The Effect of Fibre Broadband on Student Learning

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Abstract

We estimate the impact of ultra-fast broadband on schools' academic performance using a difference-in-difference study of a new fibre broadband network. We show that fibre broadband increases primary schools' passing rates in standardised assessments by roughly one percentage point. Estimates are robust to alternative specifications, such as controlling for time-varying covariates. We find no evidence that gender, ethnic minorities or students enrolled in remote schools benefit disproportionately. However, we find some evidence of a larger benefit within schools that have a greater proportion of students from lower socio-economic backgrounds.

JEL codes

H43; H54; I28

Keywords

Fibre broadband, UFB, Education, Difference in difference

Summary haiku

Students with access
to fibre broadband learn more,
thousands benefit.

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1 Introduction

The New Zealand Government has spent $1.2 billion since 2008 developing an 'ultra-fast broadband' network, with school connections prioritised (Mirza and Beltrán 2014). A large literature has demonstrated that information technology's effects on educational performance are negligible (Bulman and Fairlie 2016). However none of this literature has analysed the educational impact of ultra-fast broadband. This paper evaluates the impact of ultra-fast broadband on schools' academic performance using a difference-in-difference study of a new fibre broadband network.

Fibre broadband expands the set of technologies available to a school. These technologies may offer more individualised teaching, students may find them more engaging, and they may allow better monitoring of student performance (Barrow, Markman, and Rouse 2009). If we assume both that schools care only about educational performance and that the effects of new technology are known to the school, the effect of fibre broadband on educational performance should be non-negative. However schools may mistakenly install harmful technology, or schools may (legitimately) care about non-educational outputs such as student wellbeing. Thus the overall effect of fibre broadband provision on school performance is ambiguous.

We estimate that effect by studying New Zealand's 'Ultra-Fast Broadband Initiative'. Prior to 2008, fibre broadband was available only in a small number of urban areas.[1] By 2016 fibre broadband had been made available to almost all state schools. We exploit differences in the timing of broadband availability to study the effects of broadband provision on student learning as measured by New Zealand's National Standards. Our difference-in-difference specification can control for any time-invariant school characteristics and school-invariant year effects. We also control for time-varying school characteristics.

We find fibre broadband increased the proportion of students *at or above* each National Standard by about one percentage point. These estimates are very precise, with standard errors equal to roughly 3% of a standard deviation. Estimates controlling for time-varying school characteristics are close to those from pure difference-in-difference specifications. Estimated effects on proportions *above* the standard are statistically indistinguishable from zero.

We find no evidence that either gender benefitted disproportionately. There is no evidence that Māori or Pasifika students benefited more than other students,[2] although there is some evidence that students in low-socioeconomic schools benefited more than others. Estimated effects within rural schools and within schools without an alternative form of wired broadband are imprecise and cannot be distinguished from the effects in other schools.

[1] See https://www.comcom.govt.nz/dmsdocument/4258, p. 12.
[2] Māori are the indigenous people of New Zealand. Pasifika people trace their ancestry to various Pacific islands.

Our positive results contrast with the international literature which has either failed to find significant effects or has found significant effects which are negative. Goolsbee and Guryan (2006) study school internet subsidies in California. A school's eligibility for the subsidy was discontinuously determined by the proportion of that school's students who were eligible for the federal school lunch program. They found a traditional regression discontinuity design insufficiently powerful and so studied the subsidies using a linear regression controlling for a continuous function of the forcing variable. Though the subsidy increased internet use, they find no significant effect on school performance. The school performance estimates' 95% confidence intervals have upper bounds mostly near 10% of a standard deviation. Hazlett, Schwall, and Wallsten (2016) study the same programme in North Carolina and find the subsidies caused a small decrease in SAT scores. Belo, Ferreira, and Telang (2013) study the effect of increased school internet usage in Portugal. When they instrument for a school's per-student internet usage using the physical distance between the school and the school's internet service provider – a determinant of internet quality – they find that internet usage harms school performance.

The literature evaluating the effects of internet access is part of a broader literature examining the relationship between technology and education; if broadband availability affects school performance it probably does so by making new technologies available. A New Zealand example of such technology use is Manaiakalani, a programme subsidising laptops for students enrolled in the low-income Auckland suburbs of Glen Innes, Point England and Panmure. Manaiakalani schools have improved their performance relative to national averages, especially in writing (Jesson et al. 2015). However in a summary of the international literature Bulman and Fairlie (2016) find mostly negligible effects, especially in developed countries.

This paper extends the literature on the relationship between education and technology by being, as far as we are aware, the first research specifically evaluating the effects of fibre broadband on educational attainment. The paper also contributes to the nascent literature evaluating the New Zealand Ultra-Fast Broadband programme. The programme's emphasis on schools allowed Fabling and Grimes (2016) to use school proximity as an instrument for the use of fibre broadband in for-profit firms. They find that the programme increased the productivity of those firms who used it, provided that the firms also introduced complementary investments like employee training.

In the next section we describe the Ultra-Fast Broadband Initiative, the policy shock we are studying. In Section 3 we describe our data. In Section 4 we discuss our estimates. Section 5 concludes. In an appendix we extend our analysis to another measure of student learning, the National Certificate of Educational Achievement – these estimates, which cover a much smaller sample of schools with more senior students, are mostly very imprecise.

2 The Ultra-Fast Broadband Initiative

Until 2008 fibre broadband was only offered by a small number of local initiatives. Those not covered by these initiatives had to rely on slower forms of broadband internet, primarily copper ADSL. In 2009 the New Zealand Government announced the 'Ultra-Fast Broadband Initiative', aiming to provide fibre broadband to 75 percent of New Zealand households within ten years.[3] Almost all New Zealand state schools had been provided access by the end of 2015.[4] The provision of fibre broadband is supplemented by the 'Network for Learning' service which provides free internet access to state schools. The Network for Learning also offers internet security and filtering to its client schools.

Figure 1: Geographical distribution of fibre availability dates

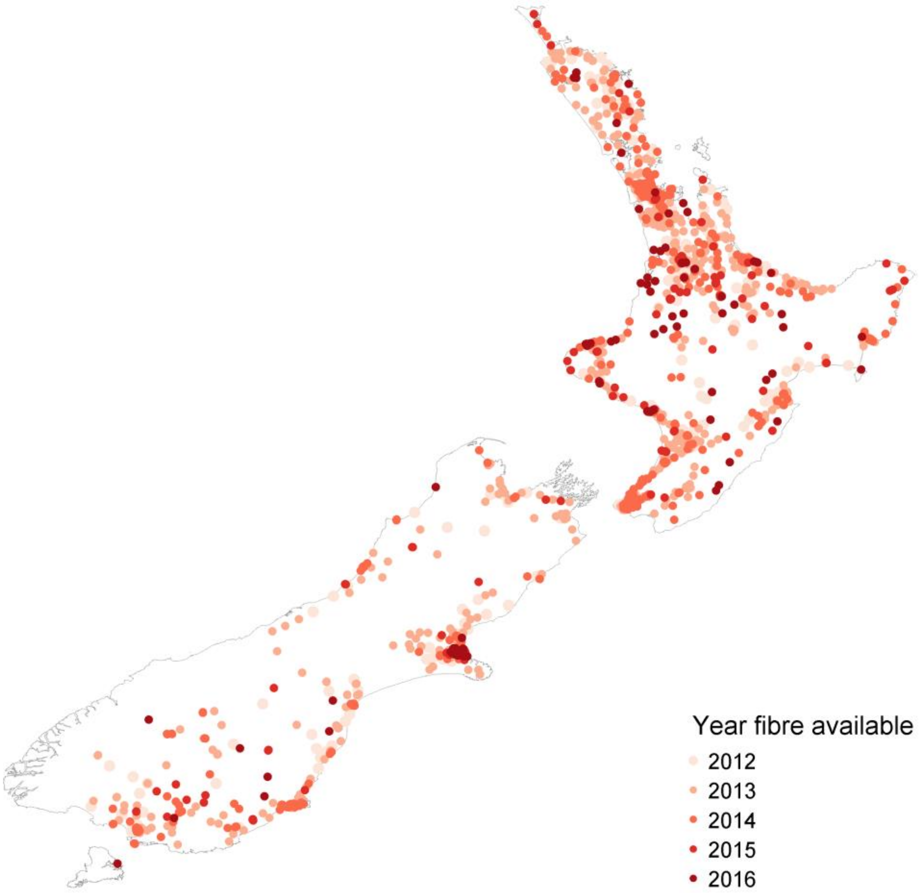


Figure 1 displays the spatial and time variation of schools' access to fibre broadband.[5] The figure demonstrates substantial time variation even within geographical regions. This will allow us to supplement our difference-in-difference specification with specifications which control for year-region interactions, making our estimates robust to regional trends. Figure 1 also

[3] See https://www.beehive.govt.nz/release/ultra-fast-broadband-investment-proposal-finalised.
[4] Note that we treat schools which received access to fibre after February 2015 as having fibre first available in 2016. As of March 2017, 31 schools still lack fast broadband. An additional 71 remote schools, which we omit from our analysis, received fast wireless broadband instead of fibre broadband.
[5] Figure 1 uses our analytic sample described in Section 3.

demonstrates that a wide range of schools could access fibre broadband in the early years of the program. As our school performance data series ends in 2015, schools which received broadband in 2016 do not directly identify our causal estimates.[6]

3 Fibre Connection and Standardised Assessment Data

This study matches standardised assessment data to dates at which schools could access fibre broadband. Data on fibre broadband access is provided by New Zealand's Ministry of Education and covers 86% of state schools. Schools lacking connection date data are mostly those which could access fibre prior to the Ultra-Fast Broadband Initiative. The New Zealand school year runs from February until December and thus we treat a school as being able to access fibre broadband in a year if it could access broadband by the end of February of that year.[7] We study only state schools as data on private schools is generally unavailable.[8]

Since 2010, New Zealand students in the first 8 years of schooling have been assessed against National Standards.[9] Each student is measured against standards of expected competency for their age in each of reading, writing and mathematics. A student is graded as being either 'above', 'at', 'below' or 'well below' the standard for each subject. While the assessment is informed by standardised tests, ultimate judgement is made by the teacher. The standards are low-stakes: a student's performance does not affect her entrance into future education and teachers' pay is not formally linked to their students' performance, though aggregate league tables of school performance are published. Annual school results from 2011, disaggregated by gender and ethnicity, have been provided by the Ministry of Education.[10]

We study the proportion of enrolled students in a school either at or above each National Standard subject. We use the proportion of enrolled students – as opposed to the proportion of students who were assessed against National Standards – as the latter can be manipulated by school management.[11]

We also include school demographic data, provided by the Ministry of Education, as a control in some of our specifications. To demarcate subsamples we map school coordinates against Statistics New Zealand's urban area classification to determine whether a school is rural

[6] These schools do indirectly identify our causal estimates by helping identify the year fixed effects and the controls.
[7] Estimates are very similar if we treat a school as being able to access fibre broadband in a year only if it could access broadband by 1st of January of that year.
[8] We include state-integrated schools in our sample. State-integrated schools are former private schools which have been integrated into the state system. They are afforded more autonomy than other state schools.
[9] National Standards are only assessed in state English-medium schools.
[10] National Standards results were not collated in 2010. In the 2011 data we cannot distinguish zeros from missing observations and thus in the 2011 data we treat all zeros as missing.
[11] The number of students enrolled at a school can vary over the year while our counts of enrolled students are as at 1 July (midway through the New Zealand school year). As such 1.4% of observations show at least one passing rate greater than 1. This also means that if schools with fibre broadband tend to attract many students after 1 July our estimates will be biased upward. See also Footnote 18.

or in a minor urban area (we refer to both as 'rural'). We also demarcate schools with a time-invariant variable indicating whether they could access an alternative form of wired broadband.[12]

Table 1 summarises our sample of school-year observations which include at least one non-missing dependent variable. It groups schools by the year in which they could access fibre broadband, demonstrating that early access to the programme was selective and thus that our estimates will need to control for pre-existing differences. Figure 2 plots average National Standards grouped by both year and the year in which schools could access fibre. This figure demonstrates that groups of schools follow parallel trends before receiving fibre broadband, validating our difference-in-difference identification. An exception is the trend for schools treated in 2016, which are substantially more variable. This group comprises relatively few schools, and as 2016 National Standards data is unavailable this group does not directly identify our causal estimates. Figure 2 also demonstrates that fibre broadband had no large effect on school performance: disproportionate National Standards increases in the years schools receive broadband are, at most, very subtle. However small effects can still be meaningful, and thus more formal estimates are required.

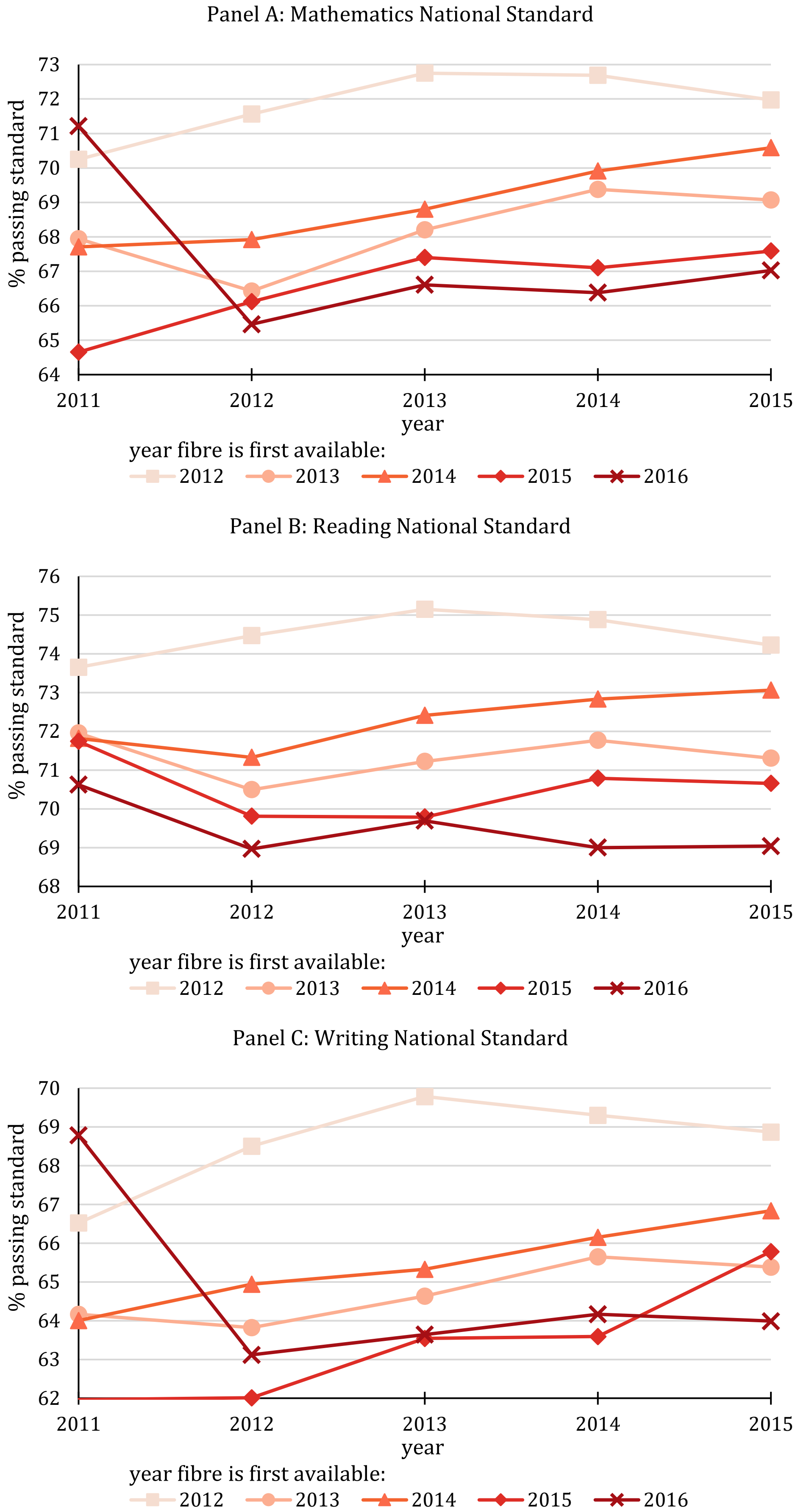
Table 1: Summary statistics

	year fibre first available:					
	2012	2013	2014	2015	2016	missing
number of students	149.8	257.9	275.4	186.1	129.4	324.9
% of students European[18]	63.8	52.4	53.6	54.9	52.5	60.7
% of students male	51.5	51.0	51.3	51.9	51.4	51.4
proportion in a rural area	0.67	0.44	0.29	0.60	0.54	0.33
% passing mathematics National Standard	71.9	68.2	69.0	66.6	67.2	70.5
	(13.9)	(15.4)	(13.8)	(15.2)	(18.1)	(16.3)
% passing reading National Standard	74.5	71.3	72.3	70.5	69.4	74.3
	(13.1)	(15.5)	(13.9)	(16.3)	(17.8)	(15.0)
% passing writing National Standard	68.6	64.7	65.5	63.4	64.6	67.7
	(14.2)	(16.3)	(15.1)	(16.4)	(17.8)	(15.4)
number of schools	183	862	558	126	92	286
number of observations	888	4158	2712	609	442	1199

School-year means outside parentheses, school-year standard deviations within parentheses.

[12] Data indicating whether a school could access alternative broadband has been web-scraped from the National Broadband Map available at https://broadbandmap.nz/. This data was scraped on the 19th of December 2016, though this timing matters little as ADSL access has not substantially changed in New Zealand across the years in our sample.

Figure 2: Primary school performance by year and fibre availability



4 Difference-in-Difference Analysis

We study the effect of fibre availability using a standard fixed effects implementation of the difference-in-difference model. For school s in year t let P_{st} represent the school's (per-student) academic performance,[13] let F_{st} indicate whether the school can access fibre broadband and let x_{st} be a vector of time- and school-varying control variables.[14] We estimate the model

$$P_{st} = \beta \cdot F_{st} + \gamma \cdot \mathrm{x}_{st} + \delta_t + \alpha_s + \varepsilon_{st}$$

in which β is the parameter of interest. In estimating standard errors we allow error clustering within each school.[15] We leave our estimates unweighted, though estimates weighted by student counts are similar.

Table 2: Estimated effects on overall National Standards passing rates

	(1)	(2)	(3)	(4)	(5)	(6)
	Mathematics		Reading		Writing	
effect on % at or above standard	1.149***	1.232***	0.847**	0.857**	0.964**	1.045**
	(0.414)	(0.424)	(0.397)	(0.413)	(0.402)	(0.419)
effect on % above standard	0.416	0.407	0.230	0.274	0.263	0.297
	(0.282)	(0.289)	(0.366)	(0.376)	(0.292)	(0.299)
controls	no	yes	no	yes	no	yes
number of schools	1,818	1,818	1,817	1,817	1,817	1,817
number of observations	8,733	8,732	8,771	8,770	8,698	8,697

Robust standard errors, allowing within-school error clustering, are in parentheses. P-values follow *** < 0.01 < ** < 0.05 < * < 0.1. All specifications control for school and year fixed effects. Counts are for specifications studying effect on those at or above the standard, the counts for the specifications studying the effect on only those above the standard are sometimes 1 lower because of missing data.

We first consider the effect on overall National Standards performance. Table 2 presents estimated effects for each of the three subjects assessed in National Standards. For each subject we present both estimated effects on the percentage of students *above* the standard and estimated effects on the percentage of students either *at or above* the standard (for simplicity we term the latter 'passing rates'). We complement our main estimate for each dependent variable with an estimate from a simpler difference-in-difference model without controls.

We find that the availability of fibre broadband increases National Standards passing rates in each of the three subjects by about one percentage point – per year, by about 2 students at the average-sized primary school and by about 4600 students across all the schools within our sample. Including controls leaves our estimates essentially unchanged. The estimate for

[13] Estimates are qualitatively similar to those from log-linear regressions in which the effect of fibre broadband is presumed to me multiplicative.

[14] The vector of control variables comprises year-region interactions, the school's official socioeconomic decile (see Footnote 17), and the proportions of students in the examined age group who are Māori, Pasifika, Asian, European and male. If we additionally include school-specific linear time trends our estimates attenuate insignificantly towards zero.

[15] Standard errors which allow clustering within 18 geographic regions have also been estimated. These are similar to those presented and are often smaller.

mathematics passing rates is slightly higher than that for writing passing rates, which in turn is slightly higher than that for reading passing rates.[16] The effects on the percentage of students above each standard are substantially smaller and statistically insignificant, though they remain positive.

In Table 3 we consider effects on the passing rates of three at-risk groups: Māori students, Pasifika students and students at low decile schools.[17]

Table 3: Estimated effects on National Standards passing rates among at-risk groups

		(1)	(2)	(3)
		Mathematics	Reading	Writing
Māori students				
	effect on % at or above standard	0.488	1.035	2.134
		(0.716)	(0.684)	(1.692)
	difference p-value	0.817	0.588	0.143
	number of schools	1,712	1,708	1,705
	number of observations	6,663	6,760	6,580
Pasifika students				
	effect on % at or above standard	-1.329	-0.425	2.507*
		(1.694)	(1.580)	(1.373)
	difference p-value	0.751	0.872	0.343
	number of schools	1,211	1,208	1,195
	number of observations	3,655	3,758	3,588
at Decile 1 schools				
	effect on % at or above standard	2.175	0.732	4.220**
		(2.010)	(1.743)	(2.097)
	difference p-value	0.435	0.850	0.074
	number of schools	230	230	230
	number of observations	846	861	839
at Decile 1-3 schools				
	effect on % at or above standard	2.271**	1.826*	2.153**
		(1.002)	(0.958)	(0.984)
	difference p-value	0.128	0.175	0.122
	number of schools	599	597	599
	number of observations	2,506	2,534	2,492

Robust standard errors, allowing within-school error clustering, are in parentheses. P-values follow *** < 0.01 < ** < 0.05 < * < 0.1. All specifications control for school and year fixed effects and a set of controls described in the text. Reported 'difference p-value' tests cross-equation restrictions comparing effects on Māori or Pasifika students to effects on non-Māori, non-Pasifika students and comparing effects on Decile 1 or Decile 1-3 students to effects on Decile 4-7 students.

[16] When these estimates are produced within a seemingly unrelated regressions model, a cross equation restriction that the effects on mathematics, reading and writing passing rates are identical is not rejected, with p-value = 0.54 for both the specification with controls and the specification without.

[17] A school's socioeconomic decile is a number between 1 and 10 used by the Ministry of Education in determining school funding. Decile 1 schools have the highest proportions of low-income students, Decile 10 schools have the least.

Given the smaller number of relevant students within each school, these estimates are less precisely estimated. To avoid spurious comparisons we include 'difference p-values' for each specification: cross-equation tests on the restriction that these estimates are equal to estimates from a broader comparison group. The comparison group for Māori and Pasifika students is non-Māori, non-Pasifika students (European, Asian and other). The comparison group for students at Decile 1 schools and at Decile 1-3 schools is students at Decile 4-10 schools. When estimating the difference p-values for Māori students we retain only observations that have defined passing rates for both Māori and for our comparison group; we do similarly for Pasifika students.

We find no evidence that Māori and Pasifika students benefit more from fibre broadband than do other students. However, we do find weak evidence suggesting that students at low decile schools benefit more than students at higher decile schools: the point estimates are, with one exception, substantially larger but the estimates are noisy and the difference tests never reject their null with 95% confidence. If the most optimistic estimate, that for the effect on the writing National Standard at Decile 1 schools, was correct it would mean that on average providing fibre broadband caused an additional 7 students at each Decile 1 school to pass. We have an insufficiently large sample to estimate the effect specifically on Māori or Pasifika passing rates at low decile schools. However if students at low decile schools do benefit disproportionately, it is likely that this includes a disproportionate number of Māori and Pasifika students: about 90% of Decile 1 students and 70% of Decile 1-3 students are Māori or Pasifika.

Table 4: Estimated effects on National Standards passing rates by gender

	(1)	(2)	(3)
	Mathematics	Reading	Writing
boys			
effect on % at or above standard	1.814***	0.933*	1.071**
	(0.510)	(0.491)	(0.502)
number of schools	1,796	1,798	1,793
number of observations	8,393	8,448	8,274
girls			
effect on % at or above standard	1.262**	0.831*	1.178**
	(0.489)	(0.483)	(0.481)
number of schools	1,797	1,799	1,793
number of observations	8,378	8,453	8,326
difference p-value	0.270	0.669	0.865

Robust standard errors, allowing within-school error clustering, are in parentheses. P-values follow *** < 0.01 < ** < 0.05 < * < 0.1. All specifications control for school and year fixed effects and a set of controls described in the text. Reported 'difference p-value' tests cross-equation restrictions comparing effects on boys to effects on girls.

Table 4 presents estimates which delineate the effects of fibre broadband by students' gender. Paradoxically, the mathematics and writing estimates for both boys and girls are larger than the estimates for the overall effect: this is because the estimated effect within the subsample of schools on which these variables are non-missing is slightly larger than it is in the full sample. The point estimates suggest only slight differences between the effect on boys' and girls' passing rates, except for in mathematics where the estimated effect on boys' passing rates is about half a percentage point larger. However the difference test – which here simply compares boys' passing rates to girls' – cannot reject its null hypothesis that the effects on boys' and girls' mathematics passing rates are equal.

Table 5: Estimated effects on National Standards passing rates by geography

	(1)	(2)	(3)
	Mathematics	Reading	Writing
at rural schools			
effect on % at or above standard	1.466**	1.052	1.219*
	(0.737)	(0.710)	(0.715)
difference p-value	0.423	0.602	0.566
number of schools	780	781	781
number of observations	3,748	3,771	3,733
at schools without alt. wired broadband			
effect on % at or above standard	-1.227	-1.794	1.476
	(2.659)	(2.634)	(2.553)
difference p-value	0.294	0.245	0.837
number of schools	64	64	64
number of observations	304	307	301

Robust standard errors, allowing within-school error clustering, are in parentheses. P-values follow *** < 0.01 < ** < 0.05 < * < 0.1. All specifications control for school and year fixed effects and a set of controls described in the text. Reported 'difference p-value' tests cross-equation restrictions comparing effects within rural schools to effects within other schools and comparing effects within schools without alternative wired broadband to effects within schools with alternative wired broadband.

Table 5 presents our final difference-in-difference estimates for the effects on National Standards. These estimates ask whether isolated schools benefit more from fibre than did schools in larger cities. We find no evidence that they do: the point estimates for the effects within rural schools are similar to those presented earlier, and estimates for the few schools without an alternative form of wired broadband are, for two subjects, actually negative (though these estimates are particularly imprecise and their difference p-values are insignificant).

Overall, our estimates indicate that the availability of fibre broadband seems to have a reliable, small, positive effect on National Standards pass rates. The effect is similar on each of mathematics, reading and writing. There is no evidence that any ethnicity, gender or geographic classification benefits more or less than average, but the effect within low-decile schools does seem to be slightly larger.

Our final estimates consider the dynamic effects of fibre broadband. Doing so serves two purposes. First, by checking whether fibre appears to increase school performance in the year before fibre is implemented we perform a robustness check on our difference-in-difference estimator. Second, we check whether the estimated effects of fibre increase in later years. Table 6 suggests that neither potential concern is warranted. Estimated effects for the year before fibre is available are insignificant. Marginal effects on National Standards results in later years are small and insignificant.

Table 6: Estimated effects before and after fibre availability

	(1)	(2)	(3)
	Mathematics	Reading	Writing
effect on % passing:			
year before fibre is available	-0.109	0.279	0.0611
	(0.664)	(0.701)	(0.671)
first year fibre is available	1.004	1.091	0.996
	(1.085)	(1.152)	(1.106)
additional effect 1 year after	0.787	0.760	0.737
	(0.565)	(0.587)	(0.571)
additional effect 2 years after	0.310	0.261	0.146
	(1.044)	(1.097)	(1.087)
additional effect 3 years after	0.162	0.644	0.214
	(1.644)	(1.681)	(1.690)
number of schools	1,818	1,817	1,817
number of observations	8,732	8,770	8,697

Robust standard errors, allowing within-school error clustering, are in parentheses. P-values follow *** < 0.01 < ** < 0.05 < * < 0.1. All specifications control for school and year fixed effects and a set of controls described in the text. 'Additional effect' rows report the additional effect of fibre broadband a certain number of years after it was made available, above the effect in the initial year.

5 Discussion and Conclusions

Evaluating the cost-effectiveness of network infrastructure like fibre broadband is difficult because such infrastructure has many users over a long timeframe. This paper has exploited exogenous timing in the availability of fibre broadband to identify causal estimates of its effects. We find that primary schools have benefited from their use of fibre broadband. As increasing educational performance was a policy justification for the Ultra-Fast Broadband Initiative, the programme can be considered a success in that respect.

The effect size we estimate is positive but not large. Nevertheless we can distinguish it from zero because our estimates are particularly precise: our primary specifications have 95% confidence intervals equal to 3% of a standard deviation, while insignificant estimates in the existing literature have confidence intervals equal to 10% of a standard deviation (Hazlett, Schwall, and Wallsten, 2016). We find no large differences in effect sizes among ethnic groups or genders, or between urban schools and those which are more isolated. We do, however, find some evidence that low-socioeconomic schools benefit more than those with wealthier students.

Our data cannot identify the mechanism through which fibre broadband increases school performance. In our introduction we emphasised the expansion in the set of technologies available to educators, which may allow teaching to be more individualised and more engaging, or may facilitate better monitoring of student performance. However alternative mechanisms are possible. Traditional academic skills could be complementary to computer skills and thus, if broadband provision results in greater computer skills, broadband may induce students or their families into greater investments in academic skills. Alternatively, broadband may allow schools to perform previously-expensive tasks cheaply, reallocating their resources towards academic achievement. Data on the ways that schools are using fibre broadband or evaluations of more specific pedagogical interventions would help elucidate which of these mechanisms are important.

References

Barrow, Lisa, Lisa Markman, and Cecilia Elena Rouse. 2009. "Technology's Edge: The Educational Benefits of Computer-Aided Instruction." *American Economic Journal: Economic Policy* 1 (1): 52–74. doi:10.1257/pol.1.1.52.

Belo, Rodrigo, Pedro Ferreira, and Rahul Telang. 2013. "Broadband in School: Impact on Student Performance." *Management Science* 60 (2): 265–82. doi:10.1287/mnsc.2013.1770.

Bulman, George, and Robert W. Fairlie. 2016. "Technology and Education: Computers, Software, and the Internet". Working Paper 22237. National Bureau of Economic Research. http://www.nber.org/papers/w22237.

Fabling, Richard, and Arthur Grimes. 2016. "Picking up Speed: Does Ultrafast Broadband Increase Firm Productivity?" Motu Working Paper 16-22. http://motu-www.motu.org.nz/wpapers/16_22.pdf.

Goolsbee, Austan, and Jonathan Guryan. 2006. "The Impact of Internet Subsidies in Public Schools." *Review of Economics and Statistics* 88 (2): 336–47. doi:10.1162/rest.88.2.336.

Hazlett, Thomas W., Benjamin Schwall, and Scott Wallsten. 2016. "The Educational Impact of Broadband Subsidies for Schools Under E-Rate". SSRN Scholarly Paper ID 2796048. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=2796048.

Jesson, Rebecca, Stuart McNaughton, Naomi Rosedale, and Tong Zhu. 2015. "Manaiakalani Evaluation Programme Final Report 2012 – 2014". The University of Auckland.

Mirza, Farhaan, and Fernando Beltrán. 2014. "Consumer Resistance Factors for the Adoption of FTTH Ultra-Fast Broadband in New Zealand." *Journal of Information Policy* 4: 128–43. doi:10.5325/jinfopoli.4.2014.0128.

Appendix: Effects on the National Certificate of Educational Achievement

New Zealand students in the last three years of schooling – years 11, 12 and 13 – normally sit the three levels of 'NCEA', the National Certificate of Educational Achievement.[18, 19] In this appendix we study the effects of fibre broadband on NCEA performance. Estimated effects on the proportions of students achieving each level of NCEA are much less precise because there are fewer secondary schools in our sample. 95% confidence intervals for these estimates are between 6 and 10 percentage points wide and always include zero. However we find that fibre broadband does significantly increase the proportion of students meeting NCEA's numeracy requirements.

NCEA is a series of formal qualifications recognised by tertiary-educators and employers,[20] assessed by a combination of internal assessments (managed by the school) and external assessments (managed by the New Zealand Qualifications Authority). League tables of NCEA results are published, and again teachers are not formally paid on the basis of their students' performance. NCEA data has been provided by the New Zealand Qualifications Authority. We include NCEA results from 2008.

Our NCEA dependent variables are the proportions of enrolled students who had passed each level of NCEA by the end of the year in which that level of NCEA is generally first attempted: Level 1 by year 11, Level 2 by year 12 and Level 3 by year 13. As in our analysis of National Standards we divide passing counts by enrolment counts.

A subset of students who pass NCEA have their qualification endorsed with merit or excellence. About a quarter of students who pass NCEA level 1 have their qualification endorsed with merit, an additional 10% have their qualification endorsed with excellence. Proportions at higher levels are somewhat smaller. NCEA Level 1 has numeracy and literacy requirements which traditionally required students pass papers in mathematics or statistics (for numeracy) and in English or Te Reo Māori (for literacy).[21]

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[18] Some students sit the International Baccalaureate or the Cambridge International Examinations. These are mostly students at private schools who are excluded from our analysis. However the small number of students at state schools who sit these assessments will be included in our data and will be treated as failing NCEA. If the probability that a student at a state school sits these alternative qualifications changes following the availability of ultra-fast broadband to that school, our estimates will be biased. Regression estimates excluding schools which offer these alternative qualifications are very similar to those estimated on the full sample, differing by less than a tenth of a percentage point.

[19] A small number of students attend school in year 14 or year 15. We omit these students from our sample.

[20] University entrance requires a separate qualification, though that qualification is based off performance in NCEA courses.

[21] In 2013 the literacy and numeracy requirements were loosened, see http://www.nzqa.govt.nz/qualifications-standards/qualifications/ncea/subjects/literacy-and-numeracy/level-1-requirements/.

Appendix Table 1 summarises our sample and Appendix Figure 1 plots NCEA performance by year and by the year in which schools received fibre broadband. The larger amount of pre-treatment data allows us to more easily confirm the validity of the parallel trends assumption; again the trend in schools which received fibre in 2016 differs from that elsewhere.[22]

Appendix Table 1: NCEA Summary Statistics

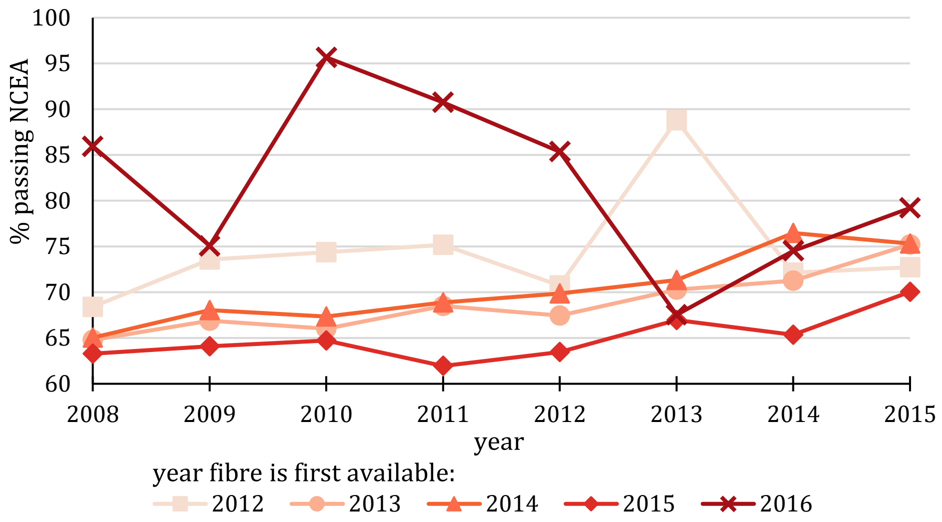
	year fibre first available:					
	2012	2013	2014	2015	2016	missing
number of students	420.8	615.3	634.4	377.9	481.8	1,025.9
% of students European[18]	49.3	47.1	50.3	46.5	39.3	53.7
% of students male	53.3	51.4	46.6	48.6	38.2	49.7
proportion in a rural area	0.55	0.40	0.38	0.66	0.28	0.12
% passing NCEA level 1	74.5	68.9	70.3	65.1	81.6	72.6
	(30.2)	(18.4)	(18.9)	(20.7)	(26.2)	(21.7)
% passing NCEA level 2	78.7	73.5	73.6	71.5	94.6	74.6
	(23.3)	(19.6)	(17.7)	(20.5)	(70.9)	(19.4)
% passing NCEA level 3	65.4	57.6	58.2	53.9	74.2	63.2
	(27.4)	(23.3)	(22.4)	(25.3)	(30.1)	(21.4)
% achieving NCEA level 1 literacy	90.4	86.5	86.9	85.4	89.2	87.5
	(9.8)	(12.4)	(12.5)	(12.6)	(15.7)	(13.1)
% achieving NCEA level 1 numeracy	88.1	87.3	88.2	83.9	88.7	88.2
	(11.4)	(11.8)	(11.9)	(15.0)	(12.1)	(13.6)
number of schools	23	159	96	29	10	124
number of observations	177	1212	750	213	72	908

School-year means outside parentheses, school-year standard deviations within parentheses.

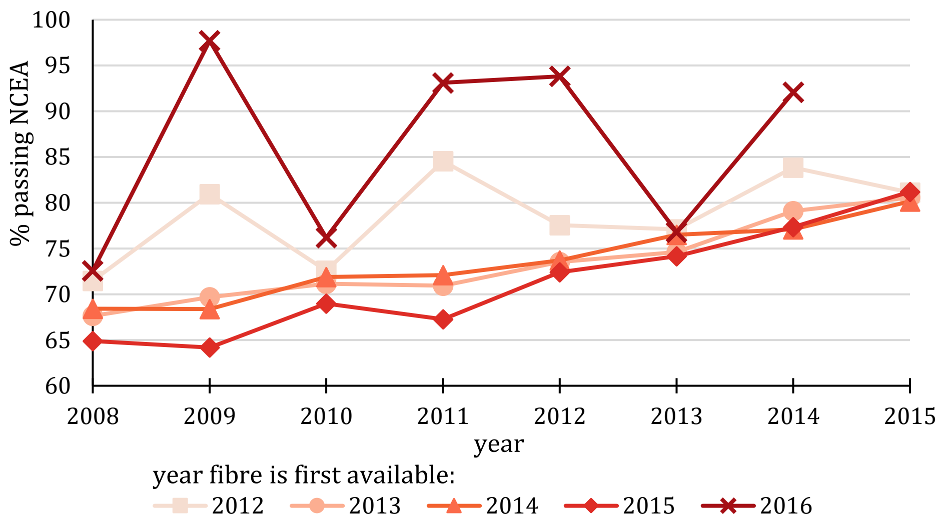
[22] Panel 3B omits the 2015 NCEA Level 2 data point for schools which received fibre broadband in 2016, an outlier caused by a school with only 1 year 12 student (as at 1 July) having a passing rate of 600% (see Footnote 11).

Appendix Figure 1: Secondary school performance by year and fibre availability

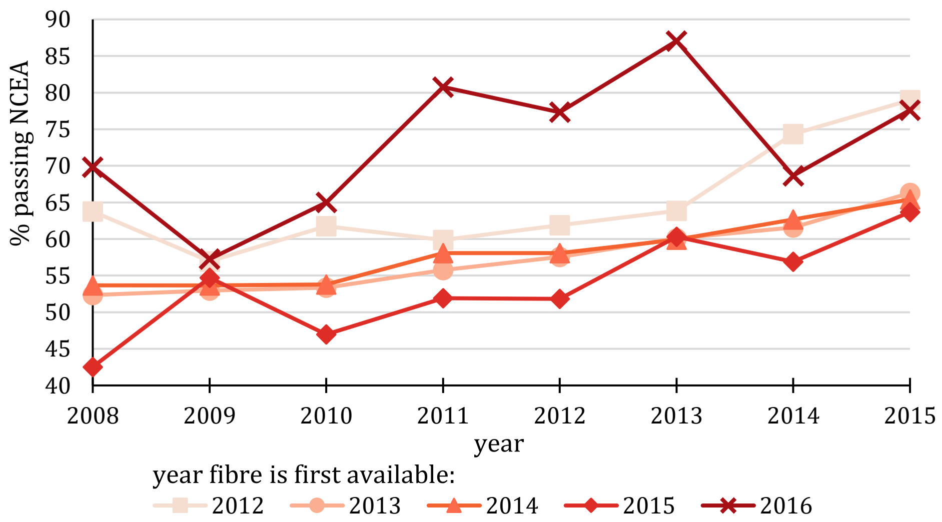
Panel A: NCEA Level 1



Panel B: NCEA Level 2



Panel C: NCEA Level 3



Appendix Table 2: Estimated effects on NCEA passing rates

	(1)	(2)	(3)	(4)	(5)	(6)
	Level 1		Level 2		Level 3	
effect on % passing	2.515	2.964	-3.489	-3.405	0.0103	0.383
	(1.767)	(1.959)	(2.535)	(2.301)	(1.655)	(1.678)
effect on % receiving merit	0.115	-0.123	-1.423	-1.577*	0.231	0.655
	(0.829)	(0.864)	(0.933)	(0.895)	(0.705)	(0.744)
effect on % receiving excellence	0.511	0.796	-0.579	-0.634	0.610	0.558
	(0.598)	(0.692)	(0.513)	(0.546)	(0.396)	(0.410)
effect on % achieving literacy requirements	0.590	0.740	—	—	—	—
	(0.852)	(0.825)				
effect on % achieving numeracy requirements	1.762*	2.269**	—	—	—	—
	(1.024)	(1.073)				
controls	no	yes	no	yes	no	yes
number of schools	314	314	313	313	308	308
number of observations	2,364	2,364	2,368	2,368	2,284	2,284

Passing proportions include those receiving merit or excellence. Robust standard errors, allowing within-school error clustering, are in parentheses. P-values follow *** < 0.01 < ** < 0.05 < * < 0.1. All specifications control for school and year fixed effects. Counts correspond passing, merit and excellence specifications, 315 schools were included in the literacy requirement regressions and 317 were included in the numeracy requirement regressions.

Appendix Table 2 displays estimated effects on the percentages passing each level of NCEA, the percentages receiving merit and excellence at each level and the percentages achieving NCEA level 1's literacy and numeracy requirements. As before we complement our main estimates with estimates from a simpler difference-in-difference model which excludes controls.

There is no evidence that fibre broadband substantially affected NCEA passing rates. Estimates are imprecise, insignificant, and as often negative as positive. Estimated effects on those receiving merit or excellence are closer to zero – rarely larger than a percentage point in absolute terms – and are insignificant. The effect on the percentage of students passing the literacy requirements is small and insignificant. The effect on the percentage of students passing the Level 1 numeracy requirements is a little smaller than the estimated effect on overall Level 1 pass rates. However it is more precisely estimated and thus significant at the 95% level.

We repeated our NCEA analysis for subsamples of schools and for certain demographics, as we did in our analysis of the National Standards data, but (as would be expected given the precision of the estimates in Table 6) these estimates are noisy and very rarely reject their null.

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