	0.0513***
Second. carer edu third level	REF		REF	
No Secondary carer	-0.204	0.0603***	-0.182	0.0612***
Second. carer edu not reported	-0.203	0.0698***	-0.224	0.0708***
SC Professional workers	REF		REF	
SC Managerial & technical	-0.0633	0.0474	-0.0684	0.0472
SC Non-manual	-0.114	0.0568**	-0.140	0.0569**
SC Skilled manual	-0.169	0.0626***	-0.188	0.0627***
SC Semi skilled	-0.181	0.0709**	-0.202	0.071***
SC Unskilled	-0.111	0.115	-0.111	0.119
SC Unclassified	-0.154	0.0822*	-0.192	0.0818**
(Log) HH Net Equivalent Income	0.0618	0.0333*	0.0517	0.0335
Intellectual disability	-0.838	0.0516***	-0.847	0.0532***
Chronic illness or disability	-0.0916	0.0472*	-0.11	0.0461**
Time index of survey, child level	-0.000280	0.000231	-0.000173	0.000237
Constant	-1.05	0.363***	-1.00	0.367***
Frequency of computer use in class	Not significant		Not significant	
Quality of school computer facilities	Not significant		Not significant	
N	5,779		5,648	
R^2	0.205		0.204	

Notes: Standard errors are robust to clustering at teacher level, and survey weights are used. REF = the reference category for each factor variable. The single, double and triple asterisks represent the 1%, 5%, and 10% levels of significance respectively.

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