THE IMPACT OF LOCAL BROADBAND ACCESS ON HIGH SCHOOL GRADUATION RATES

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ABSTRACT

The United States government has been funding infrastructure expansions and upgrades to bring Internet access to schools and households. While this broadband funding has increased access and adoption, it is unclear how improvements in Internet access affect student performance because Internet access has both productivity and distraction effects. The Internet provides students with access to vast amounts of educational content, instructional videos and other valuable resources that increase productivity. It also provides students access to social media, video games and other forms of entertainment that distract students and reduce student performance. While the literature shows that advances in technology (computers) and Internet access improve firm performance (Brynjolfsson and Hitt 1996), recent studies find that increased access to the Internet has almost no effect on student performance. Using a dataset of 247 counties in Texas with broadband penetration and graduation rates in public schools in 2000, 2010 and 2017, I find that a 10 percentage-point increase in broadband penetration is associated with a statistically significant 1.83 percentage-point increase in graduation rates after correcting for endogeneity. This result differs from what other published literature find on this topic.

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INTRODUCTION

The use of computers and the expansion of Internet access has increased substantially in the past 20 years. Today, 99 percent of public schools are equipped with computers that have Internet connections.[1] Despite this, there are still 19 million Americans that have not adopted a home-based fixed broadband service.[2] Politicians and regulators actively push for funding and expansion of Internet infrastructure, and as a result, the U.S. Government's Broadband Equity, Access and Deployment (BEAD) program allocates a $42.5 billion to ensure that every household in the United States and its territories has access to fast and reliable Internet service. It is designed to bring infrastructure to unserved and underserved communities.

Local Internet access and school performance became one of the main topics when the COVID-19 pandemic forced most schools to move to remote learning and dramatically increased the importance of Internet Access.[3] It was no longer a question whether the Internet should be used to enhance instruction, but Internet access became a necessity for students taking classes online. Students without Internet access found it extremely difficult to attend classes and continue their studies. However, there is a distinction between the ability to attend instruction and how the Internet access affects performance under normal conditions.

Recent studies find that increased access to the Internet has almost no effect on student

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[1] Landmark achievement that was accomplished and celebrated in 2019.
https://www.nga.org/news/commentary/governors-prioritize-expanding-internet-access-for-k-12-students/

[2] Annual report published by FCC about deployment of Internet infrastructure.
https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2020-broadband-deployment-report
Under the current definition, set by the Federal Communications Commission in 2015, internet service counts as "broadband" if it delivers download speeds of at least 25 megabits per second (or Mbps) and upload speeds of at least 3 Mbps.

[3] Decisions to temporarily shift to remote learning were made by schools, school districts and generally followed assessments of local and state governments.

performance. For example, the E-rate program provided funds that increased access to the Internet in schools and libraries across the US. Goolsbee and Guryan (2006) find that the E-rate program had no measurable impact on student performance.[4]

High-speed Internet access provides users access to a broad range of services, including information, artificial intelligence tools, communications, streaming services, educational and employment opportunities, tele-medicine and social media. Broadband access, and information technology in general, is responsible for increases in firm productivity and improvements in market performance. Zuo (2021) shows that increases in broadband access increased wages and employment rates for eligible low-income customers in targeted markets. The local economy can also benefit from Internet infrastructure. Increases in broadband access (especially in rural areas) increase the likelihood of firms entering local markets (Kim and Orazem 2016).

While the literature shows that advances in technology (computers) and Internet access improve firm performance (Brynjolfsson and Hitt 1996), there is little evidence that an increase in Internet access improves student performance. Research shows that children using the Internet and computers spend large amounts of time playing video games (Malamud and Pop-Eleches, 2011). Chen, Mittal and Sridhar (2021) find that it might also increase disciplinary issues in schools. This study uses data from 2000, 2010 and 2017, and a correction for the

[4] "The universal service Schools and Libraries Program, commonly known as "E-rate," provides discounts of up to 90 percent to help eligible schools and libraries in the United States obtain affordable telecommunications and internet access. The program is intended to ensure that schools and libraries have access to affordable telecommunications and information services." https://www2.ed.gov/about/inits/ed/non-public-education/other-federal-programs/fcc.html

endogeneity of Internet access to estimate the effect of Internet access on student performance.

LITERATURE REVIEW

Goolsbee and Guryan (2002) examined the effect of the E-rate on Internet access and student performance.[5] The E-rate program provides affordable telecommunications, Internet access and internal connections to schools and libraries, with a strong focus on connecting rural and low-income communities. They find that while the E-rate subsidy program significantly increased internet access, it had no significant effect on test scores and academic performance. Similarly, Hazlett, Schwall and Wallsten (2016) find that E-rate subsidies had no impact on SAT test scores in North Carolina public high schools. Ward (2006) finds that E-rate subsidies in Texas high schools had no impact on SAT scores and had a negligible impact on ACT scores or the fraction of students who enrolled in college. [6] Studies examining the impact of the E-rate program on student performance generally find that the program had no statistically significant effect on student performance.

Belo, Ferreira and Telang (2014) find a negative relationship between middle-school student performance and Internet usage. Students in schools that deny access to Youtube, however, outperformed students in schools without online content restrictions. Faber, Guarner and Weinhardt (2015) find similar results when studying increased access to Internet and Internet speeds to the home. While they find that Internet consumption and access has increased, increased Internet access has no significant impact on educational attainment or the time spent studying.

Chen, Mittal and Sridhar (2021) find that an increase in school spending on Internet

[5] The E-rate program funding equaled to $25B and funding came from Universal Service Fund tax equal to 18.2% of telephone charges identified as long-distance calling.
[6] $50M of funds on average is annually infused to sampled schools.

access has a positive impact on student performance. They find that a one standard deviation increase in Internet-access expenditures increased graduation rates by 4.7 percentage points. Similar results are found for college readiness and performance on state-mandated exams. However, they also find that a one standard-deviation increase in funding increases offense-related disciplinary problems by five percentage points. They find that there are both positive and negative consequences associated with increases in spending on Internet access and that both effects are amplified in school districts where household internet penetration rates are relatively high. In the study, Chen, Mittal and Sridhar used two stage-least-squares to correct for the potential endogeneity of Internet access and to estimate the impact of Internet spending on school performance and disciplinary actions. Grimes and Townsend (2017) find that availability of fibre Internet in primary schools in New Zealand increased passing rates of the National Standard assessment by one percentage point.[7]

A related line of literature examines the effects of computers and information technology in schools on student performances. Theoretically, the effects of information technology on student performance depend on how it is used and integrated into the curriculum. The use of technology in the classroom can be treated as a substitute or a complement to more traditional forms of instruction. Angrist and Levy (1999) study the impact of computerization on both the instructional use of computers and student test scores. They find that increased computer usage has no significant effect on test scores. They argue that

[7] "The National Standards give schools reference points to assess students" progress and achievement with a focus on raising achievement in reading, writing and mathematics. The standards are to be used in conjunction with assessment practices developed by each school to help with this process."
https://nces.ed.gov/statprog/handbook/pdf/naep.pdf

computers likely displace other traditional forms of productive instruction.[8] The study also finds that additional time spent with traditional instruction as a supplement after the introduction of computers in classroom had no impact on student test scores.

Bulman and Fairlie (2015) argue that new technologies displace more effective traditional teaching methods and distract students but can be effective when used as a supplement to traditional instruction. They also note that computer-assisted instruction is most effective in developing countries, where schools usually do not have well-developed or strong traditional instruction.

Fuchs and Woessmann (2004) find a negative correlation between student achievement and the availability of computers at home and at school using data from 32 countries. They find a significant relationship between home computer use and educational programs. Computer use at home increases computer skills, but this improvement is at the expense of other skills. Similarly, Falck, Mang and Woessmann (2018) find mixed effects among fourth and eighth graders. They find positive effects of using computers to look up information and negative effects of using computers to practice skills. Fairlie and Robinson (2013) conducted an experiment where computers were randomly allocated to households and find that computers had no significant effect on educational outcomes.

More recent research on local Internet access also covers the impacts of Covid 19 on school performance. Children in households with less reliable Internet and fewer devices were at a disadvantage as they spent fewer hours a day remote learning (Weller, Francis 2022). In

[8] The resources, such as computers and computer training were provided to teachers in elementary schools based on a remedial basis while the allocation of resources was given to regions and towns with highest fraction of stand-alone schools.

households with less educated parents, the parents spent equal time helping children as better educated parents but face significantly more problems with local computer and Internet access (Starr, Bansak 2021). One quarter of students increased their time studying by more than four hours per week during the pandemic, while another quarter decreased their study time by more than five hours per week. This heterogeneity often followed existing socioeconomic differences; lower-income students are 55 percent more likely to have delayed graduation due to COVID-19 than their peers from higher-income households. (Aucejo, French, Araya, Zafar, Nov 2020).

Overall, the literature finds very little evidence that the Internet, computers, and information technology in general, have a positive and significant effect on student performance. If any positive effects are found, the authors usually describe them as of low magnitude. Additionally, multiple studies report the negative impact of the Internet and computers on students, such as increased disciplinary actions or distractions caused by computers. My paper adds to the literature by estimating the effect of Internet access on high-school graduation rates in Texas. In contrast to much of the literature, this study examines the effects of Internet access at the household level, using data on Internet access from 2000, 2010, and 2017, and correction for the endogeneity of Internet access.

THEORETICAL DISCUSSION

Local Internet access is generally defined as wireline broadband access to the home. Internet access is regarded as an important educational input and its benefits can contribute to an increase in student productivity. The Internet allows students to access more information and gives them access to learning tools such videos, online meetings, or additional textbook-like materials. Moreover, students can communicate with other students in the classroom and cooperate on assignments or test preparation. Parents can oversee the performance of their children by communicating with teachers via email or student portals. For example, parents can schedule a virtual meeting with a teacher rather than waiting for quarterly parent-teacher conferences to address any concerns. They can also track their children's day-to-day classroom performance. These factors can have a positive productivity effect on students and their performance in school.

The Internet can be used for leisure as well as schoolwork. Students can use the Internet to play games, stream movies, watch videos or chat with friends on social media. This increase in the quality of leisure activities may lead students to consume more leisure and spend fewer hours on schoolwork. In some cases, Internet access may lead to bullying and disciplinary issues. These distraction effects reduce student performance. Overall, the effect of Internet access has an ambiguous effect on student performance. Because my data provide information on Internet adoption rates at the county level, I use data on share of students who graduate from high school to gain information on the overall effect of Internet access on graduation rates.

EMPIRICAL FRAMEWORK

Local Internet access has both productivity (positive) and distraction (negative) effects on student performance. The impact of the two competing effects of the Internet on student performance depends on the relative impact of these effects. To gain insight, I estimate the following:

$$Y_{ct} = \alpha_c + \tau_t + M_{ct}\beta + \delta Internet_{ct} + \varepsilon_t$$

The dependent variables, Y_{ct}, equals the share of high-school students in county c who graduated in year t. The vector M_{ct} contains controls for county characteristics. $Internet_{ct}$ equals the Internet penetration rate in county c in year t. The vectors *β and* δ include the coefficients for M_{ct} and $Internet_{ct}$, and ε_t equals the random disturbance term. δ measures the effect of the Internet penetration rates on graduation rates. The time variable τ_t accounts for all changes impacting students and schools in Texas over time.

This paper's primary interest is the effect of Internet on student outcomes as measured by the estimate of δ. Estimates of the effects of the Internet and our control variables on student performance will be inconsistent and biased when the individual heterogeneity factor, α_c, is correlated with any of the variables included in the vector M_{ct} or the $Internet_{ct}$. As a result, I use a standard fixed-effects specification to control for this individual heterogeneity. I also include time fixed effects to control for state-wide time-varying unobservables.

The likelihood that a student graduates high school depends on the student's ability, the effect of the peers, household inputs, school inputs and graduation standards. The effect of access to the Internet on the likelihood of graduation depends on the Internet's effect on these inputs. Existing research shows that while there is evidence that Internet access provides students access to additional resources and can increase the productivity of parent and school inputs, it can also reduce student effort and student peer effects can impose costs on students that reduce student effort and performance.

The model can suffer from omitted variable bias when time-varying unobserved characteristics that affect graduation rates are correlated with Internet penetration rates. Failing to control for omitted variables can result in biased and inconsistent estimates of the effect of Internet access on graduation rates. My analysis of the problem, and the related literature, provides no unambiguous expectation about the direction of this potential bias. Consider an unobserved shock that increases the demand for information and educational materials. This shock increases the demand for the Internet and is also likely to improve student performance. As a result, a comparison of graduation rates between counties with high and low Internet penetrations will overestimate the effect of Internet penetration rates on graduation rates. By contrast, an unobserved shock that increases the entertainment demand for Internet access could result in a downward bias of the estimated effect of Internet access on graduation rates. My estimation strategy includes controls for observed county characteristics and the individual heterogeneity of counties. I also use two-stage least squares to address the endogeneity of Internet access.

I deploy an instrumental variable approach to correct for potential omitted variable bias. Two-stage least squares allows me to estimate the coefficient of Internet penetration using instrumental variables if the instruments satisfy the conditions of instrument relevance and validity. The instruments are relevant and valid when they are correlated with Internet penetration but are not correlated with ε_t. The first stage links the Internet penetration with the instrument variables (Z),

$$Int_{ct} = \eta_0 + \alpha_c + \tau_t + \eta_1 Z_{ct} + v_{ct}$$

where Z includes the vector M and instrumental variables W. η_0 is the intercept, η_1 is the slope and v_i is the error term. Since W_{ct} is exogenous, this component of Z_{ct} is uncorrelated with the error term v_{ct}.

DATA

I compiled the data for this study from various sources. The study includes data for 247 counties in Texas in 2000, 2010 and 2017. Figure 2 in the Appendix lists all counties included in this study. I obtained data on high-school graduation rates from Texas Academic Performance Reports (TAPR) and Academic Excellence Indicator System (AEIS). Both systems are managed by the Texas Education Agency. AEIS is TAPR's predecessor that was used before 2012-2013. This study uses 2010 data from AEIS and 2017 data from TAPR. The definitions of all variables used in this study are identical for both systems. The data are collected at the school district level and then aggregated to county level using a weighted average. The variable $\textit{Graduation Rate}_{ct}$ is the dependent variable and equals the share of students who graduate high school in five or fewer years from their freshman year. The definition of graduation is the same in 2000, 2010 and 2017 but it is unclear if the standard for graduation has changed over time. The consolidated sample of graduation rates is made up of 1,100 school districts as some of the districts did not have data readily available for all years used in this research. 147 districts were omitted from the study because they did not have data for at least one of the studied school-specific years. TAPR and AEIS also provide school specific independent variable. $\textit{Teachers Experience}_{ct}$ equals the percentage of teachers who have more than 10 years of experience teaching.

I obtained data for Internet penetration rate from FCC and NTIA. $\textit{Internet}_{ct}$ equals the share of residences in the market with a fixed Internet connection over 200 kbps for the year 2010 and 2017. For the year 2000, the data comes from 2001 as that is the closest available data point. The data point for 2001 is interpolated based on the ratio of 2001 to 2010 Internet penetration for each metropolitan statistical area which is subsequently matched to counties based on its appropriate location. (Savage and Wimmer 2022) 247 counties with varying characteristics are available for the study.

The remaining independent variables come from U.S. Census Bureau survey. For 2000, data points come from decennial census and for 2010 and 2017, data points are pooled come from the 5-year American community survey (ACS). I match county-level student-performance and internet-access data to demographics and other socioeconomic variables for the years t= 2000, 2010, and 2017. The variable $English_{ct}$ equals the percentage of population with children who speak English only or speak English well or very well along with another language. Language can be a barrier and impact educational attainment. $College\ Degree_{ct}$ equals the percentage of household heads with children under 18 and who have a bachelor's degree or higher. $Single\ Mother_{ct}$ variable is defined as a percentage of all households with a family consisting of a mother and one or more children. The variable $Poverty_{ct}$ equals the percentage of population living at or below poverty. $Non\text{-}White_{ct}$ equals the share of population by ages 5 to 18 that is not white. $Hispanics_{ct}$ equal the share of population by ages 5 to 18 who are Hispanic of any race.

This study includes two instrumental variables. The first instrumental variable is $Road\ Miles_{ct}$. It is defined as number of road miles per square mile in a county and comes from Topologically Integrated Geographic Encoding and Referencing (TIGER) local roads files. The second instrumental variable is $Housing\ Density_{ct}$. $Housing\ Density_{ct}$ is sourced from decennial census and TIGER system, and equals the number of housing units per county road mile. For the estimators to be consistent, instrumental variables need to be relevant (correlated with endogenous variable) and related to dependent variable only through the endogenous variable, meaning the variable has an effect on Internet penetration rates but no effect on high school graduation rates. $Road\ Miles_{ct}$ and $Housing\ Density_{ct}$ meet this criterion as they are supply factors of Internet driven by costs to build out and expand broadband infrastructure. These variables are correlated with the cost of delivering broadband services to households. Increases in household density reduce the average cost of building and maintaining broadband infrastructure because it allows costs to be shared by households. Thus, an increase in density lowers costs and increases internet penetration rates. I believe that, conditional on my controls and Internet penetration, these cost shifters do not affect high-school graduation rates.

The summary statistics in table I provide some interesting observations. The data presented in table 1 are divided into three tiers (low, mid, high) based on the county broadband penetration rates. For example, the “low 1/3” category with broadband penetration rate of 14.4 percent reflects the weighted average broadband penetration rate for 89 out of 247 counties in this study with lowest penetration rates. Other variables are reported accordingly to the groupings created with broadband penetration.

Average county broadband penetration rate in Texas averaged 79.4 percent in 2017 which is almost on par with national average of 82 percent.[9] The top 89 counties in Texas averaged the penetration rate exceeded the national average in 2017, however, only 31 counties achieved the penetration rate of 82 percent or more. Looking back to 2001, Texas average broadband penetration rate of 21.4 percent was higher than the national average rate

[9] https://www.lightreading.com/broadband/us-home-broadband-penetration-reaches-90-study-/d/d-id/782492

of 9.1 percent.[10] Average county broadband penetration rates increase from 2000 to 2017 for each segment, however, the average percentage-point discrepancy between low and high counties remains large in terms of Internet penetration. While in 2000, the low and high county broadband penetration averages stand at 14.4 percent and 29.7 percent respectively, in 2017, these values are 49.9 percent and 84.4 percent. This suggests that broadband penetration grew more in certain counties, contributing to the digital divide.

The average county graduation rate is relatively equal across the three tiers and increases across the years. The national average graduation rates were 80.6 percent in 2000, 86.1 percent in 2010 and 93.7 percent in 2017. Texas achieves higher graduation rates in 2010 and 2017 compared to the national average while students in Texas are on par with national average in 2000. The data suggests that with increases in broadband penetration rates, the graduation rates also increase. The purpose of this study is to understand how the broadband penetration rates affect graduation rates.

From a socioeconomic standpoint, another notable variable is $College\ Degree_{ct}$. The data suggests that households in the high tier of broadband penetration rates have higher rates of household heads with a college degree while overall household college degree rates increased across years. In 2017, 31.4 percent of household heads in the top broadband penetration tier had a college degree while only less than half, 14.1 percent, of household heads had a college degree in the low broadband penetration tier. $Poverty_{ct}$ appears higher in tiers with low and mid broadband penetration rates. This observation is consistent across the years. Even more apparent is the shift of counties when looking at the $Housing\ Density_{ct}$. In 2000, when average

[10] NTIA 2004 published report.

county broadband penetration rates were relatively equal across counties, the highest, 12.8 average of *Housing Density*$_{ct}$ was in counties with lowest penetration rates. However, counties with higher *Housing Density*$_{ct}$ started shifting towards counties with higher broadband penetration rates in 2010 and 2017. The data suggests that the broadband expansion took place in counties with higher housing density.

Summary statistics suggest that the level of broadband penetration rate does not necessarily mean higher graduation rates. Also, the data suggests that broadband penetration is higher in areas with higher *Housing Density*$_{ct}$ and less *Poverty*$_{ct}$. Remaining summary data statistics do not offer any much of other insights. This study examines what impacts graduation rate increases across the years using statistical analysis and whether broadband has an impact on graduation rates.

RESULTS AND DISCUSSION

In the first step, I discuss the validity and relevance of instrumental variables used for the Internet, and I estimate the first-stage Internet equation to obtain functions that correct for the endogeneity of the Internet access in graduation rates. I use the instrumental variables to estimate the impact of Internet on graduation rates and check robustness of the model using alternative specifications that include $\textit{Teacher Experience}_{ct}$, control for regional effects, and use of a different functional form.

The effects of the Internet are identified by variation in Internet penetration in each county and by exclusion restrictions. I use supply related factors, $\textit{Housing Density}_{ct}$ and $\textit{Road Miles}_{ct}$, as instruments for the $\textit{Internet}_{ct}$. Fixed broadband access is more likely in markets where costs can be shared, and economies of density can be applied. The total miles of local roads in the county approximates the size and common cost of infrastructure build-out to connect the Internet to each household. More houses per road mile reduces the average cost of deployment and maintenance, $\textit{Housing Density}_{ct}$ will be positively correlated with the Internet. The key assumption is that conditional on controls for individual heterogeneity, control variables and $\textit{Internet}_{ct}$, $\textit{Housing Density}_{ct}$ and $\textit{Road Miles}_{ct}$ do not have a direct effect on graduation rates.

Table II shows the first-stage regression results. The first-step has an R-squared of 0.46 and an F-test rejects the null that the estimated coefficients on the instrumental variables jointly equal zero ($F(2, 248) = 24.79$; $Prob > F = 0.00$). Column 1 presents the results for my preferred fixed-effects regression. The estimated coefficients for instrumental variables $\textit{Housing Density}_{ct}$ and $\textit{Road Miles}_{ct}$ are statistically significant and have the expected positive sign. The availability of the Internet is more prevalent in areas with more concentrated population as expected. The J-statistic equals 0.293 and we cannot reject the null hypothesis that the overidentification restrictions are appropriate.

A couple of other variables in this regression are statistically significant with interesting implications. For example, Internet penetration increases with decreases in single-mother households, and with increases in college-educated households. These results are consistent with our expectations as single-mother households are considered lower income households with less means to purchase Internet access while the opposite is true for households with college-educated parents. Both year variables, *y10* and *y17*, are also statistically significant at the 0.01 level. This suggests that changes to broadband penetration matter between the studied years. Columns 2 through 4 show alternative specifications with results that are consistent with preferred regression.

Table III provides estimates of the Internet and other characteristics on the graduation rates. For comparison, column 1 reports OLS results and column 2 reports fixed effects with no correction for endogeneity. Columns 3 through 8 report estimates for our preferred fixed-effects specification with controls that correct for endogeneity of the Internet. The estimated effects of the Internet penetration on graduation rates show some interesting findings. In the uncorrected fixed-effects specification, $Internet_{ct}$ is not statistically significant from zero at the ten percent level, and the coefficient for $Internet_{ct}$ equals negative 0.009. This estimate changes sign of the coefficient to positive and increases to 0.183, and is statistically significant at the one percent level in my preferred two-stage-least-squares fixed-effects regression. This finding is consistent with the notion that unobserved increases in the demand for entertainment affect both the demand for Internet and student performance.

To assess the magnitude of *Internet*$_{ct}$*'s* impact on graduation rates in the corrected specification, we measure percentage increase in graduation rates with 10 percentage-point increase in broadband penetration. With a 10 percentage-point increase in broadband penetration, the graduation rate is expected to increase 1.83 percentage points. This outcome is surprising in comparison to other studies that primarily find that Internet access has no significant impact on school performance. These results are consistent with findings of Chen, Mittral and Sridrag who find a statistically significant and positive impact of the Internet on student performance when controlling for endogeneity as I do in this study. This outcome suggests that Internet's productivity effect outweighs distraction effects.

Estimates of socio-economic control variables in the model are not significant at the 0.1 level. This is likely because I lost variation in the data when I aggregated school districts to counties. It is possible that two school districts with opposing characteristics averaged out during aggregation process to county level, thus removing the effects of variation of studied variables. Both year variables, *y10* and *y17*, are also statistically significant at 0.01 in the fixed-effects regression, however, not significant at 0.1 level in the two-stage-least squares fixed-effects regression.

For robustness checks, I estimate models that include region-by-year controls, a school-specific variable and use a log-linear functional form; the results of these robustness checks are presented in columns 4 through 8. I use region-by-year fixed effects to control for unobserved time-varying regional effects. Counties are divided into eleven distinct public health regions.[11]

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[11] Center for health statistics provides county by public health region data.

The inclusion of region-by-year fixed effects control for unobserved events such as increases in regional growth, changes in regional demographics or increases in desirability of region schools. In table III, column 4 shows results of the two-stage-least-squares preferred regression with region-by-year fixed effects. $Internet_{ct}$ coefficient is smaller at 0.152 compared to 0.183 in the preferred regression but still statistically significant at the 0.01 level. Column 5 presents results of the preferred two-stage-least-square fixed-effects regression when I use the natural logarithm of $Graduation\ Rate_{ct}$ (log-linear model) as the dependent variable. This model estimates that a 10 percentage-point increase in $Internet_{ct}$ leads to a 2 percentage-point increase in the average $Graduation\ Rate_{ct}$, when evaluated at the average $Graduation\ Rate_{ct}$ in 2017 (93.7 percent). Column 6 combines the region-by-year fixed effects with the log-linear model of the preferred two-stage-least-squares regression. The impact of the $Internet_{ct}$ on average graduation rate in 2017, 93.7 percent, is 1.8 percent for every 10 percentage-point increase in Internet penetration when including region-by-year fixed effects.

Next, I consider school-specific variables that can be correlated with graduation rates. Column 7 presents results of the two-stage-least-squares fixed-effects preferred regression with $Teacher\ Experience_{ct}$ that controls for school quality. Results show that $Teacher\ Experience_{ct}$ is statistically significant at the 0.01 level with the coefficient of 0.212. This estimates that with a 10 percent increase in share of teachers with more than 10 years of experience, the graduation rate is estimated to increase by 2.12 percentage-points. Also, this specification has the coefficient of $Internet_{ct}$ at 0.18 vs 0.183 in the preferred two-stage-least-squares specification. This finding is consistent with review of research on whether teaching experience increases teacher effectiveness. Kini and Podolsky (2016) find from the review of existing literature that teaching experience is positively associated with student achievement. More experienced teachers not only benefit students but also colleagues and schools as a whole. Column 8 shows results of the two-stage-least-squares preferred regression with region-by-year fixed effects and with *Teacher Experience*$_{ct}$. Coefficient of the *Internet*$_{ct}$ is 0.15 compared to 0.183 in the main regression but still significant at the 0.01 level. Results of these alternative specifications are generally consistent with the two-stage-least-squares fixed-effects preferred model. These findings suggest that the estimated effects of the Internet on school performance are robust to the alternative specifications.

Table IV presents results with *Population Density*$_{ct}$ as an instrument for the Internet. The estimates of this model are entirely consistent with the original specification as expected, and *Population Density*$_{ct}$ shows the same characteristics of my original instrumental variables. Coefficient of the *Internet*$_{ct}$ is 0.176 compared to 0.183 in the preferred two-stage-least-squares fixed-effects regression but still significant at the 0.01 level.

CONCLUSION

The main goal of this study is to better understand the impact of local Internet access on graduation rates and examine whether controlling for socioeconomic factors plays a significant role in student performance. I find that with 10 percentage-point increase in broadband penetration increases the graduation rate by 1.83 percentage point in high schools across Texas. This is a surprising result considering other studies generally do not find a positive impact of broadband on student performance. Results suggest that the productivity effect outweighs the distraction effect when controls for the endogeneity of the Internet are included in the model.

The study is conducted on the county level because I was unable to obtain district level data. Future work on this topic should incorporate the effects of the Internet penetration on student effort, peer effects and disciplinary problems. Also, future work at a more granular, school-district level, could provide more variation in the data, possibly resulting in more insights.

APPENDIX

Table I: Summary Statistics

	2000				2010				2017				All Years
	Low 1/3	**Mid 1/3**	**High 1/3**	**All Counties**	**Low 1/3**	**Mid 1/3**	**High 1/3**	**All Counties**	**Low 1/3**	**Mid 1/3**	**High 1/3**	**All Counties**	**All Counties**
Broadband Penetration (%)	**14.4**	**21.7**	**29.7**	**21.4**	**29.3**	**49.0**	**68.7**	**59.9**	**49.9**	**63.2**	**84.4**	**79.4**	**56.2**
Graduation Rate (%)	79.5	85.4	81.1	80.6	87.5	85.5	86.0	86.1	96.2	94.3	93.4	93.7	87.3
10+ years Teacher Exp (%)	49.5	56.5	46.5	48.8	50.0	46.4	44.4	45.4	55.2	51.1	45.3	46.7	46.9
College Degree Rate (%)	21.9	14.1	26.5	23.3	15.2	21.8	28.9	25.8	14.1	18.7	31.4	28.6	26.1
Poverty Rate (%)	16.4	18.1	12.0	14.7	22.4	17.8	15.4	16.7	18.1	22.3	14.7	16.0	15.9
Single Mother Rate (%)	15.3	13.9	14.0	14.7	18.0	18.3	17.1	17.5	18.3	19.5	18.2	18.4	17.0
Share of Non White (%)	35.8	26.0	33.5	34.1	23.0	34.0	32.6	31.9	19.7	18.0	30.0	27.7	27.7
English (%)	94.9	97.6	95.7	95.4	96.1	96.8	96.5	96.5	98.5	97.5	97.2	97.3	96.5
Road Miles	2.4	2.1	2.5	2.3	1.9	2.2	2.7	2.3	2.0	2.2	2.8	2.3	2.3
Housing Density	12.8	4.3	12.2	9.8	5.8	8.7	17.3	10.6	4.3	9.0	21.1	11.5	10.6

Notes: All variables (except Road Miles and Housing Density) are weighted by population
Source: Texas Academic Performance Reports, Academic Excellence Indicator System, Decennial Census, American Community Survey, FCC, and NTIA

Table II: First-stage Results

VARIABLES	(1) First Stage	(2) log	(3) School	(4) Region
Single Mother	-0.382***	-0.006**	-0.398***	-0.352***
	(0.129)	(0.003)	(0.130)	(0.125)
Poverty	-0.117	-0.002	-0.094	-0.023
	(0.217)	(0.004)	(0.209)	(0.227)
English Speakers	0.053	0.004	0.035	-0.008
	(0.311)	(0.007)	(0.305)	(0.321)
College Degree	0.956***	0.019***	0.973***	0.748***
	(0.285)	(0.006)	(0.276)	(0.275)
Share of Non-White	-0.008	0.001	-0.011	-0.009
	(0.068)	(0.002)	(0.066)	(0.074)
Hispanics	0.074	0.003	0.019	0.078
	(0.131)	(0.003)	(0.140)	(0.125)
Road Miles	7.690***	0.171***	7.537***	9.604***
	(1.563)	(0.044)	(1.556)	(1.693)
Housing Density	0.969***	0.013**	1.002***	1.085***
	(0.164)	(0.006)	(0.163)	(0.180)
y10	23.010***	0.666***	23.039***	18.126***
	(1.583)	(0.034)	(1.592)	(3.718)
y17	38.828***	0.992***	38.772***	38.619***
	(2.240)	(0.044)	(2.235)	(3.022)
Teacher Experience			-0.282***	
			(0.103)	
Constant	-20.476	1.882***	-1.259	-19.021
	(32.147)	(0.717)	(32.604)	(32.487)
J-Statistic	0.293	0.37	0.019	0.535
Observations	747	746	747	747
R-squared	0.811	0.822	0.815	0.829
Number of gcounty	249	249	249	249

Notes: column 1 presents the preferred regression with fixed effects; column 2 presents a fixed-effects log-linear form of preferred regression; column 3 includes the preferred regression with fixed effects, including $\textit{Teacher Experience}_{ct}$; column 4 includes controls for region-by-year fixed effects

Table III: Regression Results

VARIABLES	(1) OLS	(2) FE	(3) Preferred 2SLS	(4) 2SLS Region	(5) 2SLS Log	(6) 2SLS Log Region	(7) 2SLS School	(8) 2SLS School Region
Internet	0.143***	-0.009	0.183***	0.152***	0.002**	0.002**	0.180**	0.150**
	(0.013)	(0.019)	(0.071)	(0.058)	(0.001)	(0.001)	(0.071)	(0.060)
Single Mother	-0.001	-0.043	0.033	-0.013	0.000	-0.000	0.045	-0.008
	(0.048)	(0.064)	(0.068)	(0.069)	(0.001)	(0.001)	(0.062)	(0.063)
Poverty	-0.213***	0.017	-0.013	0.004	-0.000	0.000	-0.031	-0.002
	(0.057)	(0.078)	(0.090)	(0.102)	(0.001)	(0.001)	(0.084)	(0.096)
English Speakers	0.235*	0.023	0.012	-0.052	-0.000	-0.001	0.023	0.004
	(0.129)	(0.167)	(0.180)	(0.190)	(0.002)	(0.003)	(0.168)	(0.178)
College Degree	-0.181***	0.061	-0.178	-0.067	-0.002	-0.001	-0.189	-0.065
	(0.034)	(0.104)	(0.152)	(0.127)	(0.002)	(0.002)	(0.142)	(0.121)
Share of Non-White	-0.088***	-0.016	-0.022	-0.023	-0.000	-0.000	-0.020	-0.019
	(0.020)	(0.025)	(0.028)	(0.031)	(0.000)	(0.000)	(0.028)	(0.030)
Hispanics	-0.011	0.041	0.028	0.042	0.000	0.000	0.069	0.073
	(0.012)	(0.062)	(0.067)	(0.063)	(0.001)	(0.001)	(0.063)	(0.057)
y10		5.271***	0.792	1.526	0.011	0.021	0.839	1.532
		(0.776)	(2.004)	(2.293)	(0.026)	(0.028)	(1.988)	(2.164)
y17		10.022***	2.184	6.412**	0.026	0.075**	2.349	5.968*
		(1.024)	(3.215)	(3.075)	(0.041)	(0.038)	(3.199)	(3.116)
Teacher Experience							0.212***	0.206***
							(0.048)	(0.052)
Constant	70.758***	82.147***						
	(12.943)	(16.737)						
F-Test			24.79***	26.45***	24.79***	26.45***	26.13***	26.73***
Observations	747	747	747	747	747	747	747	747
R-squared	0.290	0.562	0.463	0.013	0.418	0.008	0.497	0.070
Number of gcounty		249	249	249	249	249	249	249

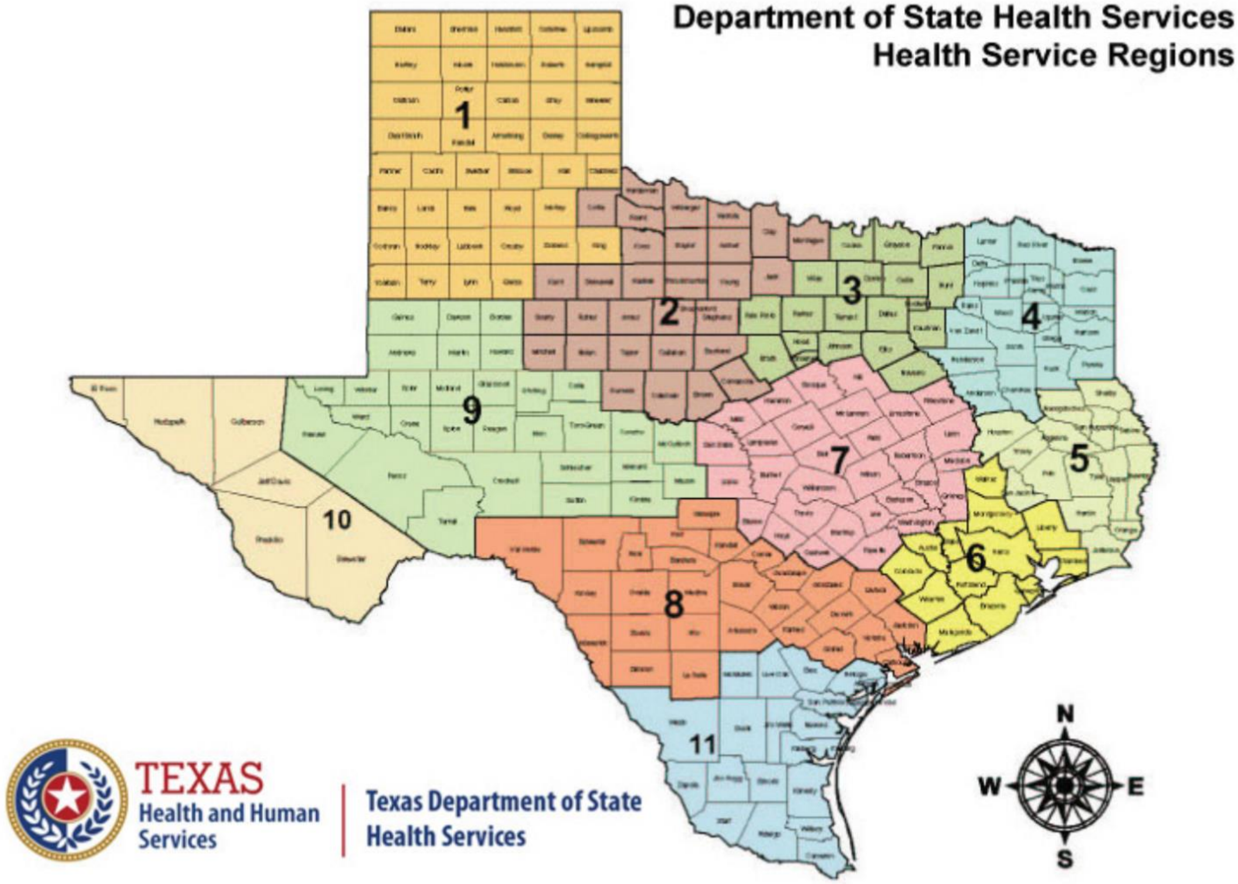
Notes: column 1 presents results of the OLS regression where *Graduation Rate*$_{ct}$ is the dependent variable; column 2 presents results of the fixed-effects regression; column 3 presents results of the preferred fixed-effects two-stage-least-squares regression; columns 4 includes region-by-year fixed effects controls for the two-stage-least-squares regression; column 5 presents the two-stage-least-squares fixed-effects regression where the dependent variable is the natural logarithm of *Graduation Rate*$_{ct}$ (log-linear model); column 6 presents results of the two-stage-least-squares fixed-effects log-linear model with region-by-year controls; column 7 presents the two-stage-least-squares fixed-effects regression with *Teacher Experience*$_{ct}$ to control for school quality; Column 8 presents the region-by-year fixed-effects regression with *Teacher Experience*$_{ct.}$

Table IV: Regression Results – Population Density as Instrumental Variable

VARIABLES	(1) Preferred 2SLS	(2) 2SLS Region	(3) 2SLS Log	(4) 2SLS Log Region	(5) 2SLS School	(6) 2SLS School Region
Internet	0.176***	0.169***	0.002***	0.002***	0.156***	0.151***
	(0.055)	(0.058)	(0.001)	(0.001)	(0.055)	(0.058)
Single Mother	0.031	-0.007	0.000	0.000	0.035	-0.007
	(0.069)	(0.068)	(0.001)	(0.001)	(0.062)	(0.060)
Poverty	-0.012	0.001	-0.000	0.000	-0.027	-0.002
	(0.090)	(0.105)	(0.001)	(0.001)	(0.083)	(0.097)
English Speakers	0.013	-0.052	-0.000	-0.001	0.024	0.004
	(0.180)	(0.192)	(0.002)	(0.003)	(0.166)	(0.178)
College Degree	-0.170	-0.084	-0.002	-0.001	-0.159	-0.066
	(0.137)	(0.119)	(0.002)	(0.001)	(0.125)	(0.111)
Share of Non-White	-0.022	-0.023	-0.000	-0.000	-0.019	-0.019
	(0.028)	(0.032)	(0.000)	(0.000)	(0.027)	(0.031)
Hispanics	0.029	0.041	0.000	0.000	0.070	0.073
	(0.066)	(0.063)	(0.001)	(0.001)	(0.061)	(0.057)
Teacher Experience					0.205***	0.206***
					(0.048)	(0.051)
y10	0.955	1.197	0.009	0.015	1.394	1.513
	(1.612)	(2.376)	(0.021)	(0.029)	(1.603)	(2.176)
y17	2.470	5.712*	0.023	0.062	3.318	5.927**
	(2.584)	(3.125)	(0.033)	(0.039)	(2.576)	(3.015)
F-Test	23.34***	23.26***	23.34***	23.26***	24.80***	24.47***
Observations	747	747	747	747	747	747
R-squared	0.470	-0.016	0.412	-0.031	0.518	0.068
Number of gcounty	249	249	249	249	249	249

Notes: column 1 presents results of the preferred fixed-effects two-stage-least-squares regression; columns 2 includes region-by-year fixed effects controls for the two-stage-least-squares regression; column 3 presents the two-stage-least-squares fixed-effects regression where the dependent variable is the natural logarithm of $\textit{Graduation Rate}_{ct}$ (log-linear model); column 4 presents results of the two-stage-least-squares fixed-effects log-linear model with region-by-year controls; column 5 presents the two-stage-least-squares fixed-effects regression with $\textit{Teacher Experience}_{ct}$ to control for school quality; Column 6 presents the region-by-year fixed-effects regression with $\textit{Teacher Experience}_{ct}$

Figure 1: Texas by Public Health Region



Source: https://www.dshs.texas.gov/sites/default/files/IDCU/data/annual/2000s/2019/2021-Texas-HSRs-Map.pdf

Figure 2: Counties by Public Health Region

Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11
Armstrong	Archer	Collin	Anderson	Angelina	Austin	Bastrop	Atascosa	Andrews	Brewster	Aransas
Bailey	Baylor	Cooke	Bowie	Hardin	Brazoria	Bell	Bandera	Coke	Culberson	Bee
Briscoe	Brown	Dallas	Camp	Houston	Chambers	Blanco	Bexar	Concho	El Paso	Brooks
Carson	Callahan	Denton	Cass	Jasper	Colorado	Bosque	Calhoun	Crane	Hudspeth	Cameron
Castro	Clay	Ellis	Cherokee	Jefferson	Fort Bend	Brazos	Comal	Crockett	Jeff Davis	Duval
Childress	Coleman	Erath	Delta	Nacogdoches	Galveston	Burleson	DeWitt	Dawson	Presidio	Hidalgo
Cochran	Comanche	Fannin	Franklin	Newton	Harris	Burnet	Dimmit	Ector		Jim Hogg
Collingsworth	Cottle	Grayson	Gregg	Orange	Liberty	Caldwell	Edwards	Gaines		Jim Wells
Crosby	Eastland	Hood	Harrison	Polk	Matagorda	Coryell	Frio	Glasscock		Kleberg
Dallam	Fisher	Hunt	Henderson	Sabine	Montgomery	Falls	Gillespie	Howard		Live Oak
Deaf Smith	Foard	Johnson	Hopkins	San Augustine	Walker	Fayette	Goliad	Irion		McMullen
Dickens	Hardeman	Kaufman	Lamar	San Jacinto	Waller	Freestone	Gonzales	Kimble		Nueces
Donley	Haskell	Navarro	Marion	Shelby	Wharton	Grimes	Guadalupe	McCulloch		Refugio
Floyd	Jack	Palo Pinto	Morris	Trinity		Hamilton	Jackson	Martin		San Patricio
Garza	Jones	Parker	Panola	Tyler		Hays	Karnes	Mason		Starr
Gray	Kent	Rockwall	Rains			Hill	Kendall	Menard		Webb
Hale	Knox	Somervell	Red River			Lampasas	Kerr	Midland		Willacy
Hall	Mitchell	Tarrant	Rusk			Lee	Kinney	Pecos		Zapata
Hansford	Montague	Wise	Smith			Leon	La Salle	Reagan		
Hartley	Nolan		Titus			Limestone	Lavaca	Reeves		
Hemphill	Runnels		Upshur			Llano	Maverick	Schleicher		
Hockley	Scurry		Van Zandt			McLennan	Medina	Sterling		
Hutchinson	Shackelford		Wood			Madison	Real	Sutton		
Lamb	Stephens					Milam	Uvalde	Terrell		
Lipscomb	Stonewall					Mills	Val Verde	Tom Green		
Lubbock	Taylor					Robertson	Victoria	Upton		
Lynn	Throckmorton					San Saba	Wilson	Ward		
Moore	Wichita					Travis	Zavala	Winkler		
Motley	Wilbarger					Washington				
Ochiltree	Young					Williamson				
Oldham										
Parmer										
Potter										
Randall										
Sherman										
Swisher										
Terry										
Wheeler										
Yoakum										

Notes: Omitted counties due to unavailable data: Borden (Region 9), Kenedy (Region 11), King (Region 1), Loving (Region 9) and Roberts (Region 1)

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