Closing the Digital Divide: Evaluation of FCC's Connect America Fund

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I have always been aspiring to be an economist since high school. Now, six years later, I still believe that most sufferings and injustices in the world could be understood and solved by economics. This thesis is my first serious, complete endeavor in the field.

Abstract

The still-unfolding IT revolution is a key driver for the remarkable performance of the U.S. economy since the 1990s. Getting on the rising tide requires a high-speed internet connection. The COVID-19 pandemic has further intensified the existing digital divide by driving most essential activities online. 18 million Americans that lack high-speed broadband connection are falling behind. The Connect America Fund is the largest on-going federal support for broadband buildout to unserved areas. This paper provides the first econometric assessment of the Connect America Fund between 2014 and 2018 using county-level data. It does not find robust evidence in support of the program. While subsidy recipient counties do not see substantial improvement in terms of the number of high-speed providers, the elasticity of the equilibrium subscription rate to total subsidies is near zero. Solely tackling the supply side shortfall is clearly not sufficient to produce a desirable outcome in the broadband market. As billions of taxpayer's money is expected in the next decade, it is necessary to address the sluggish demand to make sure the newly deployed infrastructure is not standing idle.

JEL classification: H43; H32; H45

Keywords: Federal Communication Commission, Internet, Infrastructure, Technology Diffusion, Market Failure

Introduction

Our world is becoming increasingly digital every day. The still-unfolding IT revolution is a key driver for the remarkable performance of the U.S. economy since the 1990s. Getting on the rising tide requires a high-speed internet connection. The COVID-19 pandemic has further intensified the digital divide by driving most essential activities online. Almost overnight, high-quality internet becomes as much of a necessity as electricity for modern life. After we weather the storm of pandemic and come out the other side, the outlook of future commerce, work, education, medicine, and service will only be more digitalized. 18 million Americans that lack broadband connection are falling behind.

In recognition of the benefit of high-speed broadband and the digital opportunity it brings, the Federal Communications Commission (FCC)'s top priority has been closing the digital divide in the past decade. The Connect America Fund (CAF) was established in 2011 with a mission to encourage the voice and broadband buildout to rural, insular, and high-cost areas. While the economic benefit of broadband deployment and access has been extensively discussed in the literature, the effectiveness of government subsidies has not been sufficiently analyzed. This paper contributes to the literature by providing the first econometric assessment of the FCC's Connect America Fund between 2014 and 2018. Specifically, using county-level data, it examines if the supports have led to significant increases in the number of (high-speed) broadband providers and broadband subscription rate in the recipient county.

The paper is laid out as follows. The first section gives an overview of the digital divide in the United States, followed by a review of the on-going federal level subsidies. It then discusses the empirical specification of the model and the data involved. Results for the regression estimation are presented in the fifth section, with concluding remarks at the end of the paper.

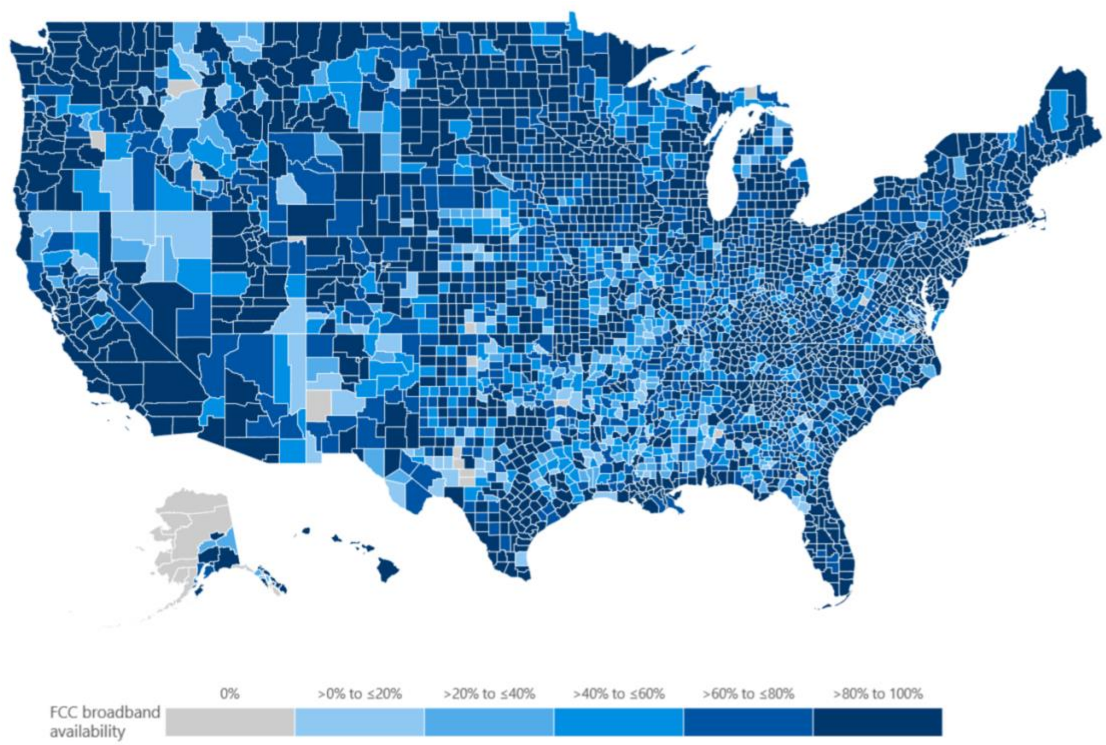
The empirical results in this paper suggest that the Connect America Fund is not efficient in addressing market failure in the fixed broadband market. As total subsidies (lagged in one year) in a county increase by 1%, the number of high-speed providers and subscription rate is expected to grow by only 0.02% and 0.002%. Together with the fact that each county, on average, has five high-speed providers and a subscription rate of 84.4%, the Connect America Fund hitherto is not successful in encouraging broadband buildout and adoption based on these indicators. This result is crucial for policymaking, as the next decade is expecting stronger support. The CAF Phase II auction was concluded in 2018, for which the FCC awarded more than $1.488 billion. Rural Digital Opportunity Fund with $20.4 billion was proposed in August 2019 as the biggest single step to date toward closing the digital divide. To make sure taxpayers' money is spent efficiently, tackling the supply side shortfall itself is not sufficient. The FCC should take measures to address sluggish demand in the broadband market.

The Digital Divide

Broadband is a telecommunication technology that is faster than traditional dial-up access through Digital Subscriber Line (DSL), cable modem, fiber, wireless, satellite, and Broadband over Powerlines (BPL). Access to high-speed internet is often associated with higher income (DiMaggio and Bonikowski 2008), easier knowledge and skills acquisition (Joshson et al. 2005), more efficient job search (Beard et al. 2012), and less social isolation and related mental health problems especially in the COVID-19 pandemic (Purtle 2020). Yet the distribution of fixed broadband in the United States has been persistently characterized by uneven rates of access and adoption among various socioeconomic groups. Economists worry that existing socioeconomic inequalities may be aggravated by the digital divide (Drabenstott 2001). The FCC estimates that nearly 24 million Americans do not have access to fixed terrestrial broadband at speeds of 25/3

Mbps in 2018. In particular, the urban/rural digital divide has received the most attention from researchers and policymakers. While 94.4% of the overall population has access to high-speed broadband service, 22.6% of Americans in rural areas lack such coverage. (population density)

Figure. 1 Broadband Deployment Map at Speed at least 25/3 Mbps in 2017



Data Source: FCC Broadband report and Form 477
Graph produced by Microsoft, https://news.microsoft.com/rural-broadband/
Data available at https://github.com/microsoft/USBroadbandUsagePercentages

Figure. 2 Deployment Rate of Fixed Terrestrial 25/3 Mbps Services

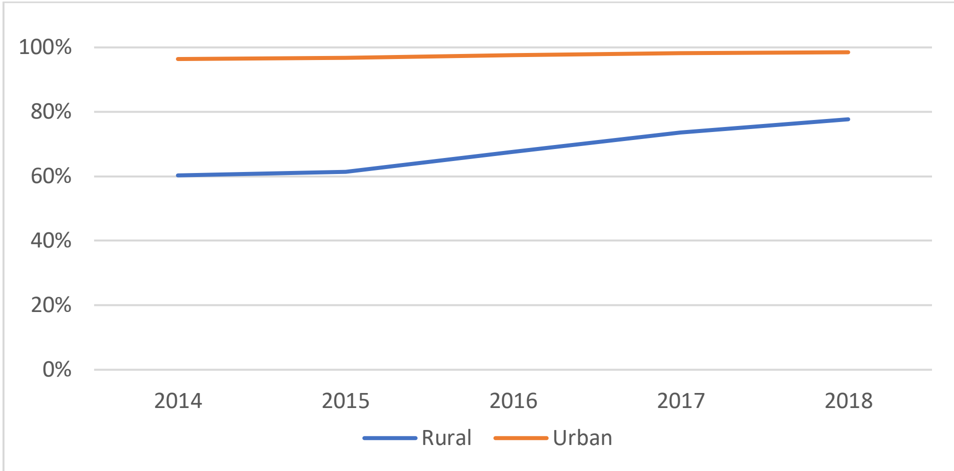


Table. 1 Deployment Rate of Fixed Terrestrial 25/3 Mbps Services

	2014	2015	2016	2017	2018
United States	89.1%	89.7%	91.7%	93.4%	94.4%
Rural Areas	59.2%	60.8%	67.0%	73.3%	77.4%
Urban Areas	96.3%	96.7%	97.7%	98.3%	98.5%

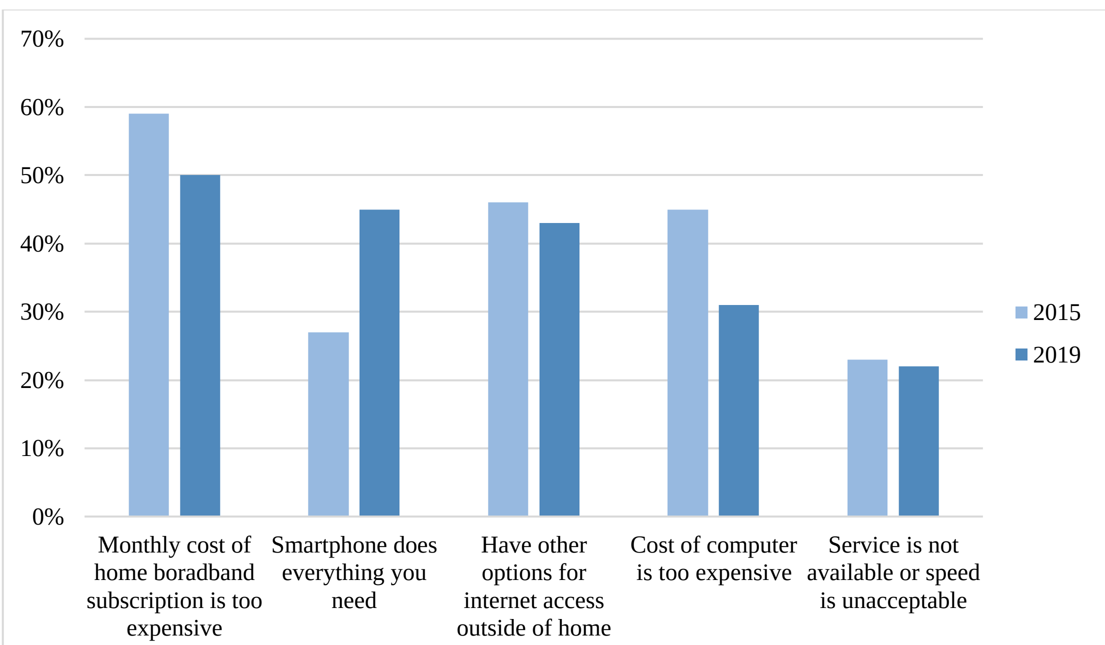
Data Source: 2020 Deployment report

The digital divide is contributed by a powerful combination of supply- and demand-side drivers. On the supply side, inadequate broadband penetration in unserved areas is often an outcome of insufficient infrastructure deployment. Private capital is only attracted by profitable business cases, but unserved and underserved areas are often rural and have long suffered from high cost and low revenue. Particularly for wireline broadband technologies such as cable modem and fiber, longer distances between customers drive up the construction and operation cost, and lower population density leaves a smaller customer base from which to recover the investment of installing and maintaining the network (Downes & Greenstein, 2002). As a result, broadband diffusion is found to follow an S-shaped diffusion path over time and space, and availability and uptake rate diminish with business and household density (Geroski, 2000; Whitecare 2010).

Addressing the supply-side shortfalls is not sufficient to raise the equilibrium broadband adoption rate. To analyze the determinants of demand, studies such as Chaudhuri et al. (2005), Flamm and Chaudhuri (2007), Prieger and Hu (2008), and NTIA (2012) find that broadband adoption rate is positively associated with households with higher income and higher education level, and negatively associated with those who are older, African American or Hispanic, and living in rural areas. The 2019 survey from the Pew Research Center reports that 27% of adults in the United States do not have broadband at home, and their characteristics confirm the findings of earlier studies (Anderson 2019).

Figure. 3 Reasons for not having broadband subscription at home

% of non-broadband users who say the followings are reasons why they do not have broadband service at home



Data Source: Pew Research Center
Mobile Technology and Home Broadband 2019

When non-adopters are asked why they do not have broadband subscription at home, the most striking difference between 2015 and 2019 is the trend that smartphones (and hence mobile broadband) are increasingly regarded as a perfect substitute among those who do not have a fixed broadband subscription at home. Affordability is less of a barrier today than it was four years ago, but it remains the most commonly cited reason for not subscribing to home broadband. What also remains the same between 2017 and 2019 is the number of people who do not have a residential subscription because of the lack of access to high-quality broadband service. Indeed, it has been shown that fast, reliable speed is an important determinant of willingness-to-pay (Rosston et al., 2010; Octavian et al., 2015). In theory, the problem of affordability and accessibility could be solved by subsidies that encourage broadband buildout and market entry. Despite efforts in encouraging the expansion of high-speed coverage to unserved and underserved areas in recent years, half of the non-broadband users are still put-off by the price tag of broadband plans, and merely 1% have stopped worrying about the access and quality of broadband service. This calls into question the effectiveness of public funding in the past four years.

Public Investment

Beginning in the 1930s, government programs were established to attempt to remedy the lack of market provision of telecommunications services in rural areas. Two major ongoing vehicles at the federal level that support broadband buildout are the Rural Utilities Service (RUS) of the U.S. Department of Agriculture, and the Connect America Fund under the Federal

Communications Commission.[1] The former metes out about $800 million every year for rural loans[2], while the FCC provides about $8.8 billion per year in broadband subsidies.

Kandilov and Renkow (2010) find no evidence that the RUS loan recipient communities had experienced significant economic development using difference-in-differences analysis and propensity score matching. However, by regressing economic indicators directly on subsidy, they make a logical jump assuming that subsidies had already successfully increased broadband availability in the local communities. As follow-up research, Dinterman and Renkow (2017) ask whether the RUS increases the number of broadband providers in the designated location – "a necessary, but by no means sufficient, condition for the programs producing economic impacts." It turned out loan recipient ZIP codes experienced approximately 0.092 additional broadband providers annually. In other words, one loan led to one provider entry in a zip code area over a decade.

The Connect America Fund is the focus of this study. The High-Cost program under the Universal Service Fund is the CAF's predecessor. It had long been criticized as inefficient and extravagant. Hazlett (2006) reveals that it would cost the government less if it outright paid the bills for individuals in high-cost areas than subsiding the deployment through the fund. Acknowledging the need for reform, the FCC took several steps to switch subsidies from narrowband (voice) service to broadband service and put in place several efficiency-improving measures in 2011.[3] The newly established CAF carries the same mission to encourage broadband

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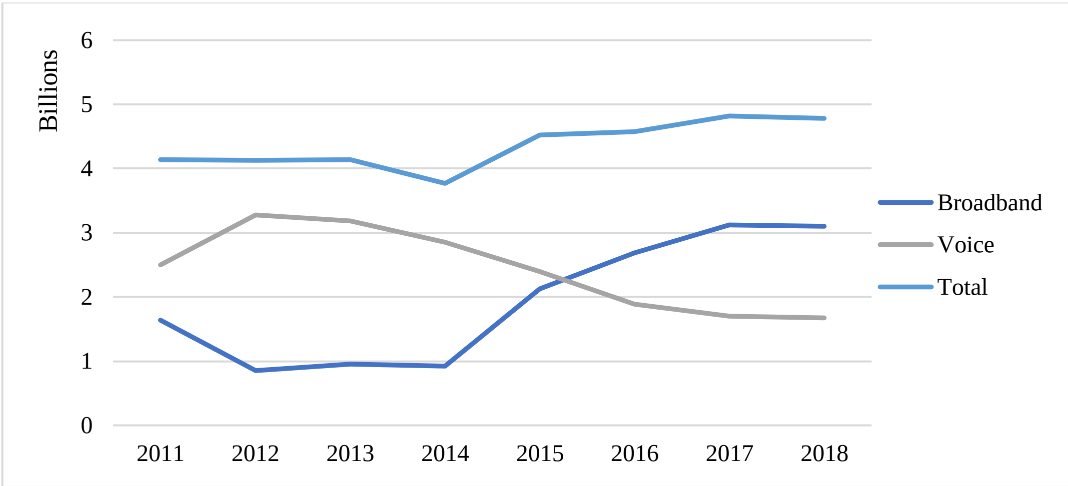
[1] The National Telecommunications and Information Administration released an updated Guide to Federal Funding of Broadband Projects https://broadbandusa.ntia.doc.gov/ sites/default/files/resource-nfiles/ntia_guidetofedfunding_062317.pdf.

[2] Congressional Research Service, *Broadband Loan and Grant Programs in the USDA's Rural Utilities Service* (CRS Report No. RL33816). (March 22, 2019).

[3] Federal Communications Commission, *In the Matter of Connect America Fund, Report and Order and Further Notice of Proposed Rulemaking*, WC Docket No. 10-90 (November. 18, 2011).

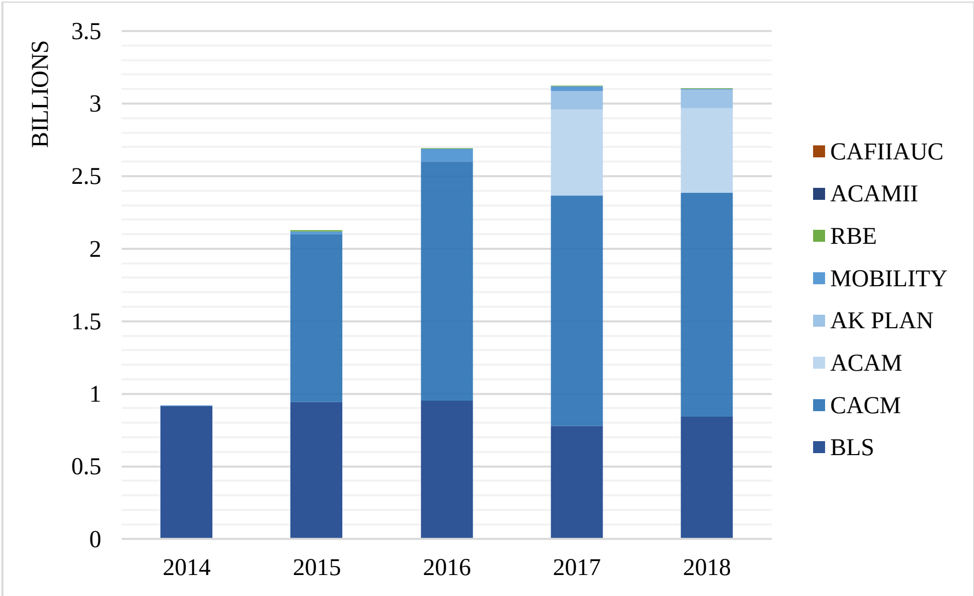
investment to unserved areas where market force alone is not sufficient to produce equitable outcomes. It avoids giving duplicating subsidies to the same geographic area, adopts market-based mechanisms to determine the amount of funding, and introduces deployment obligations upon the receipt of subsidy.

Figure. 4 High-Cost Program Disbursement (in billion dollars)



Data Source: 2019 Universal Service Monitoring Report, Universal Service Joint Board

Figure. 5 Broadband Disbursement under High-Cost Program for (in billion dollars)



Data Source: 2019 Universal Service Monitoring Report, Universal Service Joint Board

There are nine modernized and fifteen legacy funds in operation under the Connect American Fund (See Appendix 1). Between 2011 and 2018, CAF disbursed a total of 34.9 billion dollars. As supports for voice service were gradually withdrawn, subsidies dedicated to broadband have experienced a sustained rise in recent years. This study focuses on the period between 2014 and 2018, during which 12.5 billion dollars were disbursed. The average annual subsidy per program for a study area is $634,312. As shown in Figure. 5, Broadband Loop Support (BLS) has been providing consistent support throughout the period. While the Connect America Cost Model (CACM) accounts for over half of total broadband subsidy since 2015, the Alternative Connect America Cost Model (ACAM) kicked off in 2017.

The next decade is expecting stronger support. The CAF Phase II auction was concluded in 2018, for which the FCC awarded more than $1.488 billion over ten years to 103 winning bidders to serve more than 713,000 rural homes and businesses.[4] Rural Digital Opportunity Fund was proposed in August 2019 as the biggest single step to date toward closing the rural digital divide. Another $20.4 billion is to be directed to the unserved rural areas that had not been thoroughly covered by previous subsidies.[5]

However, it is unclear if the "modernization" of the funds is producing efficient outcomes. The FCC's current monitoring report does not yield constructive insights. Lyons (2019) points out that it lacks a data-analysis mechanism to evaluate the effectiveness of the fund's activities.

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[4] Connect America Fund Phase II Auction Scheduled for July 24, 2018 Notice and Filing Requirements and Other Procedures for Auction 903, AU Docket No. 17-182, WC Docket No. 10-90, Public Notice, 33 FCC Rcd 1428 (2018); 220 Applicants Qualified to Bid in the Connect America Fund Phase II Auction (Auction 903); Bidding to Begin on July 24, 2018, AU Docket No. 17-182, WC Docket No. 10-90, Public Notice, 33 FCC Rcd 6171 (2018) (announcing the qualified bidders for the auction and confirming timing); Connect America Fund Phase II Auction (Auction 903) Closes; Winning Bidders Announced, AU Docket No. 17-182, WC Docket No. 10-90, Public Notice, 33 FCC Rcd 8257 (2018).

[5] Federal Communications *Commission, In the Matter of Rural Digital Opportunity Fund, Connect America Fund, Notice of Proposed Rulemaking,* WC Docket No. 19-126 (August. 1, 2019).

Similarly, the U.S. Government Accountability Office has repeatedly urged the FCC to improve accountability and transparency.[6] Hazlett and Wallsten even claimed that the CAF "will fail in the future – as it has until now – to benefit the consumers it is supposed to help" because structural inefficiencies remain intact during the reform (2013: 8). This paper seeks to empirically examine the effectiveness of the Connect America Fund between 2014 and 2018. Specifically, it analyzes if the supports have led to a significant increase in the number of (high-speed) broadband services provided by suppliers and broadband subscription rates.

Empirical Specification

This study assesses the effectiveness of the Connect America Fund at the county level, including the fifty States and the District of Columbia but not the U.S. Territories. The data covers the period from December 2014 to December 2018, which corresponds to the data collection period of the FCC's Form 477 since its reform. The random and fixed effect regressions are specified as the following:

$$Y_{it} = \alpha + Subsidy_{Dummy} + \beta TotalSubsidy + ln\,(CountyArea) + \gamma X_{it} + \mu_i + \varepsilon_{it}$$

$$Y_{it} = \alpha + \beta TotalSubsidy + \gamma X_{it} + \mu_i + \varepsilon_{it}$$

where, Y_{it} is the variable of interest, including the number of broadband providers, the number of high-speed broadband providers, and the broadband subscription rate in county i at

[6] U.S. Government Accountability Office, "FCC Has Reformed the High-Cost Program, But Oversight and Management Could be Improved" 10-11 (2012). See also U.S. Government Accountability Office, "FCC Should Improve the Accountability and Transparency of High-Cost Funding" 21 (2014)

time t. $Subsidy$ is the cumulative amount of subsidy a county has received since 2014.[7] X_{it} is a metric of control variables such as population, the number of business establishments, median income, the percentage of senior population, the percentage of African Americana and Hispanic population, and the percentage of the population with a below high-school education.[8] Urbanization data tend to be at a aggregated level and are less frequently updated. Population density and the business establishments density in the random effects model serve as proxies for the degree of urbanization in a county. μ_i is a county fixed effect, controlling for time-invariant county-specific characteristics that might be correlated with other independent variables. ε_{it} is the error term that is assumed to be uncorrelated with other variables and with a mean of zero.

In particular, the subsidy dummy is 1 if a county has ever received a subsidy between 2014 and 2018. The dummy is used to control for the fact that subsidies are not disbursed randomly. Unserved and underserved areas with little provider presence or high-speed broadband service are more likely to receive subsidies in the first place. Moreover, a firm's decision to apply for a grant and then increase broadband buildout in an area might be motivated by an intention to capture a gap in an underserved market. The above unobserved variables could cofound both response and independent variables. The most ideal instrument is an indicator for whether an area is eligible for the funds, but there are eight separate on-going broadband-related programs under the CAF providing support under dissimilar rules. An area's and a carrier's qualifications vary greatly from program to program, and most eligibility data are not publicly available.

[7] This one-year period is somewhat arbitrary, but the idea is that it takes time for the subsidies to take effect. The same specifications are run with cumulative subsidy in the past a year and half and two years. They produce stable and substantive conclusions to those that are presented in the paper.

[8] Previous survey suggests computer ownership and smartphone ownership may play a role in broadband deployment and adoption, but explanatory data analysis shows that these two factors are highly correlated with population, owing to the fact that 76% of American own a computer or laptop and 96% have a smartphone of some kind.

Another dummy that is considered in this paper is if the county has at least one high-speed service in 2014 (with upload speed > 3Mbps and download speed > 25Mbps), but most counties in the United States have at least one high-speed broadband provider and the dummy does not overlap well with the eligibility map that we have access to. Therefore, the subsidy dummy is used in the regression. One advantage is that if a county has ever received a subsidy in the four-year period, then it must have been eligible for support at some point.

Data Overview

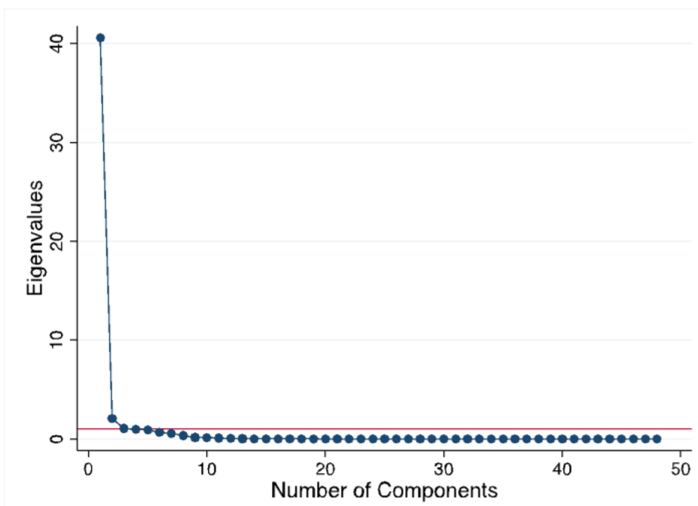
This paper relies on the FCC's Form 477 to measure fixed broadband deployment. Despite criticisms[9] Form 477 provides the most reliable and comprehensive data that is currently publicly available on the deployment of fixed terrestrial broadband in the United States. Each broadband provider is required to report deployment of a particular technology and bandwidth in a particular census block file Form 477 twice a year starting from December 2014. We code each round of data collection as one time period. As a result, our data covers nine periods from December 2014 to December 2018. Following the FCC's current benchmark, we define high-speed service providers as the carriers that offer at least one fixed terrestrial broadband service at speeds no slower than 25/3 Mbps. Although a provider that reports deployment in a census block may not necessarily offer that service everywhere in the block, Kolko (2010) finds a monotonic relationship between the number of providers and actual service coverage on the ZIP code level. This validates that the number of providers is a meaningful proxy for broadband availability.

Another outcome variable this paper examines is broadband subscription rates. While the number of providers is a proxy for accessibility, subscription rates reflect equilibrium outcomes

[9] See also Jett 2018, Molla 2019, Ford 2019

based on both the supply of broadband and demand for broadband when available. The American Community Survey (ACS) collects data on computer ownership and internet subscription for counties with populations over 65,000 since 2015, which amounts to 840 out of 3143 counties every year. Data are collected by asking respondents to select "Yes" or "No" to each computer and internet subscription type. Based on 48 initial variables[10] covering dimensions such as age, education, race, income, occupation, and industries of a county, we use principal component analysis to predict broadband subscription ownership in the remaining 2,303 unsurveyed counties. Principal components are constructed as linear combinations of the initial variables in such a way that they are uncorrelated and most information is compressed into the first component, then the second, and so on.

Figure. **6** Principle Components vs. Eigenvalues



[10] These variables include housing units; median income; mean income; poverty rate; land area; male; female; age under 5, 5-9, 9-14, 15-19, 20-24, 25-34, 35-44, 45-54, 55-59, 60-64, 65-74, 75-84, over 85; the population that aged between 18 and 24 with less high school graduate, high school graduate, some college, bachelor or higher education; the population that aged 25 or over with less than 9th grade, 9th-12th grade but no diploma, higher school, some college, associate's degrees, bachelor's degrees, and graduate or professional education; annual income less than $10000, $10000-$14999, $15000-$24999, $25000-$34999, $35000-$44999, $50000-$74999, $75000-$99999, $100000-$149999, $150000-$199999, above $200000; White, Black or African American, Native American, Asian, Hawaiian population and other race.

The above Scree plot suggests that only the first two components are statistically significant with an eigenvalue >1. Regressing broadband subscription on them produces a R-square of 0.9854, meaning almost all variance in broadband subscription can be explained by the first two components. This enables us to predict the pattern of broadband subscription for unsurveyed counties.

Our subsidy data comes from FCC's Connect America Fund Monitoring Report Supplementary Material. It documents the total dollars disbursed under the High-Cost program and the Connect America Fund by program and by year. While certain legacy programs dedicated to telephone providers are still in operation, only broadband-related programs are included.[11] The dataset is collected at the level of study area. A study area is a geographic segment of an incumbent local exchange carrier's (ILEC) operation and generally corresponds to an ILEC's entire service territory within a state. Carriers operating in more than one state typically have one study area for each state. Using boundary files, we overlay each study area on the county boundary shapefile to map the relationship between two graphical units. For cases where a study area resides in multiple counties, we weight the subsidy by overlapping land areas.

The Census Bureau's American Community Survey (ACS) is the main source for our demographic control variables.[12] Median household income in the past twelve months is converted to 2018 Inflation-Adjusted Dollars. The percentage of people with less than high school education includes those who attended high school but do not have a GED or high school diploma. The percentage of seniors is the ratio of the population aged over 65 to the total

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[11] Among various voice and broadband programs, the following funds are examined in this paper as broadband-related: Alaska Plan, Alternative Connect American Cost Model, Alternative Connect America Cost Model II, Connect American Fund Phase II, Connect American Fund Phase II Auction, Broadband Loop Support, Mobility Fund, and Rural Broadband Experiments. See also Appendix 2.

[12] See Appendix 1.

population in a county. The percentage of African American and Hispanic population is the proportion of the population who are self-identified as African American or Hispanic and Latino as at least one of their races in the total population. In addition, another source for control variables is the Census Bureau's County Business Pattern. It is an annual series that provides subnational economic data. It records total mid-March employees and the number of business establishments in a county.

Results and Discussion

Both random effects and fixed effects regressions are performed. This paper prioritizes within-county variation because it is rarely the case that between-unit variation will yield plausible estimates of a causal effect, whereas counties tend to differ systematically from one another in unobserved ways, as indeed indicated by the Hausman test. Differences in culture, geographic location, and terrain landscape could all contribute to various broadband deployment and socioeconomic patterns. Fixed effect eliminates all time-invariant confounding factors and between-county variation.

Nevertheless, fixed effect estimates have larger standard errors than random effects. This is because random effects use information both within and between counties, whereas fixed effects essentially discard all between-counties information. The fixed effect estimates could be imprecise (Allison 2009) for two reasons: (1) independent variables, such as the percentage of seniors or minority population, vary greatly across counties but have much less variation over time for each county, and (2) these control variables are only documented on an annual basis amounting to only five observations for each county. As a result, random effects are also reported in this paper.

Table 2. Random Effects Estimates

VARIABLES	(1) ln(Number of Broadband Providers)	(2) ln(Number of High-speed Broadband Providers)	(3) ln(Broadband Subscription Rate)
Subsidy Dummy	-0.0370***	-0.000136	-0.00507
	(0.0131)	(0.0181)	(0.00450)
ln(Total Subsidy)	0.0110***	0.0382***	0.00450***
Lagged one year	(0.00100)	(0.00200)	(0.000523)
ln(Median Income)	0.289***	1.208***	0.350***
	(0.0241)	(0.0386)	(0.00972)
ln(Establishments)	0.0659***	-0.152***	-0.00817
	(0.00844)	(0.0117)	(0.00518)
ln(Population)	0.264***	0.330***	0.00869
	(0.00990)	(0.0129)	(0.00624)
ln(CountyArea)	-0.0299***	0.0416***	0.00711**
	(0.00733)	(0.0104)	(0.00335)
ln(Below HS Education %)	-0.0144	-0.0522**	-0.0682***
	(0.0140)	(0.0212)	(0.00844)
ln(Black or Hispanic %)	0.0112	0.0299***	0.0279***
	(0.00809)	(0.00812)	(0.00422)
ln(Senior %)	0.232***	0.635***	0.0987***
	(0.0309)	(0.0424)	(0.0103)
Constant	-3.200***	-13.42***	-4.094***
	(0.286)	(0.410)	(0.107)
Observations	25,682	25,682	25,682
Number of counties	3,215	3,215	3,215

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table. 2 presents the random effects estimates for the number of providers, the number of high-speed providers, and the broadband subscription rate. All variables are in the natural log form except for the dummies, as this allows us to interpret the coefficients in terms of elasticities and make comparisons across different variables.

The coefficient of the one year lagged total subsidy is positive and significant across all three models. In particular, the number of high-speed providers is more responsive to the total subsidy than the total number of providers (0.0382>0.01110), perhaps because there is a deployment requirement associated with the recipient of a subsidy. All providers are obliged to provide service at speed at least 25/3 Mbps. Another reason might be that there are fewer high-speed providers than normal providers to start with, and thus a one percent increase in subsidy has a greater effect in terms of the percentage change. Third, the elasticity of the broadband subscription rate is very low (0.00450), meaning it is not very responsive to change in total subsidy.

Regarding control variables, the coefficient of the subsidy dummy is negative, which captures the fact that subsidies are disbursed to areas where not many providers are present and broadband usage is less prevalent. Counties with higher median income and population density are associated with higher numbers of (high-speed) providers and broadband subscription rates. The proportion of below high-school education population negatively affects all three response variables. Although exploratory data analysis indicates a negative relationship between the response variables and the proportion of seniors as well as the proportion of African American and Hispanic population, these effects are accounted for by other variables.

Table 3. Fixed Effects Estimates

VARIABLES	(1) ln(Number of Broadband Providers)	(2) ln(Number of High-speed Broadband Providers)	(3) ln(Broadband Subscription Rate)
ln(Total Subsidy)	0.0103***	0.0221***	0.00180***
Lagged one year	(0.00103)	(0.00214)	(0.000522)
ln(Median Income)	0.294***	1.739***	0.421***
	(0.0352)	(0.0723)	(0.0441)
ln(Establishments)	-0.0707	-0.0165	0.113
	(0.0565)	(0.125)	(0.0780)
ln(Population)	-0.540***	-0.410	-0.516***
	(0.120)	(0.287)	(0.154)
ln(Below HS Education %)	0.00453	-0.137***	-0.0712***
	(0.0173)	(0.0375)	(0.0219)
ln(Black or Hispanic %)	-0.0154	0.00470	-0.0304
	(0.0181)	(0.0259)	(0.0356)
ln(Senior %)	0.361***	1.028***	0.306***
	(0.0623)	(0.145)	(0.0923)
Constant	5.882***	-11.67***	0.836
	(1.240)	(2.851)	(1.650)
Observations	25,682	25,682	25,682
R-squared	0.093	0.279	0.487
Number of counties	3,215	3,215	3,215

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table. 3 presents the result of fixed effects estimations. As cumulative subsidies increase by 1 percent within counties, the number of providers, the number of high-speed providers, and broadband subscription rate respectively grow by 0.01 percent, 0.02 percent, and 0.002 percentage points -- all positive and significant. Compared to the random effect models, most control variables are no longer significant. In a five-year period, changes above or below the county-level mean in socioeconomic circumstances do not affect the broadband market in meaningful ways. Median income is one exception. It remains to be the most significant and strongest predictor for the number of (high-speed) providers and broadband subscription rate in the model. Senior proportion is another exception, which does not align with our expectations in both fixed and random effects models.

It should be noted that in both random and fixed effects regressions, higher subsidy levels do not seem to be as effective in raising broadband subscription rate, which is the ultimate goal of the policy. The broadband subscription rate almost remains unchanged even if subsidies double. This suggests that it is not enough to increase fixed broadband deployment on the supply side. The policy implication is that, to ensure no Americans are falling behind the unfolding communication revolution, it is necessary to address the problem of affordability. As previously discussed, half of non-broadband adopters regard monthly costs of broadband subscriptions as a major barrier in 2019. Furthermore, as smartphones and mobile broadband are increasingly seen as a substitute for fixed broadband, eight in ten non-broadband users expressed that they are not interested in subscribing in the future. The reason might be that they are not aware of the benefit of fixed broadband. Indeed, 60% of non-broadband users have never had high-speed internet service at home in the past. Given the small decline in the number of people who are discouraged by the subscription price since 2015, firm entry and market competition are apparently not sufficiently robust to reduce the price to an affordable level in the past four years.

Conclusion

This paper has sought to evaluate the Connect America Fund between 2014 and 2019. It did not find strong evidence in support of the program. As total subsidies (lagged in one year) in a county increase by 1%, the number of high-speed providers is expected to increase by merely 0.02%. While counties in the United States on average have five high-speed fixed broadband providers, the outcome of the Connect America Fund cannot be said as remarkable. Furthermore, the broadband subscription rate is not responsive to higher levels of subsidies. In other words, the fund is not effective in improving equilibrium outcomes. Therefore, the FCC's "modernization" reform is inadequate in enhancing the efficiency of the Connect America Fund. As billions of subsidies are expected in the next decade, the FCC should take measures to address sluggish demand in the broadband market to make sure the newly deployed infrastructure is not standing idle.

Appendix 1: Data Source Overview

Variable	**Unit**	**Source**
Broadband deployment	Census Block	Federal Communications Commission, Form 477
Subsidy disbursement	Study Area	Federal Communications Commission, 2019 High Cost Disbursement Report Supplementary Material
Study area boundary	Study Area	Federal Communications Commission
County boundary files	County	Census Bureau
Broadband subscription	County	2015-18 American Community Survey (ACS) Types of Computers and Internet Subscriptions 1-Year Estimates
Median income	County	2014-18 American Community Survey (ACS) Selected Economic Characteristics 3-Year Estimates
Popultion with less than Education	County	2014-18 American Community Survey (ACS) Selected Educational Attainment 3-Year Estimates
African American and Hispanic population	County	2014-18 American Community Survey (ACS) Demographic and Housing 3-Year Estimates
Business establishments	County	Census Bureau, County Business Pattern

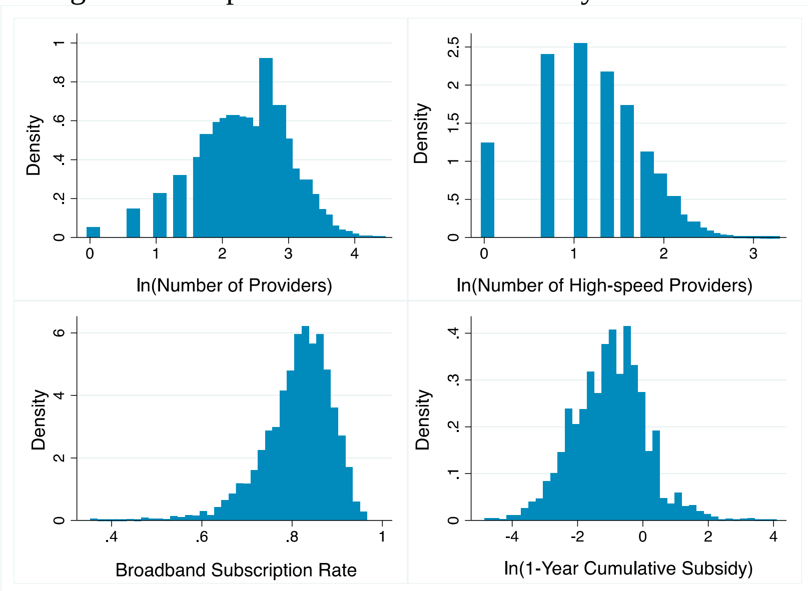
Appendix 2: Program Overview of Connect America Fund

Fund	Code	Type	Detail
		Modernized Fund	
Alaska Plan	AK_Plan	Voice and Broadband	Supports carriers in Alaska and their wireless affiliates, to maintain, extend, and upgrade broadband service.
Alternative Connect America Cost Model	ACAM	Voice and Broadband	Provides monthly support to carriers that voluntarily elected to transition to a new cost model for calculating High Cost funding
Alternative Connect America Cost Model II	ACAM II	Voice and Broadband	Provides monthly support to carriers that voluntarily elected to transition to a new cost model for calculating High Cost funding
Connect America Cost Model	CACM	Voice and Broadband	Provide support based on a forward-looking model of the cost of constructing modern networks for deploying voice and broadband services in states with unserved areas.
Connect America Fund Phase II Auction	CAF Phase II Auction	Voice and Broadband	Provides support to carriers to deliver service in areas where the incumbent price cap carrier didn't accept CAF Phase II model-based funding and in extremely high-cost areas located within the service areas of the incumbent price cap carriers.
Broadband Loop Support	BLS	Broadband	Helps carriers recover the difference between loop costs associated with providing broadband-only service and consumer broadband-only loop revenues.
Mobility Fund	Mobility	Broadband	Phase I provides immediate one-time support to accelerate the deployment of mobile broadband and voice service to unserved areas. Phase II provides ongoing support to deploy and maintain mobile broadband and voice service in high-cost areas.
Rural Broadband Experiments	RBE	Broadband	Provides funding for experiments in price-cap areas to bring robust, scalable broadband networks to residential and small business locations in rural communities.

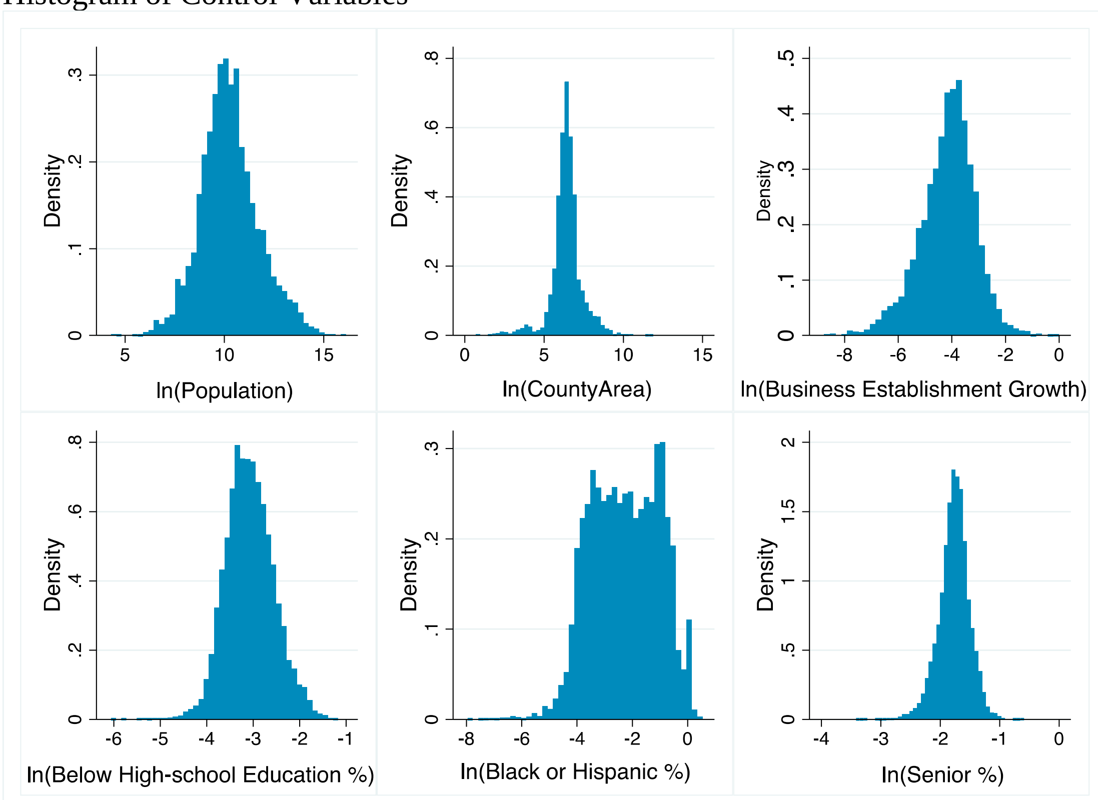
Legacy Fund			
Frozen High Cost Support	FHC	Voice	Under which the FCC froze support for HCL, SNA, SVS, HCM, LSS, IAS
High Cost Loop	HCL	Voice	Support for the last mile of connection for rural carriers in service areas where the cost to provide this service exceeds 115 percent of the national average cost per line.
Intercarrier Compensation Recovery	ICC	Voice	Facilitate incumbent LEC's transition from regulated, per-minute intercarrier compensation charges to a bill-and-keep methodology
Safety Valve Support	SVS	Voice	Provide additional support above the HCL cap that is available to rural carriers that acquire high-cost exchanges and make substantial post-transaction investments to enhance network infrastructure.
Safety Net Additive Support	SNA	Voice	Support for the “last mile” of connection for non-rural carriers where cost to provide service in the state exceeds two standard deviations above the national average cost per line
Interstate Access Support	IAS	Voice	Offsets interstate access charges for price-cap carriers, where $650 million in implicit support removed from access charges of price-cap carriers
Local Switch Support	LSS	Voice	Helps cover the high fixed switching costs for companies that serve 50,000 or fewer access lines.

Appendix 3: Distribution of Key Variables

Histogram of Response Variables and Subsidy



Histogram of Control Variables



Appendix 4. Correlation Matrix

	ln(nprovider)	ln(nProvider_HS)	Subscription rate	Subsidy Dummy	ln(Total Subsidy)	ln(Median Income)
ln(nprovider)	1					
ln(nProvider_HS)	0.6509	1				
Subscription rate	0.3308	0.3057	1			
Subsidy Dummy	0.0124	0.0344	-0.0304	1		
ln(Total Subsidy)	0.0554	0.1453	0.1107	0.6635	1	
ln(Median Income)	0.3677	0.2304	0.7541	-0.0599	0.0389	1
ln(Establishment)	-0.1655	-0.0881	-0.1803	-0.0181	0.0294	-0.2117
ln(Population)	0.7114	0.3505	0.298	-0.0521	-0.0046	0.3133
ln(Area)	0.0749	0.1862	-0.0206	0.1614	0.0582	-0.0349
ln(Below HS Edu %)	-0.0486	-0.0849	-0.457	0.0062	-0.0255	-0.434
ln(Black/Hispanic %)	0.1848	0.0283	-0.1316	-0.0251	-0.0032	-0.1529
ln(Senior %)	-0.2937	-0.1412	-0.1552	-0.0196	0.0351	-0.2252

	ln(Establishment)	ln(Population)	ln(Area)	ln(LowEdu)	ln(Black/Hispanic%)	ln(Senior%)
ln(nprovider)						
ln(nProvider_HS)						
Subscription rate						
Subsidy Dummy						
ln(Total Subsidy)						
ln(Median Income)						
ln(Establishment)	1					
ln(Population)	-0.2134	1				
ln(Area)	-0.0787	0.0502	1			
ln(Below HS Edu %)	0.0477	0.1194	0.0506	1		
ln(Black/Hispanic %)	-0.049	0.4052	-0.1259	0.6027	1	
ln(Senior %)	0.1142	-0.243	0.0511	-0.0305	-0.2947	1

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