Books or Laptops? The Cost-Effectiveness of Shifting from Printed to Digital Delivery of Educational Content[1]

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Abstract

Information and communication technologies, such as laptops, can be used for educational purposes as they provide users with computational tools, information storage and communication opportunities, but these devices may also pose as distractors that may tamper with the learning process. This paper presents results from a randomized controlled trial in which laptops replaced traditional textbook provision in elementary schools in high poverty communities in Honduras in 2013 through the program *Educatracho*. We show that at the end of one school year, the substitution of laptops for textbooks did not make a significant difference in student learning. We additionally conducted a cost-effectiveness analysis, which demonstrated that given the low marginal costs of digital textbook provision, the substitution of three additional textbooks in the program (for a total of five) would guarantee computers to be more cost-effective than textbooks. Therefore, textbook substitution by laptops may be a cost-effective manner to provide classroom learning content.

JEL codes: I21, I28, J24, O15

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Research Highlights:

- Options to access reading resources are increasingly shifting from print to electronic versions that can be viewed on digital devices, such as computers. In education in particular, research studies have shown that providing digital content on computers has lower marginal costs but higher fixed costs in comparison to textbooks for schools.
- Information and communication technologies (ICT), such as computers and laptops, provide users with computational tools, information storage and communication opportunities. However, these devices may also pose as distractors that tamper with the learning process.
- Using a randomized controlled trial in elementary schools in Honduras, we show that at the end of one school year, the substitution of laptops for textbooks did not make a significant difference in student learning.
- A cost-effectiveness analysis we conducted demonstrated that the substitution of three more textbooks would guarantee computers to be more cost-effective than textbooks. This suggests that textbook substitution with laptops may be a cost-effective manner to provide content information in elementary schools.

1.Introduction

Over the past 20 years, the use of technology to deliver education has increased in many regions of the world (World Bank, 2016). This is especially true in Latin America and the Caribbean. Thirty one countries in Latin America and the Caribbean had information and communication technology (ICT) policies implemented in schools by 2012 (UNESCO, 2012). Moreover, government and private providers have distributed about 10 million laptops to public schools (Arias-Ortiz and Cristia, 2014).

However, it is unclear the extent to which introducing computers or laptops into classrooms affects what students learn compared to traditional ways of teaching and learning. Some studies have shown that laptops may support teacher instruction by offering individualized instruction, providing learning opportunities outside of the classroom and complementing other inputs of the educational process (Machin et al., 2004; Banerjee et al., 2007; He et al. 2008; Linden, 2008; Barrow et al., 2009). Moreover, ICT such as computers provide users with computational tools, information storage and communication opportunities. These features open the possibility of additional gains. For example, students may become digitally literate; communication costs may decrease; and a wide range of information may become accessible through the World Wide Web. However, recent evidence suggests that computers may pose as distractors that tamper with the learning process (Beuermann et al., 2015 and Malamud and Pop-Eleches, 2010) or may decrease peer-to-teacher interactions that may be relevant for learning (Banerjee and Duflo, 2014).

Given the expansion of resources using computers and software, a key question is whether laptop distribution is cost effective for educational service provision. A dimension mostly over-looked in the education policy literature is the shift of a significant amount of pedagogical contents from print to digital versions as a result of increased computer usages and the implications of the shift on learning outcomes. In Latin America, educational content is traditionally provided through textbooks. Recent evidence from low performance students in elementary schools in the United States shows that the provision of textbooks leads to gains in student learning (Holden, 2016). However, computers may allow for electronic provision of information, and electronic formats may decrease the marginal cost of providing content. Therefore, they may decrease the burden of education costs taken on by providers and households. On the other hand, computers have large fixed and maintenance costs relative to textbooks.

In this paper, we specifically study whether laptops may be a cost-effective way to provide educational content. We first explore whether replacing textbooks with laptops affects student learning. Then, we conduct a cost-effectiveness analysis to assess scenarios in which such replacement would be cost-effective. We take advantage of data that come from a randomized controlled trial in 271 elementary schools in Honduras. About half of the schools were randomly selected to receive laptops with digital content and Internet access. These schools did not receive Spanish or Mathematics textbooks. The other half of the schools received textbooks, but did not receive laptops. The study focuses on grades 3 and 5.

We find that at the end of the school year, both laptops and books allowed for students to achieve similar gains, particularly in Mathematics and Spanish test scores. At the end of the school year, both groups improved test scores by 0.46 standard deviations. This implies that the provision of books or laptops did not cause differences in terms of student learning. Our results suggest this is true for third and fifth graders and for academic and non-academic outcomes. We also show that there seems to be a significant effect of the program on improving digital-related skills.

Then, we move to the cost-effectiveness analysis. We consider the actual costs of the program, and we assume a one percent premium to digital literacy (a very conservative scenario given the digital premiums reported in several papers). Our results suggest the distribution of laptops with digital content provides gains of one standard deviation for US$100, and textbooks provide 1.6 standard deviations per US$100. This is a result of the fact that while digital provision of educational content has lower marginal costs than textbooks, the use of computers involves much higher fixed and maintenance costs. Given that the program we evaluated provided the content of two textbooks, we find that the substitution of three more textbooks (for a total of five) in the *Educatracho* intervention would guarantee computers to be more cost-effective than textbooks.

This paper makes several contributions to the existing literature on technology in education. First, to our knowledge, this is the only randomized evaluation to explore the effects of replacing textbooks with laptops in a real setting. Indeed, many studies have explored the effects of introducing technology to enhance student learning, but in those settings, computers were typically introduced as complements to other inputs to education (with the exception of Linden, 2008, who assessed the substitution of teacher-delivered curricula using computers). Additionally, we are unaware of any studies that have explored how the substitution of textbooks by laptops has an effect on learning despite its relevance in evaluating the effects of a specific dimension of the transition from traditional to online instruction using massive online open courses (MOOCS) and other technologies on student learning (Banerjee and Duflo, 2014). Our results suggest that there are no differences in cognitive dimensions between using digital or textbook content in classrooms, at least at the primary school level.

Second, we estimate the relative effects of digital and textbook content delivery within the same randomized controlled trial (a limitation of the Linden, 2008 study is that two separate randomized controlled trials are used to identify whether computers substitute or complement teachers). This strategy allows us to observe students with textbooks and with laptops in the exact same context (i.e., our study groups worked with the same curriculum and within the same administration and institutional setting, among other factors).

Third, the aforementioned contributions combined with cost estimates of pedagogical content provision using computers and of digital premiums allow us to analyze the cost-effectiveness of the substitution of laptops for textbooks. Indeed, several education systems face limited resources and low performance. This is important as this paper could assist decision making on how to allocate educational resources. Some educational systems are fast expanding educational resources in digital format. Coupled, the cost of laptops has decreased in the last years. In addition, educational systems aim to align student abilities with those demanded by the labor market. Digital abilities are one such skill. Moreover, adding premium for digital contest is important as the labor market is increasing the demand for digital skills (World Bank, 2016).

The organization of this paper is as follows. Section 2 provides a summary of the literature on the provision of educational content through textbooks or computers. Section 3 describes the *Educatracho* program which provided an opportunity to assess the substitution of textbooks with laptops. Section 4 describes the data. Section 5 describes the methodology applied to compare student learning in both groups. Section 6 describes results of the impact and cost-effectiveness analyses of the intervention. Section 7 concludes.

2. What we know about how laptops and books compare to promote student learning

In this section, we review literature on how substituting laptops with physical books could affect student learning. Then, we discuss the experimental evidence on the cost-effectiveness of books and laptops. Finally, we discuss features of delivering content through print and digital means that seem to play a determinant role in the effectiveness of teaching.

The evidence on how substituting books with laptops is scarce. We only found two quantitative studies in the United States. Wells (2012) study the use of tablets or printed materials to read a passage in one class period in North Carolina using performance outcomes of 140 students in middle and high school. The results suggest that the program did not have an effect on reading skills, comprehension or motivation. Daniel and Woody (2013) study the performance of approximately 300 US college students who read a chapter of a psychology textbook using digital or traditional textbooks in both lab and in-home experiments. They found no big differences in learning outcomes, but students using electronic materials spent more time reading, especially in the in-home setting. The authors provide some evidence that, especially in the in-home environment, this is consistent with multi-tasking. They also argue that there is some evidence that subjects use different strategies when reading electronic content compared to traditional content. Other descriptive studies support the idea that substituting books with laptops does not have an effect on learning (Wright et al., 2013; Merkt et al., 2011; Baron, 2015). We found no published evidence on substitution effects at the elementary school level or in developing countries.

Several studies explore the effects of laptops or books on student learning in different types of programs. However, using this evidence to infer how laptop substitution would affect learning is difficult. The reason is that the effectiveness of both books and laptops vary and also because studies consider very different ways of providing computers and/or books. For example, McEwan (2014) reviewed 15 computer or other technology related programs. He calculated a mean average effect size of 0.15 standard deviations ($p=0.003$). Similarly, Glewwe et al. (2011) reviewed high quality studies from 1990 to 2010 and found five randomized controlled trials. They concluded the results were inconclusive. What is more, Kremer et al. (2013) compared the cost-effectiveness of several education interventions. They found that a reading program in the Philippines led to gains of 1.18 standard deviations per US$100 in the short-term (Abeberese et al., 2016). They also found an adaptive software program in India led to 1.54 standard deviations per US$100 (Banerjee et al., 2007). However, Kremer et al. (2013) also included two other programs that explored laptop or book provision. One assessed laptop provision in Peru (Beuermann et al., 2015). Another assessed book provision in Kenya (Glewwe et al., 2009). These two programs did not lead to any improvements in student learning.

There are two features of laptops or books that influence their relative efficacy to promote student learning. First, relative to books, computers may facilitate the provision of information to students. More specifically, laptops may provide software that adapts to the needs of the student. Indeed, Banerjee et al. (2007) and Barrow et al. (2009) explored the effects of laptop distribution with adaptive software. Both studies find positive effects on student learning in India and the United States, respectively. Moreover, Barrow et al. (2009) found some suggestive evidence that the impact of the adaptive software was stronger for kids not located in the top quartile of baseline test scores. In contrast, Glewwe et al. (2009) estimated the effects of book provision in Kenya. They find gains only for those students that had higher achievement levels before book distribution. Therefore, our reading of the evidence is that the use of laptops jointly with software that adapts to students seem to have an advantage relative to books. Thus, laptops can assist users to find pertinent and relevant information.

Second, laptops may pose as distractors to users. As a result, they may demand support by facilitators to guide their use. For example, Malamud and Pop-Eleches (2010) explored the effects of computer use at home in Romania. They found that computers had a negative effect on student learning. However, they found that those students for whom parents mediated computer use showed no effects. Similarly, Beuermann et al. (2015) evaluated the One Laptop per Child program in Peru. They found that students were less likely to read a book yet there was an association of computer use with playing computer games and listening to music. They did not find effects of laptops on academic performance. As already discussed, Daniel and Woody (2013) documented the existence of multi-tasking especially in more flexible environments for college students. For these cases, facilitators are important. An extreme case is the study by Barrera-Osorio and Linden (2009). They evaluated a program that provided laptops in Colombia. They found no effects on student learning and that teachers did not use laptops to teach or as a resource to enhance learning.

Facilitators are also important to determine the efficacy of books. For example, Borkum et al. (2012) found that the provision of a library to schools in India resulted in low use. On the contrary, Abeberese et al. (2016) analyzed a program that led to improvements in student reading. They evaluated a program in the Philippines that provided age-appropriate reading materials and enhanced student reading in a 31-day read-a-thon. Teachers received training, and the curriculum was adapted to facilitate change. Therefore, neither laptop nor book provision alone has an effect on student learning. Computers and books seem to require mediation by teachers or parents to enhance learning.

This discussion clarifies the contribution of our work to the existing literature. The evidence on how replacing books with laptops is scarce. In addition, indirect comparisons are difficult. Features such as adaptability to students needs and moderation of use vary. Therefore, our work contributes to this literature. We assess a replacement of books with laptops in a context in which the program did not change contents. Laptops had textbooks pre-loaded and pre-loaded fiction books in pdf format. The program did not change the role of teachers or parents as facilitators.

3. The Educatracho Program

The Honduras Government introduced the *Educatracho* program in 2013. It was part of an effort to improve the quality of education provision in elementary schools in poor areas. The program provided an XO 1.75 laptop equipped with Fedora 17 and Open Office 3 software. The laptops had Mathematics and Spanish textbooks stored in its memory. The textbook contents were adapted for on-screen use. In addition, the laptops were equipped with interactive exercises that were not designed to adapt to users' learning patterns. Nonetheless the computers' home screens did have a link to a learning site. Students could do exercises and access additional Math or Spanish information online. In addition, the laptops included a chat program, a drawing program, and a word processor. Children were not allowed to take the laptops home because of security reasons.

The program targeted public schools in poor communities, and school selection and program implementation occurred in five stages. Honduras had 10,906 public schools in 2013. First, the implementation team restricted the list to 3,695 schools based on the following eligibility criteria: schools were eligible if they had access to electricity, one teacher available for each of the study groups, and students enrolled in 3rd and 5th grades. In the second stage, the team ordered the 3,695 schools eligible from the first stage by the percentage of poor households in the community using information on poverty rates from the cash transfer program *Programa Bono Diez Mil* (Bono 10,000). In the third stage, the team scheduled the allocation and delivery of 120,000 laptops over a two-year period. Schools located in communities with higher percentages of poor had priority than those with lower percentages. The distribution resulted in 1,503 targeted elementary schools. All communities with targeted schools had a poverty rate of 58% or higher. In the fourth stage, the team confirmed using administrative data that 1,198 out of the 1,503 met the targeting criteria. In the fifth stage, the team selected 272 schools to implement and evaluate the first year of the program. Selection of the 272 schools was random and with equal probability. One school had to be excluded because of safety concerns surrounding data collection. As a result, the evaluation focused on 271 schools with 9,600 students.

Figure 1 presents a timeline of the program implementation. The school year in Honduras runs from early February until late November. The Ministry of Education delivered Mathematics and Spanish textbooks to the control schools in January and February 2013 and laptops to the treatment schools in February and March 2013. Teacher training on the use of technology in the classroom took place from April to August and was received by teachers for both treatment and control schools. At least half of the teachers had started using computers by April. However, some teachers started using laptops as late as June. Students in the treatment group had access to computers for an average of seven months. Before the use of laptops, it is likely students used old textbooks, which were available to students in treatment and control schools. As for treatment schools, new textbooks were delivered towards the end of the school year (Mathematics textbooks in September and October to only about one fourth of treatment schools and Spanish textbooks in November and December to all treatment schools).

In terms of the actual implementation of *Educatracho,* we collected administrative data on laptop delivery, and survey information from principals, teachers, and students on computers and Internet use at the school. Principals and teachers reported that all the schools in the treatment group had computers available, in contrast with just 40% in the control group. Similarly, principals reported that Internet access increased from about 34% in the control schools to 100% in the treatment schools. Moreover, there was a sharp difference in the type of available computers, because the presence of computers in the control group can be explained mainly by the existence of computer labs in the schools (in 33% of the control schools). Interestingly, there is no significant difference in the existence of computer labs between treatment and control groups. However, in terms of computer use, the differences are more marked. While 99% of the teachers in the treatment group reported to use computers at school, just about 20% of the teachers in the control group said they use computers at school. In sum, all this evidence suggests that *Educatracho* affected both the extensive and intensive margins of the availability of technology in the schools. Additionally, we collected administrative data that reports with high fidelity the delivery of the laptops and textbooks and other materials to the schools.

Students also reported significant changes in computer use in the school. The program increased the share of students who used computers at school from 43% in the control group to 98% in the treatment group. The use of technology in Math or Spanish class increased from 34% to 99%. In addition, the use of laptops during recess increased from 7% to 39%. Accordingly, the number of students that used Internet increased from 7% to 55%. Moreover, 87% of the students in treatment schools reported using computers as a tool to do homework (versus 38% in the control group), and the use of computers increased from 44% to 97% for computing functions. The program also increased access to online content from 10% to 90%. This confirms that the increase in availability of computers reported by principals and teachers translated to an actual increase in use by students in general and especially as educational tools.[3]

4. Data

We collected data at two points in time during the 2013 Honduran school year. The baseline round took place in March of 2013. The follow-up round took place in October in the same school year. The sample includes 9,600 students enrolled in the 271 targeted schools. Out of these students, 4,563 students were in 3rd grade, and 5,037 students were enrolled in 5th grade.

Our data collection process included the application of instruments with five modules. The first module consisted of standardized Mathematics and Spanish tests. These tests aimed to

[3] We also have access to information about computer and Internet use at home and we did not find that students who attended treatment schools changed computer ownership and use in a significant manner. This is important as these results suggest that the intervention was mainly related to the schools and have no impact on other margins related to technology use at home.

assess progress according to the curriculum for the corresponding grade. The second module consisted of a verbal fluency test. This test aimed to measure verbal ability and executive control. The score on this test correlates to vocabulary size and lexical access speed (Shao et al., 2014). In addition, it correlates to updating and inhibition ability (Shao et al., 2014). Updating ability is one process involved in working memory which refers to the capacity to change the focus of attention. The third module consisted of a coding test. This test aimed to measure processing speed and working memory. Other studies had suggested that laptops may have an effect on cognitive skills (Cristia et al., 2012, Malamud and Pop-Eleches, 2011). The fourth module included a test for digital literacy. This module was only applied to half of the students in treatment schools (with randomly selected students). The final module consisted of a student questionnaire aimed to collect information on student characteristics, including questions on age, gender and experience with laptops and technology. It also included questions on household characteristics, such as asset holdings and the parental literacy. We also surveyed 504 teachers and 271 principals. These surveys collected data to assess the technology experience of the schools. Program administrative records facilitated information on program cost (BID, 2015).

Table 1 summarizes the number of students, teachers, principals and schools in the sample. The baseline sample included most of the principals, teachers, and students included in the original study sample. Attrition rates between the baseline and the follow-up surveys vary depending on the instrument. While attrition for student questionnaires was below 2%, attrition for the tests increases to between 3% and 8%, depending on the instrument. In all, attrition rate in the sample for which we run the regressions was 7% and was not correlated with treatment status (p=0.859).

Table 2 presents a summary of the characteristics of the students included in the sample. Students were on average 10 years old, with 88% having a literate mother. About half of the students were 3rd graders and the other half were 5th graders. Teachers had an average age of 38 years and 15 years of experience, and 35% were male. Schools had 181 students on average. The student-to-teacher ratio was 30. Among the schools, 79% were rural and had high poverty rates. In addition, 26% of the families in the school received the poverty alleviation program Bono 10,000.

5. Methodology

The empirical framework for our main analysis uses observations on children who attend schools that were randomly assigned to the treatment and control groups. In particular, we estimate the following regression model:

$$y_{isc} = \mu_c + \alpha T_{sc} + \mathbf{X}'_{isc}\boldsymbol{\beta} + \varepsilon_{isc} \quad (1)$$

where y denotes the score of student i in school s, strata c, T is a dummy variable that takes a value of 1 if the school is part of the treatment group, **X** is a vector of control variables, and ε is the error term that is clustered at the school level j in each regression. Then, estimates of α quantify the differences in means between students attending schools that receive laptops but did not receive textbooks and those that did not receive it and received textbooks.

We use strata fixed effects given that the we chose schools to receive laptops through stratified random selection. We use four strata to group schools by size and poverty using the medians of size and poverty. We chose school size to define the strata, because (i) household income is one of the main determinants of educational outcomes and (ii) school size summarizes organizational demands and community size (Duflo et al., 2008; Bando, 2013, Duflo et al., 2011 and Urquiola, 2006).

We implement two additional exercises to study the robustness of our results. First, we also estimate differences-in-differences models to control for pre-treatment differences across treatment and control schools to take into account a few differences we identify at baseline in test scores. Second, given that we include a series of outcomes, we may face an inference problem related to multiple hypotheses testing (i.e., significant coefficients may emerge simply by chance, even if there are no treatment effects). Then, we calculate adjusted p-values that correct the p-value for the family-wise error rate (FWER, the probability of making a Type I error) using a Westfall and Young (1993) type correction (we follow Haushofer and Shapiro, 2013). We call these FWER p-values.

Table 2 shows descriptive statistics of student, teacher, school and community characteristics at baseline.[4] Columns (1) and (2) present averages by treatment status. Column (3)

[4] See Table A1 in Appendix A for a detailed definition of all the variables.

presents differences between the two groups. Column (4) presents p-values for a test of differences in means. For most variables, differences between treatment and control groups are not statistically different. However, we find differences for the rural status of the community, the age or education of the teacher and the literacy of the student's mother.

We address these differences in two ways. First, we test if the full set of variables can predict treatment. We reject this possibility (p=0.616). Second, we estimate differences after we control for the rural status of the community. Column (5) presents p-values for tests of differences across treatment and control groups controlling for rural status. We find no significant differences after we control for rural status.

Therefore, we analyze program effects with and without the inclusion of rural and frontier statuses. In addition, we estimate program impacts controlling for all baseline variables reported in Table 1. These alternative specifications allow us to assess if school characteristics bias estimates of program effects.

Table 3 compares student performance at baseline for students in the treatment and control groups. We focus on academic tests in Mathematics and Spanish and also combine them by calculating an average of both standardized scores. We label this average "academic tests". In addition, we analyze differences in the non-academic verbal and codes tests and we summarize the information of these tests in an index labeled "non-academic tests", which is an average of the standardized verbal and coding test scores. Columns (1) and (2) present averages by treatment status. Column (3) presents differences including strata fixed effects. Columns (4) and (5) present differences including controls for rural or frontier status and all variables listed in Table 2, respectively. We reject the null of baseline differences for all variables but for verbal correct fields for 3rd grade. However, this difference is not robust to the inclusion of controls. We conclude there are no systematic differences before program intervention.

6. Results

This section discusses first the results of estimating equation (1) under different specifications. In summary, we find that the substitution of textbooks by laptops did not have a statistically significant effect on student performance by the end of the school year. Next, in a second subsection, we discuss the implications of the results and estimate and discuss the cost-effectiveness of laptops relative to books. We conclude laptops are as effective as books if they substitute at least five textbooks.

6.1 Treatment Effects on Student Performance

Table 4 presents estimates of program effects on student performance. We observe academic, verbal and code tests after an average of seven months of exposition to laptops. Column (1) presents the performance level for students in the group of students who received textbooks. Column (2) presents the difference between the two groups when controlling for strata fixed effects. Columns (3) and (4) present estimates including controls. Results under the three specifications are not statistically different. However, the introduction of controls or individual fixed effects renders some effects statistically significant. We cannot reject the null of no program effects for Spanish and coding tests. We find a positive effect on verbal scores for 6th grade students. In addition, we cannot rule out a negative effect on Mathematics scores for both 3rd and 6th grade students.

As a robustness exercise, we check if findings could be biased by non-observable characteristics that do not change with time and estimate program impacts on differences in student learning while controlling for individual fixed effects. Column (4) presents the results. We do not find qualitative changes to the previous results.

Next, we test if the effects we observe are a result of multiple hypothesis testing. Indeed, we perform tests on 12 variables in four different models. Therefore, we perform 48 tests. We would expect Type 1 error rejections in about five tests with a 10 percent significance level. We address this issue by focusing on adjusting p-values for family-wise error rate (FWER) as in Haushofer and Shapiro (2013). Column (6) shows that we cannot reject the null of no effects once multiple inference issues are accounted for. Indeed, academic and non-academic tests are not statistically significant for either grade.

Therefore, we conclude from these exercises that the substitution of textbooks by laptops did not have an effect on student performance in a statistically significant way. Moreover, if we aggregate the academic and non-academic performance measures into one average indicator, we find that the effect is precisely estimated around zero. For instance, when considering the estimates using the specification of Column (3), we find a treatment effect of -0.05 for 3rd

graders and 0.01 for 5th graders, which are not statistically different from zero even without considering the FWER p-values.

A threat to our findings is that the substitution of textbooks by laptops may have caused a change in student composition. Two scenarios could make this the case. First, families may have transferred their children to a different school because of the program. However, we find this to not have been the case as there were 2% of new students in schools with textbooks, and schools with laptops had 0.8 percentage points fewer students (p=0.074). This small difference in student composition probably cannot explain our results. Second, it could be that the substitution affected dropout rates, and if that were the case, the remaining students would differ not only by textbook or laptop position. They would also differ on their characteristics. We find that the dropout rate between the baseline and follow-up rounds was 7%. The difference was not statistically different between the two groups (p-value=0.859). Thus, we conclude that changes in student composition did not affect our results.

We also analyze if effects vary across subgroups. However, we do not find heterogeneity on the impact of substitution textbooks by laptops. More specifically, we test if effects vary across students according to pre-intervention performance, socioeconomic status of the students, pre-intervention dispersion in class performance, and age and education of the teacher. Yet, we do not find any difference across any of these dimensions.[5] Our interpretation of these results is that this program mainly has an effect on the margin of substitution between digital and traditional content, as the laptops did not have adaptive components or software (as emphasized in the previous literature). Therefore, any difference between treatment and control groups comes mainly from this feature.

6.2 Cost-effectiveness

In this section, we discuss the implications of our results through the lens of a cost-effectiveness analysis. Our previous results imply that there are no differences in student performance with laptop provision relative to the provision of textbooks. We now follow the methodology suggested by Dhaliwal et al (2012) to estimate the cost-effectiveness of the program. We state marginal costs to laptop provision relative to textbooks. Next, we describe benefits. Finally, we discuss how program characteristics affect cost-effectiveness and include a

[5] Results on heterogeneity effects are available upon request.

sensitivity analysis. We conclude the intervention is most likely cost-effective. Considering a very conservative scenario, we find that the substitution of three additional textbooks would guarantee the intervention to be cost-effective.

Table 5 presents a list of marginal benefits and costs relative to textbook provision. In Panel A, we present a list of differential costs. We assume that laptops depreciate linearly over four years and assume that the rental price of a laptop is one fourth of its price, or US$76. We also consider other costs including technical assistance provided at US$5 per student. In addition, Internet and laptop running costs were US$9 per student, and principal training was US$5 per student. We do not include costs for teacher training because both treatment and control teachers received training. Panel B lists differential benefits. We start by considering the differential cost of savings by replacing textbooks by laptops. Each textbook had a cost of US$14 per child per year. Laptops replaced two books. Thus, this replacement implies savings of US$28.

Next, we estimate a digital literacy premium derived from the program. The questionnaires present information on digital literacy for treated students. The results imply that students that received laptops were familiar with basic applications. Indeed, over 90% of them could write a word and draw a circle using a computer, as well as access online materials. In addition, over 90% of students could access information on the server on a specific subject for their grade. We do not have information available for the students who did not receive laptops, but given the much lower use of computers and Internet in these schools, it is highly likely that these abilities are not present to this extent for most students in the control group. For instance, as we mentioned above, just 7% of students in the control group reported to use Internet at school.

Next, we estimated the returns to digital literacy. There is much literature on the topic starting from the influential study by Krueger (1993) that finds a high correlation between computer use and wage. More recently, the World Bank (2016) also cites high correlations between computer use and Internet use and wages in different places. However, a more complicated challenge is to find the causal impact of digital literacy, as DiNardo and Pischke (1997) argue. One interesting paper that tries to deal with this point is Blanco and López-Boo (2010), who implemented an audit study in two Latin American cities in which they send fake curricula that randomly signal digital literacy. They find increases in callback rates from 11-12%.

Thus, we take from this paper that there seems to be causal effect of digital literacy on wages in Latin America. We take a very conservative stand and assume a one percent wage premium for digital literacy, which corresponds to a very low number in comparison to the correlations reported in Krueger (1993), the World Bank (2016) and other papers. We then perform sensitivity analysis on this premium.

We assume students are 10 years old at the moment of evaluation. We assume they will work as adults for 30 years starting when they are 18 years old. Students achieve the average years of schooling for the country at 11 years, and 4.5% of them will be unemployed (CIA, 2015). Therefore, the expected wage for a student is US$206. We use an interest rate of 10% and an exchange rate of 20 lempiras per USD. We assume that only individuals in the labor market get returns from digital literacy, and we use the observed participation rate in the labor market in 2013 in Honduras of 53.7%.[6] Under the base scenario, the expected estimated gain in wages provided by digital literacy was US$35.

Therefore, the difference between laptop benefits and costs in this program results in a deficit of US$32 per child per year, and in this scenario, the substitution of three additional textbooks would ensure the intervention to be cost-effective.

Table 6 presents the sensitivity of the calculations to changes in the interest rate and the wage premium to digital literacy. Gains for digital literacy are realized during the work life of an individual, and as a result, high discount rates decrease the value of benefits today. A wage premium of 5% or higher would ensure gains of interest rates up to 12%. On the other hand, no digital gains ever imply the intervention to be cost-effective.[7]

We would like to highlight three intervention characteristics relevant to this result. First, we consider a scenario where laptops replace more textbooks. Indeed, laptops require a large fixed cost. However, the marginal cost of providing contents is lower. The substitution of three more printed books would guarantee computers to be more cost-effective in this program. Indeed, the laptops had 23 reading books preloaded in pdf format. If teachers and students use these

[6] Observatorio Económico y de Emprendimiento, Universidad de Honduras. http://oee.iies-unah.org/index.php/mercado-laboral/tasa-de-participacion retrieved on July 2, 2015. Assume all individuals in or out of the labor market benefit from digital literacy. Then, the cost of laptop provision per child-year is US$10.

[7] We implemented other sensitivity analyses that we do not report. For instance, if computers last about 7 years (instead of 4 as we assume in our base scenario), even the substitution of two textbooks using laptops would be cost-effective.

books to replace printed books, then the gains are enough to make the intervention efficient. Unfortunately, we do not have data to check if this was indeed the case.

Second, we would like to highlight that the cost of laptops is variable and decreasing. For example, the cost of computers for the Open Learning Exchange Program (OLE) in Nepal in 2010 was US$225 each. The provision of laptops in Montevideo in 2009 was US$260 each, and the provision of computers in Honduras in 2013 was US$303 per laptop. Laptops have become less costly over time. Barsyk and MacDonald (2001) estimated that between 1996 and 2000 prices dropped by 0.5% monthly. Nelson et al. (1994) estimated an annual decline in average computer price of 25% between 1984 and 1991. Indeed, many laptop providers expect this trend to continue. For example, the OLPC started with a cost of US$188 in 2006, and the CEO announced as a goal to provide laptops for US$100 by 2008 and of US$50 by 2010. [8] However, these targets have not yet been met.

Third, evaluation after a few months of exposure to laptops may bias cost-effectiveness towards zero. This would be true under two scenarios. To start with, the costs of complementarities can almost double the cost when laptops are delivered the first time. For example, the provision of One Laptop per Child (OLPC) in India had a cost of US$461 per laptop. However, the laptop itself was only a part of this cost. Indeed, each laptop had a cost of US$229. The rest of the cost covered shipping, chargers, maintenance (10% yearly), training, servers, procurement and back office support.[9] Running costs were lower. They were estimated at 10% of laptop costs yearly. This is important for our analysis. It is unlikely that future provision of the *Educatracho* program will demand principal training in the use of technology. If this is the case, the substitution of two more books would be enough to make the intervention cost-effective.

Another reason is that educational programs usually take time to have an impact on educational outcomes. Changes in the school community usually imply an adjustment cost. This results in an offsetting effect of performance gains. In such scenario, our estimation provides a lower bound. In addition, exposure to laptops was shorter than that of new books. Assume new books are at least as effective to aid learning as old books. In this case, any gains in the control

[8] Source: http://www.theverge.com/2014/1/7/5286050/olpc-xo2-xo-10-tablets-vivitar retrieved July 2nd, 2015
[9] Source: http://www.olpcnews.com/sales_talk/price/490_per_xo_laptop_the_real_cos.html as retrieved July 2nd, 2015

group associated with new books was compensated by laptop exposure. Thus, our estimation in this scenario also provides a lower bound.

We conclude that the replacement of three more textbooks by laptops would make the intervention cost-effective. We believe this is likely the case. As we mentioned above, laptops included 23 books in pdf formats. In addition, laptops increased Internet access which may further bring other benefits. Moreover, evidence shows that laptop cost and provision in the future is likely to decrease. As a result, future laptop provision will probably be more cost-efficient.

7. Conclusions

The use of laptops in schools has become popular under the premise that laptops will facilitate student learning, and therefore, technology will improve the quality of education (World Bank, 2016). Indeed, laptops may provide access to more resources. Laptops may provide many texts in electronic format in its memory. In addition, laptops may allow for access to the World Wide Web. However, laptops may be distractive to learning tasks. How students would be affected by replacing books with laptops remained an empirical question. We answered the question for elementary school students in Honduras.

We found textbook replacement with laptops did not affect student learning after one school year using a randomized controlled trial with 271 schools and 6,500 students. We also implemented a cost-effectiveness analysis to compare expected results of this replacement of textbooks using laptops. Laptops have a higher initial fixed cost than books and impose variable costs, such as electricity, Internet and maintenance. However, the marginal cost of providing additional content decreases.

We estimate that minimum gains for laptops to be cost-effective relative to books. Assuming a very conservative 1% wage return on digital literacy associated to the program, we estimate that laptops need gains additional to books of US$32 per year. This is equivalent to the cost of 2.3 extra books. Thus, this work contributes to the literature that explores how to provide educational services in a cost-effective manner.

Our research highlights limitations relevant for future work. First, our results correspond to one year of program exposure. The impact of the program during a longer exposure may enhance our understanding on how technology affects student learning. In particular, it would be interesting to explore the effects of laptops after its four years of working life. Second, some literature points to adaptability of software as a determinant to learning efficiency. We only explore how format provision changed student learning. Future work may test how specific software features affect its role in providing content information. Third, our results are sensitive to assumptions on student's benefits derived from Internet access, communication technologies and digital literacy. However, we do not have good causal estimates of the returns on these computer features. More information on how students benefit from computer use in the long run would provide useful information to inform policy regarding laptop provision. Fourth, a relevant area to explore is how freedom of choice may impose a cost control on users. More specifically, laptops may make it difficult for students to focus on learning tasks. Students may get distracted by games, music or social communication features.

Finally, the developed world has shifted a significant amount of reading resources from printed to electronic versions (Liu, 2006). Laptops may provide opportunities to students in developing countries. However, more work is needed to understand how to ensure benefits. Our study is consistent with quantitative and qualitative studies in that laptop provision can be as effective to deliver content as textbooks. In addition, laptops provide access to more information through the internet. Laptops also allow for communication. In addition, they are computing tools. We find that these additional features do not distract students from learning in the short run. If this is the case in the long run, then computer provision may soon become more cost effective than textbook provision.

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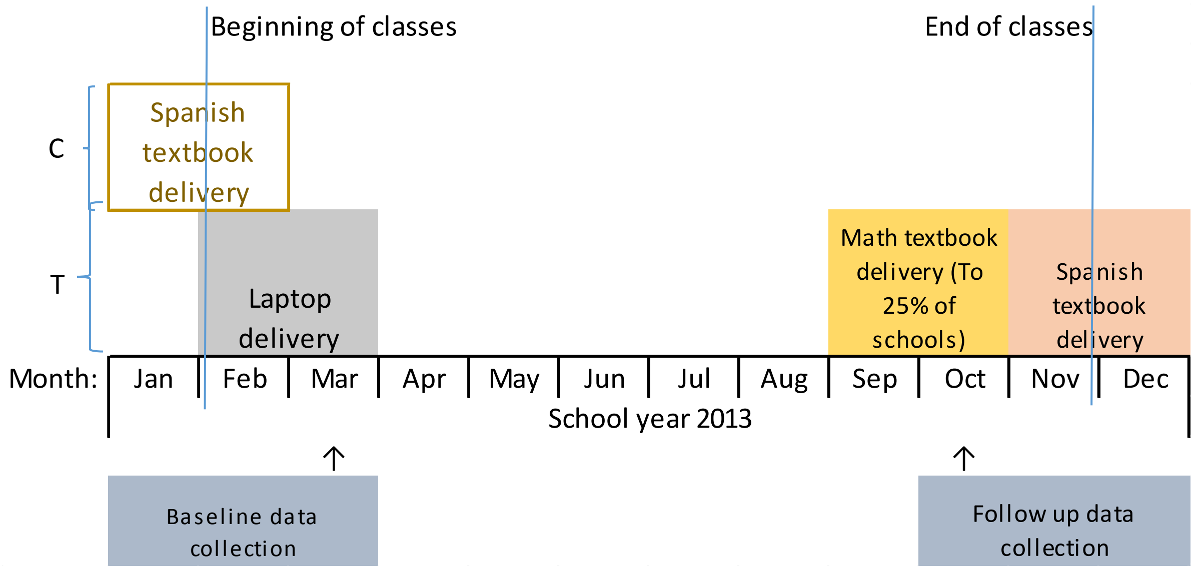

Figure 1. Program and data collection timeline

Table 1. Baseline and Follow-Up Sample Sizes

Instrument	Target	Baseline	Follow-up	Panel	Attrition
I.Survey					
Principals	272	270	271	269	99.63%
Teachers	505	504	502	497	98.61%
Students	9601	9600	9318	8954	93.27%
II. Academic Test					
Spanish	9619	9619	9160	8814	91.63%
Math	9620	9620	9209	8869	92.19%
III. Non-academic tests					
Verbal	9399	9121	9304	8859	97.13%
Codes	9399	9104	9311	8850	97.21%

Source: Own calculations

Table 2. Baseline Descriptive Statistics and Balance of Community, School and Teacher Characteristics

Variable	Control	Treatment	Difference	P-value	P-value*
	(1)	(2)	(3)	(4)	(5)
Panel A. Community characteristics					
Rural	0.74	0.84	0.10	0.030	
	(0.44)	(0.37)	(0.05)		
Border	0.11	0.12	-0.04	0.923	
	(0.32)	(0.32)	(0.04)		
Number families beneficiary of *the Bono 10,000* program	22.73	27.82	5.09	0.182	0.562
	(35.81)	(34.13)	(4.26)		
Panel B. School characteristics					
School size	195.05	165.82	-29.23	0.171	0.545
	(196.55)	(148.73)	(21.22)		
Students per teacher	29.16	30.76	1.60	0.157	0.231
	(9.30)	(10.25)	(1.19)		
Merienda Escolar lunch program	0.95	0.96	0.01	0.984	0.930
	(0.21)	(0.21)	(0.03)		
Principal with at least technical/bachelor's degree	0.89	0.91	0.02	0.493	0.558
	(0.32)	(0.28)	(0.04)		
Panel C. Teacher characteristics					
Age	39.26	37.29	-1.97	0.081	0.213
	(9.86)	(10.61)	(0.92)		
Male	0.32	0.38	0.06	0.184	0.356
	(0.47)	(0.49)	(0.04)		
Primary teacher degree	0.28	0.36	0.08	0.072	0.124
	(0.45)	(0.48)	(0.04)		
Teaching experience	15.60	14.14	-1.46	0.166	0.403
	(8.95)	(9.27)	(0.82)		
Assets index (PCA)	-0.000	0.00	-0.00	0.951	0.720
	(1.41)	(1.58)	(0.13)		
Panel D. Student characteristics					
Age	10.08	10.14	0.06	0.265	0.330
	(1.89)	(1.84)	(0.04)		
Enrolled in 3rd grade	0.52	0.52	0.00	0.895	0.633
	(0.50)	(0.50)	(0.01)		
Male	0.50	0.50	0.00	0.928	0.960
	(0.50)	(0.50)	(0.01)		
Mother can read	0.89	0.87	-0.02	0.089	0.294
	(0.31)	(0.34)	(0.01)		
Assets index (PCA)	0.11	-0.11	-0.22	0.161	0.961
	(1.75)	(1.70)	(0.04)		

Notes: P-values are for tests of the null hypothesis of equality of means. P-values include strata fixed effects. The p-value for the joint prediction to allocation of treatment is 0.422 for the community and principal variables, 0.357 for the community variables and 0.616 for the student's variables.
* Estimation includes control for the rural status of the community.
Source: Authors' calculations.

Table 2. Baseline Descriptive Statistics and Balance of Student Test Scores

	Averages		Differences in means		
Variable	**Control**	**Treatment**	**No controls**	**Controls for rurality and frontier status**	**Controls for students, teachers and school characteristics**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Panel A. 3rd grade					
Academic tests	0.02	-0.06	-0.08	0.01	0.03
	(0.86)	(0.84)	(0.07)	(0.06)	(0.06)
Math	0.01	-0.02	-0.03	0.05	0.07
	(1.00)	(1.01)	(0.08)	(0.07)	(0.07)
Spanish	0.04	-0.08	-0.12	-0.02	-0.00
	(0.98)	(0.94)	(0.07)	(0.06)	(0.06)
Non-academic tests	0.00	-0.09	-0.10	-0.04	-0.05
	(0.78)	(0.76)	(0.07)	(0.06)	(0.07)
Verbal	0.00	-0.16	-0.16**	-0.11	-0.10
	(1.00)	(0.95)	(0.08)	(0.08)	(0.08)
Codes	0.01	-0.02	-0.03	0.03	0.01
	(1.01)	(0.97)	(0.09)	(0.09)	(0.09)
Panel B. 6th grade					
Academic tests	0.03	-0.01	-0.05	0.02	0.01
	(0.82)	(0.84)	(0.07)	(0.06)	(0.06)
Math	0.02	-0.01	-0.04	0.03	0.01
	(1.00)	(1.03)	(0.09)	(0.08)	(0.08)
Spanish	0.03	-0.02	-0.05	0.00	0.01
	(0.94)	(0.94)	(0.06)	(0.05)	(0.05)
Non-academic tests	0.00	-0.11	-0.11	-0.09	-0.09
	(0.80)	(0.67)	(0.07)	(0.06)	(0.06)
Verbal	-0.00	-0.10	-0.10	-0.09	-0.10
	(1.00)	(0.88)	(0.08)	(0.08)	(0.07)
Codes	-0.00	-0.11	-0.11	-0.10	-0.08
	(1.00)	(0.87)	(0.08)	(0.08)	(0.08)

Notes: Based on a sample of 9,600 students. The estimation of differences in columns (3) to (5) includes strata fixed effects. The controls for column (5) are all the variables listed in Table 2.
Source: Authors' calculations.

Table 4. Impact of substituting textbooks with laptops on student performance.

Variable	Means in group with textbooks	Difference of means of group with laptops minus group with textbooks				
		No controls	Controls for rural and frontier status	Controls for students, teachers and school characteristics	Difference in differences	P-value FWER
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. 3rd grade						
Academic tests	0.59	-0.13**	-0.06	-0.08**	-0.07*	0.161
	(0.80)	(0.07)	(0.06)	(0.04)	(0.04)	
Math	0.63	-0.13*	-0.06	-0.09	-0.11**	0.303
	(0.92)	(0.08)	(0.07)	(0.06)	(0.06)	
Spanish	0.59	-0.14**	-0.06	-0.06	-0.04	0.303
	(0.86)	(0.07)	(0.06)	(0.04)	(0.04)	
Non academic tests	-0.00	-0.05	-0.03	-0.02	0.05	0.938
	(0.61)	(0.05)	(0.05)	(0.04)	(0.06)	
Verbal	0.14	-0.07	-0.07	-0.01	0.09	0.938
	(0.95)	(0.07)	(0.07)	(0.06)	(0.08)	
Codes	-0.04	-0.04	-0.02	-0.03	-0.02	0.873
	(0.66)	(0.05)	(0.05)	(0.05)	(0.09)	
Panel B. 6th grade						
Academic tests	0.39	-0.10	-0.06	-0.08**	-0.07	0.139
	(0.79)	(0.06)	(0.06)	(0.04)	(0.04)	
Math	0.56	-0.13	-0.10	-0.14**	-0.10*	0.139
	(1.03)	(0.09)	(0.09)	(0.06)	(0.06)	
Spanish	0.32	-0.09	-0.05	-0.06	-0.05	0.303
	(0.84)	(0.06)	(0.06)	(0.04)	(0.04)	
Non academic tests	-0.12	0.01	0.03	0.06	0.10	0.532
	(0.60)	(0.05)	(0.05)	(0.05)	(0.06)	
Verbal	-0.04	0.06	0.08	0.11**	0.15*	0.237
	(0.82)	(0.07)	(0.07)	(0.06)	(0.08)	
Codes	-0.17	-0.03	-0.01	0.02	0.07	0.938
	(0.71)	(0.06)	(0.06)	(0.06)	(0.08)	

Notes: Based on a sample of 9,600 students. All estimation of differences in columns (3) to (5) include strata fixed effects. The controls for column (4) are all the variables listed in Table 2. The p-values in column (6) are family-wise error rate estimated following the methodology described in Haushofer and Shapiro (2013).
Source: Authors' calculations.

Table 5: Benefits and costs for laptop and textbook provision per child-year.

Panel A. Costs	
Laptop provision	-76
Laptop related technical assistance	-5
Internet and laptop running costs	-9
Principal training for the use of technology	-5
Panel B. Benefits	
Textbook savings (2 books at US$14 each)	28
Digital literacy wage premium	35
Total	***-32***

Notes: Amounts expressed in 2013 USD. Environmental, computational or communicational gains are assumed to be null.

Source: Authors' calculations.

Table 6. Scenarios for net present values for shifting from textbooks to computers

	Interest rate			
	3%	5%	10%	12%
Wage premium to digital literacy				
0%	-67	-67	-67	-67
1%	136	63	**-18**	-32
5%	949	583	177	106
10%	1964	1234	422	278
20%	3996	2535	910	624

Notes: Amounts expressed in 2013 USD.

Source: Authors' calculations.

APPENDIX A. Definitions of Variables Used in Tables in Text

Table A1: Definitions of Variables Used in Tables in Text

Individual outcomes	**Definition**
Spanish test score	Standardized score for Spanish.
Math test score	Standardized score for Mathematics.
Verbal test score	Standardized number of correct answers in the verbal test.
Code test score	Standardized number of correct answers in the codes test.
Individual characteristics	
Age	Age in years.
Gender	1 if male, 0 if female.
Mother can read	1 if student's mother writes and reads, 0 otherwise.
Assets index (PCA)	Index created, following Fernald et al. (2008), using the first principal component of the following assets present in the student's house: radio, television, refrigerator, stove, car, computer and cellular phone
Teacher characteristics	
Age	Age in years
Gender	1 if male, 0 if female
Teacher has a bachelor degree in teaching	1 if the teacher has a bachelor degree in primary teaching, 0 otherwise (other advanced bachelor or advanced degrees)
Teaching experience	Number of years working as a teacher
Assets index (PCA)	Index created, following Fernald et al. (2008), using the first principal component of the following assets present in the teacher's house:

	radio, television, refrigerator, stove, car, computer and cellular phone.
School characteristics	
Total number of students	Total number of students in the school as reported by the principal.
Students per teacher	Total number of students over total number of teachers in the school as reported by the principal.
Merienda Escolar	1 if the principal reports that the children receive the *Merienda Escolar* lunch program at the school, 0 otherwise
Principal with technical or bachelor	1 if the principal has a bachelor degree in primary teaching, 0 otherwise (other advanced bachelor or advanced degrees)
Community characteristics	
Rural	1 if rural, 0 if urban.
Number families Bono 10.000	Total number of families within the community that receive Bono 10.000 as reported by the principal.