* Preliminary and Incomplete: Don't Cite *
Bridging the Rural Internet Divide

Cole Campbell

May 11, 2022

Abstract

Broadband is a crucial aspect of modern-day economies, however, for many in rural America, access is limited. I exploit discontinuities in subsidy assignment from the Connect America Fund, and employ a Fuzzy Regression Discontinuity design to estimate the effect of subsidies on access. I find subsidies to price cap carriers increases access to 10 Mbps/1 Mbps download-upload speed broadband by 4.25 percentage points, however, this effect is local around the least-costly eligible areas. Furthermore, I show that the technology, as well as, the the number of providers in targeted regions are unaffected by these subsidies. The results suggest that the subsidy amount may not have been enough to provide universal service for all targeted areas.

Keywords: Broadband, FCC, subsidies, technology.

JEL Classification: L96, L98, O33, O38

1 Introduction

Despite the perception that high-speed internet is a crucial component of most modern societies, there are stark disparities in broadband infrastructure in rural versus urban areas. As of December 2016, 92.3 percent of Americans had access to fixed broadband (25 Megabytes per second (Mbps) down/3 Megabytes per second (Mbps) up), where the gap between rural versus urban areas was 28.6 percentage points.[1] If indeed, broadband has a significant impact on labor market outcomes, widespread broadband usage and access in urban areas relative to rural areas threatens to exacerbate these differences.

Previous literature has identified improved labor market outcomes as a result of broadband expansion. Development work finds that the introduction of broadband increases employment, and creates new types of jobs (Hjort and Poulsen, 2019). While research on broadband expansion in Germany and Norway document that increased access improves job matching, decreases the length of unemployment spells, and improves the labor market outcomes of skilled workers (worsens outcomes for unskilled workers) (Bhuller et al., n.d.; Akerman et al., 2015; Denzer et al., 2018; Briglauer et al., 2019; Gürtzgen et al., 2018). Little is known, however, about the causal impact of broadband access on labor market outcomes in the US context. The potential positive labor economic effects from expanding access to high-speed internet motivates the need to understand both the benefits from expanded broadband access, as well as, the factors which drive access, and how interventions can close the rural-urban divide.

This paper estimates the causal effect of Federal Communications Commission (FCC) subsidies granted to price cap carriers through the Connect America Fund (CAF) on broadband access. The FCC employed thresholds for determining subsidy eligibility, which generated discontinuities in the probability of treatment. I use census block-level data on access from the FCC, combined with estimates of the cost-per-active subscriber obtained from CostQuest Associates. I adopt a Fuzzy Regression Discontinuity Design to compare census blocks with estimated costs just above and below the FCC thresholds.

I find that subsidies allocated to price cap carriers as part of the CAF, did not significantly improve access to broadband in targeted areas. Despite seeing no effect along the extensive margin, I show that providers increased access to broadband at speeds of 10 Mbps down/1 Mbps up by roughly 4.3 percentage points. Moreover, I show that

[1] Statistics based on the FCC's 2018 Broadband Deployment Report.

technology used to provide access is unchanged, as is the number of firms, in response to subsidies. Finally, I provide evidence that subsidized carriers gradually expanded access to mandated areas, and predominantly provided speeds of 10 Mpbs down/1 Mbps up.

Broadband expansion has been difficult to study. OLS regressions that compare labor market outcomes and broadband access are likely to biased by reverse causality, as well as, by omitted variables correlated with both outcomes and deployment. Only recently has the literature been able to employ contemporary econometric techniques to identify the effects of broadband on labor market outcomes. Hjort and Poulsen (2019) use data from 12 countries in Africa, and show a relatively large increase in the employment rate, as broadband becomes available, driven by high-skilled occupations. In the US, Dettling (2017) finds that home high-speed internet usage raises labor force participation for married women, as well as, their hours worked and employment, but no response for other groups. Atasoy (2013) analyzes aggregate expansion of broadband and finds a 1.8 percentage point increase in employment, with larger effects concentrated in more rural areas. A recent study by George Zuo and Kolliner (2019) assesses the effect of a program targeted to low-income individuals, and finds the program increased the probability that a low-income individual was employed by 4.4 percentage points, providing evidence that government interventions that improve take-up of broadband are effective in improving labor market outcomes.

In other developed countries, improved access to broadband appears to generate positive labor market outcomes for some individuals. Indeed, there is a consensus that broadband expansion increases job-finding rates (Kuhn and Mansour, 2014; Choi, 2011; Bhuller et al., n.d.; Denzer et al., 2018; Gürtzgen et al., 2018), though there is some debate on whether internet access has a causal effect (Kuhn and Skuterud, 2004). Moreover, Bhuller et al. (n.d.) provide some evidence of improved match quality where workers in Norway experience higher starting wages and more stable employment relationships following an unemployment spell. However, labor market and productivity benefits may be limited to skilled workers which take advantage of complementarity between skill and technology (Akerman et al., 2015). Briglauer et al. (2019) identify spillover effects related to national income, and show that the availability of high-speed internet marginally increases regional GDP in Germany.

Despite the pronounced benefits associated with broadband access, there is limited evidence that state programs that expand access lead to increased adoption. LaRose et al. (2011) assess the impact of rural infrastructure grants on broadband adoption; they find that adoption increased, though the results are likely biased by positive selection. A body of literature suggests that adoption may be limited due to costs, such that interventions that expand access are limited in their capacity to encourage take-up. Carare et al. (2015) find that two-thirds of all households surveyed that previously did not have an internet subscription, would not take up service at any price. Whitacre et al. (2015) decompose the rural-urban adoption gap using Oaxaca-Blinder methods, and find just 38% of the gap can be attributed to differences in infrastructure, while 52% can be attributed to observable characteristics of individuals. Within the marketing and entrepreneur literature, in a study of rural and non-rural businesses in North Carolina, Richmond et al. (2017) document limited adoption of broadband capabilities that require higher bandwidth. Thus, the efficacy of targeted supply-side policies to rural areas might be inhibited by the underlying preferences of these individuals without other targeted demand components.

Lastly, this study's focus on a wave of targeted subsidies to firms relates to a body of work that examines whether government subsidies "crowd-out" other forms of private investment. There is limited research that examines the impact of subsidies on the telecommunications industry. An analysis of the FCC Lifeline Program, which subsidizes wireless services for eligible low-income households, shows that subsidies crowd-out public expenditures on these services and save consumers more than the dollar value of the service (Conkling, 2018). Other work in the crowd-out literature focuses on municipal-owned broadband networks, which potentially crowd-out private networks. Wilson (2016) finds that public competition crowds-out private investment, however, bans on municipal-owned services reduce total welfare. Other work finds no correlation between private sector employment growth and high-speed municipal broadband, suggesting the crowd-out effect is limited (Singer, 2018) .

This paper is the first that the author is aware of that examines how government subsidies affect access to broadband. Moreover, this is the first paper to consider the distinction between the extensive and intensive margin at various policy relevant speed benchmarks. The evidence presented in this paper is relevant to policy makers that wish to provide universal service to individuals in hard to reach regions. The results suggest that subsidies are an effective tool to improve upon existing broadband access through increased speeds. However, in order to achieve universal service subsidies must be large to reach more costly areas.

2 Background and Conceptual Framework

In this section I briefly describe the policy of interest to expand broadband access (CAF), as well as, a relevant discussion of U.S. telecommunications regulation, and a description of the cost model used to implement the policy.

2.1 The Connect America Fund

In 2009, Congress mandated the FCC to develop a National Broadband Plan, which sought to ensure that all Americans had "access to broadband capability."[2] Subsequently, in 2011 the FCC issued the "USF/ICC Transformation Order," which created the Connect America Fund (CAF) to replace all other existing "high-cost" support mechanisms tasked with making broadband available to areas often deemed "prohibitively costly"[3]. The CAF has an annual budget of $4.5 billion, $4 billion of which are divided between price cap and rate-of-return areas, not to exceed $1.8 billion annually for price cap carriers[4].

Importantly, U.S. law draws distinction between price cap and rate-of-return regulation. Telecommunications industry regulation specifies geographical areas that fall under either of these regulations, where there is little to no overlap between the two. Rate-of-return (ROR) regulation allows firms to set prices to ensure that they meet some revenue requirement, which allows them to maintain their credit-worthiness, as well as, attract capital. The regulatory agency (FCC), then prescribes the "rate-of-return" for these entities, which currently in the U.S. sits at 11.25 percent[5]

In contrast, price cap regulation allows firms to increase prices to recoup unavoidable costs (i.e. inflation, tax increases), but does not allow the firm to recoup all costs through

[2]For a comprehensive timeline of universal service, see the FCC's website on Universal Service

[3]See *26 FCC Rcd 17663 (22)*, USF/ICC Transformation Order

[4]Figures from FCC order 11-161

[5]See, e.g. Prescribing the Authorized Rate of Return, Analysis of Methods for Establishing Just and Reasonable Rates for Local Exchange Carriers, WC Docket No. 10-90 (filed May 16, 2013). ROR is understood to generate perverse incentives for firms, such that they do not operate efficiently. Subsequently, much of the telecommunications industry in the U.S. was moved off ROR to price cap in the 90s (Hausman, 2003).

these price increases. A basic formula for price cap regulation, allows the price increase for a given year to be a linear function of the starting price, an inflation factor, and some productivity factor.[6] Thus, while a ROR regulated firm is able to increase prices to recover costs, so long as it falls below the prescribed rate-of-return, price cap providers must lower their prices regularly to reflect the productivity gains of an efficient provider.[7] Over 80 percent of unserved Americans lived in price cap regulated areas, such that subsidies were targeted towards the carriers that fell under the this regulation.[8]

To accelerate buildout, the CAF proceeded in two phases CAF Phase I: Round I (2012), froze the existing "high-cost" subsidies and provided \$115 million to deliver service to 400,000 individuals.[9] CAF Phase II was two-fold: it allocated subsidies from the CAF using a forward-looking cost model, and introduced a competitive bidding process for CAF subsidies where carriers declined support. Final eligibility for CAF Phase II subsidies was determined using the Connect America Cost Model (CAM) (version 4.3).[10]

The FCC established thresholds that targeted census blocks, for which the cost of service likely exceeded the revenue from end-user rates alone.[11] Based on the model, census blocks with estimated average per-location cost of deployment between \$52.50 and \$198.60 were deemed eligible for model-based subsidies.[12] The total subsidy amount to a given carrier is the estimated per-location cost of deployment, minus the funding benchmark (52.50), multiplied by the total number of locations. Price cap carriers were given the opportunity to accept all, none, or a portion of the support for which they were eligible, delivered in yearly lump sum payments. Acceptance of subsidies required

[6] For instance, a price cap formula might be represented as: $\Delta P = P_0 + I - X$, where ΔP gives the allowable price change from P_0 to P_1, I is an inflation factor, and X is a productivity factor.

[7] Price cap regulation is meant to mimic a competitive market that minimizes regulatory intervention. See "Blackman, Colin; Srivastava, Lara. 2011. Telecommunications Regulation Handbook : Tenth Anniversary Edition. World Bank and the International Telecommunication Union, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/13278 License: CC BY 3.0 IGO."

[8] See, e.g., Comments of the National Rural Electric Cooperative Association, WC Docket No. 10-90, at 2-3 (filed Jan. 28, 2013); Comments of the National Association of Telecommunications Officers and Advisors, WC Docket No. 10-90, at 2 (filed Jan. 28, 2013).

[9] Round II (2013) allocated an additional \$300 million in order to phase in implementation of CAF Phase II. See FCC 13-73, WC Docket No. 10-90 (filed May 21, 2013).

[10] See FCC 14-54, (filed April 23, 2014). The overall architecture of the model takes the following form: (1) seeks to understand potential demand, (2) designs efficient network topology, (3) computes the cost and develops solution sets, (4) defines the universe of existing coverage, and (5) evaluates different universal support amounts under user provided support amounts.For a rigorous discussion of the models inputs, assumptions, and architectural process see the Connect America Fund Cost Model Methodology

[11] See the Wireline Competition Bureau's Cost Model Virtual Workshop for a discussion of the model's assumptions and a in depth description of the cost thresholds.

[12] Blocks that were served by any carrier with speeds of 3 Mbps/768 kbps were ineligible.

providers to deploy to no fewer than 40% of the required number of locations by the end of 2017, 60% by the end of 2018, 80% by the end of 2019, and all locations by 2020, resulting in a rapid rollout of broadband technology to rural unserved Americans.[13]

2.2 Conceptual Framework

At its most basic, the policy studied in this paper is a mechanism to expand broadband access to unserved areas by lowering a firms costs through subsidies. For broadband providers their costs exhibit economies of density, such that costs are lower in higher density areas.[14] To the extent that much of the gap in access is driven by differences in costs between urban and rural areas, subsidizing buildout to more costly areas can equalize access.

Intuitively, if a price cap carrier's expected cost of expansion exceeds the expected revenue then a location remains unserved. The policy lowers a provider's marginal cost by the difference between the estimated cost of deployment and the benchmark ($52.50). Thus, conditional on accepting the subsidies, we expect the firm to expand access to required areas since its marginal revenue is now larger than its marginal cost.

Recall that providers were not required to accept the full subsidy amount. Based on the logic above, if even in the presence of the subsidy the cost of expanding access exceeds the expected revenues, then the provider would decline some portion of the subsidy and the location remains unserved. Areas that were eligible for subsidies, but the incumbent carrier declined the offer, were allocated to CAF's competitive bidding process, where a pool of eligible carriers were allowed to bid down subsidies. Therefore, providers are incentivized to accept the initial model-based offer if its value is larger than the expected subsidy value from the bidding process. Lastly, given that the policy constitutes a universal service regime, (Faulhaber and Hogendorn, 2003) note that adding a universal service constraint adds substantially to network costs, slowing down deployment and competitive entry. This implies that unless the subsidy is sufficiently large, there maybe adverse effects associated with the policy.

[13]Build out milestones are described in depth in FCC-14-190. The USF/ICC Transformation order also created mechanisms to support *rate-of-return* carriers as part of the CAF. This included a similar model-based program, the Alternative Connect American Cost Model (A-CAM). For more information see the *Rate-of-Return Resources* page.

[14]See Rural Broadband Economics: A Review of Rural Subsidies.

3 Data

3.1 FCC Form 477

Form 477 data is the most complete source of broadband availability open to the public, made available as fixed broadband deployment data from the FCC. The FCC requires that all facilities-based providers of broadband file with the FCC on a biannual basis if they have at least one connection terminating to an end-user. I have information on the maximum advertised upload and download speeds, as well as, the type of technology through which the service is offered. Using this data, I construct a biannual panel of census blocks from December 2014 to June 2019.

Other researchers have noted (Dettling et al., 2018), this data overstates households' access to broadband. The FCC requires that providers report whether they provide service to a single user in a census block, indicating a block has access, this does not mean the provider can service the entire block. Similarly, the degree of competition within a block is not implied by the raw number of carriers that report service in an area. If different providers report service in different areas within a block, the level of choice a consumer faces is not tied to the number of broadband providers.

3.2 CostQuest Associates - Cost Estimates

The running variable for the research design is comprised of estimates of the cost per active subscriber from CostQuest Associates for more than six million census blocks, binned into two dollar increments. This covers nearly every inhabited census block, many of which are covered under rate-of-return regulation. Each binned cost estimate represents the investment cost for a voice and broadband-capable network using an existing wireline network. These monthly cost estimates include monthly operation cost, depreciation of capital costs, cost of money, and income taxes.[15] Figure 3 shows the spacial distribution of these cost estimates over the contiguous states. I supplement these cost estimates with lists of supported blocks and regulation from the FCC.

[15] See documentation on the Connect America Cost Model Methodology

4 Research Design

To identify the causal effect of subsidies I use quasi-experimental variation that mimics the random assignment process. I argue that the thresholds that determined subsidy eligibility are orthogonal to potential outcomes. If the thresholds for subsidies are exogenous, then potential outcomes should be smooth across the threshold. Therefore, the causal effect of subsidies on outcomes can be estimated by comparing the outcomes of blocks just above and below the thresholds. Since, the FCC established two separate thresholds for subsidies, which I refer to as the "high-cost" and "extremely high-cost" thresholds respectively, there are potentially two treatment effects associated with subsidies.

In practice, model-based subsidies are not fully determined by a block's estimated cost per active subscriber. Providers were allowed to accept support for all, none, or a portion of the eligible blocks in a given study area, leading to imperfect compliance in subsidy assignment. Hence, to estimate the effect of subsidies on outcomes, I adopt a fuzzy regression discontinuity design, where the corresponding causal effect of interest is the Local Average Treatment Effect (LATE) (Imbens and Lemieux, 2008; Lee and Lemieux, 2010). By exploiting this discontinuity in the expected probability of receiving model-based support, conditional on the estimated cost per active subscriber, the first-stage is the effect of being just above the either the high-cost or extremely high-cost threshold. In my analysis the normalized running variable (C_i) gives the distance from either threshold ($C_i = cost_i - threshold_j$). The reduced form is the effect of being just above the threshold on different outcomes (separately estimated at each threshold).

Therefore, the first-stage and reduced form equations take the following form:

$$\text{First-Stage: } E\left[S_i|cost_i\right] = \alpha_0 + \delta 1\left\{C_i \geq 0\right\} + f(C_i) + \nu_i \tag{1}$$

$$\text{Reduced Form: } Y_i = \alpha_1 + \rho 1(C_i \geq 0) + f(C_i) + \varepsilon_i \tag{2}$$

where Y_i is the outcome for block i, $1\left\{C_i \geq 0\right\}$ is an indicator equal to 1 if block i's normalized estimated cost per active subscriber is above zero, $f(C_i)$ is a flexible control function of the running variable, and S_i the expected probability of receiving subsidies. Thus, if the probability of receiving subsidies changes discontinuously at $C_i = 0$, I am still able to identify the causal effect of subsidies even if a block's estimated cost per active subscriber is correlated with unobserved factors that determine access and other outcomes.

If potential outcomes are smooth across the thresholds prior to treatment, then the second-stage effect can be estimated via two-stage least squares (2SLS), where the second stage regression takes the following form:

$$Y_i = \alpha_2 + \gamma E\left[S_i | cost_i\right] + f(C_i) + \varepsilon_i \quad (3)$$

By estimating above equation at either threshold, I recover the treatment effect γ, which mathematically translates to the reduced form effect ρ, scaled up by the first-stage δ. Instrumenting for the expected probability of receiving model-based support with being above or below the corresponding threshold, conditional on a flexible function of the normalized running variable, I obtain a consistent estimate of the LATE of subsidies on outcomes.

5 First-Stage and Threats to Identification

Fuzzy RD is an instrumental variables (IV) approach to identification[16]. Under this framework the standard IV assumptions must hold: (1) relevance, (2) independence, (3) exclusion, and (4) monotonicity.

5.1 First-Stage: Probability of Receiving Model-Based Support

Figure 5 plots the relationship between the cost per active subscriber and the probability of receiving subsidies, demonstrating a clear discontinuous break in the probability of treatment. Figure 6 formally estimates the break, plotting the first-stage results from estimating Equation 1 at the high-cost and extremely high-cost thresholds, respectively. The x-axis displays a census block's normalized cost, and the y-axis is the probability of receiving CAF Phase II model-based subsidies.

Table 2 presents the first-stage regression results at the "high-cost" and "extremely high-cost" thresholds , where I vary the bandwidths and adjust the sample for only blocks which were previously unserved by a price cap carrier. In my preferred specification (column (2)) I estimate that blocks with cost-per-active subscriber just above the high-cost

[16]See e.g. Angrist and Pischke (2009), Imbens and Lemieux (2008) for a rigorous discussion of the identification assumptions necessary for sharp and fuzzy regression discontinuity designs.

threshold are roughly 38.4 percentage points more likely to receive model-based support. Whereas those with an estimated cost just above the extremely high-cost threshold are 44.4 percentage points less likely to receive model-based support.

5.2 Independence: Histogram Test and Covariate Smoothness

The primary threat to RD designs is fine manipulation of the running variable around the threshold(s), generating nonrandom selection on either side. If there is perfect manipulation of the cost per active subscriber around the threshold, by either CQA or the FCC, such that they're able to push some blocks just above (or below) the threshold, then receiving model-based support is no longer random within a narrow range of the threshold(s). If there is manipulation of the running variable we should expect bunching on one side of the threshold relative to the other, indicating fine manipulation. Figure 6 shows the distribution of cost estimates around the high-cost and extremely high-cost threshold respectively. I formally test the identifying assumption that there is no systematic manipulation of the running variable using a test proposed by McCrary (2008). Figure 7 shows McCrary's density plots, which evaluate the continuity of the distribution of the running variable. The results indicate no systematic manipulation of the running variable.

Moreover, if there is manipulation of the running variable such that there is differential selection on either side of the threshold, there should be discontinuities in the observable characteristics. I test this assumption by plotting a variety of outcomes using data prior to the intervention. Figures 8 and 9 shows some of the outcomes against the running variable, within a narrow band of each threshold prior to treatment.

5.3 Exclusion

The exclusion restriction requires that the instrument only affect outcomes through its effect on the endogenous regressor. Therefore, for internal validity I need to assume that for a given census block, whether it falls above or below either threshold only affects access and other outcomes, through its effect on receiving subsidies. The FCC and CQA both published lists of eligible census blocks and whether the estimated cost per active subscriber fell above or below each threshold. Hence, at some level the cost to expand access under the CAM assumptions is known to all providers. The exclusion restriction could fail if providers on the margin of providing access to certain blocks do so because they have improved information about the cost of provision. Similarly, if smaller carriers ineligible for subsidies have first mover advantage over subsidized carriers and wish to enter the market to take advantage of existing demand, this too would violate exclusion. Fundamentally, the exclusion restriction is not testable, however, I argue that a violation of this kind seems unlikely. CAF Phase II subsidies targeted census blocks unserved by an unsubsidized price cap competitor, such that all else equal, entry to unserved areas should be driven by subsidized providers. Suppose there are two firms on the margin of expanding access to an unserved block, and the market is competitive. Firm 1 receives subsidies to expand, firm 2 does not; if firms face identical costs and each firm is on the margin of providing access, then only the subsidized firm expands.

5.4 Monotonicity

As previously mentioned, the case where the first-stage treatment variable is a binary outcome, the monotonicity assumption simplifies to assuming away defiers. In this context a defier is a census block that fell above the high-cost threshold, inducing carriers to decline support, or received subsidies because it fell below the threshold (the coverse holds at the extremely high-cost threshold). A defier of the later example, which receives model-based support because it fell below the cutoff is unlikely to exist, since that runs counter to the program. Similarly, there is no economic incentive for a carrier to refuse subsidies because a block fell above the cutoff. Hence, in either case the subpopulation that would be a defier is probably not a real group, making the monotonicity assumption fairly innocuous.

6 Empirical Findings

My approach addresses three policy relevant areas. With the data available I am rigorously able to evaluate the causal effect of subsidies on access to broadband on both the extensive and intensive margin, technology used to provide access, and the number of firms that offer access.

6.1 Effects on Broadband Access

Table 3 presents the main results for the effect of subsidies on broadband access. I estimate Equation 3 using local polynomial regression with bias corrected confidence interval, and optimal bandwidths calculated using procedures proposed by Calonico et al. (2020); Imbens and Kalyanaraman (2012).[17] Each regression is separately estimated using both a linear and quadratic fit. Panel A, columns (1) and (2) present the point estimates of the effect of subsidies on whether or not a census block has any access to broadband at the high-cost threshold, varying the polynomial fit. The coefficients indicate that subsidies had no effect in expanding aggregate access. Panel B reports the same analysis at the extremely high-cost threshold, and similarly finds no change in aggregate access. Figure 11 provides reduced form evidence of high-cost and extremely high-cost results. Since subsidies were targeted to blocks that did not meet the CAF benchmark speeds (10 Mbps down/1 Mbps up) and were unserved by price cap carrier, if there were any incumbent providers we should expect to see no effect on the extensive margin.

Despite there being no discernible differences in access on the extensive margin, we might expect differences in speeds across the thresholds as providers that use subsidies to buildout to supported areas might be able to accommodate faster speeds than incumbent providers. To investigate the effect of subsidies on the intensive margin, I explore two policy relevant speed combinations: (1) 10 Mbps down/1 Mbps up, and (2) 25 Mbps down/3 Mbps up, which I will refer to as the "CAF benchmark" and "FCC benchmark" respectively.[18] The first combination, 10/1, was the contractual minimum speed carriers must provide to receive subsidies, while the second, 25/3, is the FCC's current speed benchmark for broadband.[19] Given that expanding access to 10/1 was the primary goal of the policy we should expect that subsidized carriers met this benchmark.

First, I estimate the effect of subsidies on an indicator for whether a census block's maximum advertised speeds are equivalent to the CAF benchmark. Panel A, columns (3) and (4) indicate that subsidies to blocks just above the high-cost threshold increased access to 10/1 by 4.25 percentage points on average. While, the results in panels C and

[17] I estimate Equation 3 using robust bias-corrected confidence intervals and optimal bandwidth selection in Stata via the command rdrobust (Calonico et al., 2017).

[18] I explore how the treatment effect differs using alternative definitions of the CAF and FCC benchmarks in Appendix 9.

[19] See the FCC's 2015 Broadband Progress Report.

D suggest there was no discernible impact at the extremely high-cost threshold. Indeed, Figure 12 shows reduced form evidence of the effect of subsidies on access to the CAF benchmark and corroborates the 2SLS results. It's curious that even in the presence of subsidies, blocks just below the extremely high-cost threshold would see no effect on access to CAF benchmark speeds. One explanation is that the subsidy is too small for firms to feasibly expand, and subsequently operate in these areas. Consistent with the conceptual framework outlined earlier in Section 2.2, where under a universal service regime with insufficient subsidy amounts, deployment may be stagnated.

Next, I repeat the previous exercise but for whether a block's maximum advertised speeds are equivalent to the FCC benchmark. Panel A, columns (5) and (6) indicate that there was no meaningful change in access to speeds at the FCC benchmark across the high-cost threshold.[20] Likewise, Panel B shows no effect at the extremely high-cost threshold. Figure 13 shows reduced form evidence for the null effect along this margin at either threshold. Indeed, while subsidized providers expanded access to broadband, they only did so as to meet the contractual requirement. Given that providing services at higher speeds quickly becomes more costly as the density of households drops off, if the subsidy amount was insufficient we would expect a larger treatment effect at the high-cost threshold.

A natural question that arises from this analysis is whether subsidized carriers simply did not buildout along the extremely high-cost threshold. Form 477 data has several limitations that provide a plausible explanation for this result. For a given census block, a provider's access indicator takes a value of one if they can or do provide service in a block. This places no restrictions on their capacity to serve an entire block, such that providers may serve all, some, or an individual part of a given block. Meaning that if unsubsidized carriers are able to expand to targeted blocks, but fail to serve the entire block, they may mask expansion by subsidized carriers. This issue becomes increasingly problematic, given that the geographic size of census blocks increases as population density decreases. Additionally, since providers were required to buildout to specific locations within a targeted block, it's possible that most of the expansion of broadband occurs on this margin. Absent location specific data across each of the thresholds, I cannot directly test this hypothesis using the FRD. I exploit the panel

[20]While, column 6 is significant at the 5 percent level, it is not robust to the bandwidth selection so I treat it as spurious.

nature of the Form 477 data in Section 7.2 to explore whether providers did expand access along the extremely high cost-threshold.

6.2 Technology

A relevant avenue in this paper's focus on the provision of broadband is the method by which carriers choose to provide access. For policy makers that consider other strategies that make expansion in to costly areas commercially viable, the technological choice of provision is a an important margin. If subsidies are too small to expand access using technology capable of increased bandwidth in the long-run, providers may switch to less costly investment choices to meet the universal service mandate. I consider two widely available technologies, digital subscriber line (DSL) and cable, to assess the impact of subsidies on the method of provision, where the results are presented in Table 4. Columns (1) and (2) indicate that census blocks that were just above the high-cost and extremely high-cost threshold were no more likely to have access to broadband via DSL technology. Columns (3) and (4) similarly, show no change in the likelihood of cable broadband provision as we move across the thresholds. I present reduced form evidence in Figures 14 and 15 for each type of technology. The results of this exercise show virtually no change along this margin, at either threshold.[21] This suggests that providers do not need to make significant alterations to their existing wireline network to reach these supported areas.

6.3 Competition

An important implication of the policy is how the level of choice changes across each threshold. If the policy achieved its intended effect it must be the case that a new carrier moves into unserved areas to provide service. Therefore, we should expect the number of firms to increase as we move across the high-cost threshold and decrease across the extremely high-cost threshold. If I observe no change to the number of firms, this could be evidence of firm exit as a result of subsidies or lack of expansion. I define the level of competition in a census block by summing the total number of carriers that offer access of any kind, and assess how this number varies across the thresholds. Table 4, columns (5) and (6) test this hypothesis, and Figure 16 presents the reduced form effect on the number

[21] I explore other, less widespread types of technology, and similarly find no effect from subsidies.

of providers. I find little evidence to suggest blocks that received subsidies were more competitive; rather, while insignificant, the point estimates are strongly negative at the high-cost threshold. I treat these findings as evidence to suggest that there maybe crowd-out as a result of subsidies. This is consistent with the anticipated effect of government subsidies on specific firms.

7 Discussion

An unanswered question in this analysis, is whether subsidized carriers expanded access to areas along the extremely high-cost threshold. The previous analysis asks whether subsidies improve access along either the extensive or intensive margin, however, it does not address whether subsidized providers are building out these areas. It is concerning from the policymaker perspective if subsidies do not achieve their intended effect. I explore this concern iteratively. First, I restrict the sample to just price cap carriers and estimate the effect of subsidies on access using just these carriers. Then, I stray from the FRD framework and regress whether a block has access to broadband on a indicator for if a block was supported by the model, fully interacted with time. I plot these interactions to assess whether subsidies predict if a block has access from a supported price cap carrier.

7.1 Price Cap Sample

Table 5 presents the 2SLS estimates of the effect of subsidies on access to broadband when I just restrict the sample to price cap carriers. The results of this exercise are quite similar to the full sample. Census blocks just to the right of the high-cost threshold that received subsidies saw access to the CAF benchmark improve by 5.76 percentage points on average (column (2)). I find no effect on the extensive margin, nor on access to the FCC benchmark at either threshold. Surprisingly, I detect a positive significant effect on the extensive margin at the extremely high-cost threshold. Some price cap carriers were allowed to accept support for blocks that exceeded the extremely high-cost threshold, which could explain this result. Though it is not robust to the functional form choice. Within this restricted sample we might expect pronounced effects on the extensive margin; in absence of this, the results may indicate that much of the expansion that occurred was within census blocks that were already served by an unsubsidized carrier.

7.2 Broadband Access Dynamics

Given the null results for the extremely high-cost threshold, a relevant question is whether price cap carriers builtout at all. To answer this question I see how access from subsidized carriers has evolved over time by regressing an indicator for whether a block has any access on whether or not a block has subsidies, fully interacted with time. Furthermore, I restrict the sample to a $10 locality, similar to the FRD estimates. Figures 17 and 18 plot the coefficients on the interaction terms between the time fixed effects and whether a block was supported by the CAF model.[22] If subsidized carriers did not expand access after receiving support, we expect the coefficients on the interaction terms to be zero. I find that subsidized price cap carriers significantly increased access to these areas by more than 10 percentage points by 2019 at each threshold.

7.3 Falsification Tests

Lastly, I conduct falsification tests to ensure that my results are robust estimates of the causal effect. The covariate smoothness plots I show in Figures 8 and 9 serve this purpose, as we should expect no effect on outcomes in the period prior to the policy. Given that we do not find statistically significant effects in the pre-period, and point estimates tend to be very close to zero, this suggests that observed differences in outcomes in the post period are driven by the policy. I estimate the reduced form for ROR regulated areas, to ensure that the results are not spurious. Figures 19, 20, and 21 show this evidence and indicate no significant differences in these untreated areas. Figure 22 detects a significant effect of being above the extremely high-cost threshold; however, based on the confidence bands on either end other of the threshold, this significance appears to be random.

8 Conclusion

This paper assesses the impact of federal subsidies administered to price cap carriers to expand broadband access to high-cost areas. I adopt a fuzzy regression discontinuity design to estimate the effect of subsidies on outcomes. I characterize the effect of subsidies on both the extensive and intensive margins of access, as well as, how technology of provision and the number of firms change in response to receiving support.

[22]Regressions are run using just he price cap sample, and June 2015 is normalized to zero

I find that subsidies expanded access to the CAF benchmark speeds of 10 Mbps down and 1 Mbps up by 4.25 percentage points for census blocks with estimated cost-per-active subscriber just above $52.50. I find no effect on access at the extensive margin for either threshold, or on the intensive margin for blocks near the extremely high-cost threshold. Moreover, I show that providers do not significantly alter their technology choice in response to subsidies, suggesting they do not differentially alter their existing wireline network to provide access in high-cost areas. Lastly, I assess how market competition changes in response to the buildout of subsidized competitors. I find that subsidies do not significantly affect the number of broadband providers, providing evidence that subsidies to select firms may crowd-out other unsubsidized carriers.

I address the concern that blocks at the extremely high-cost threshold did not see precipitous changes in access from subsidies in two ways. First, I separately estimate how subsidies affect access, restricting to only price cap carriers, the results of which largely confirm the main analysis where I consider the effect of the policy among all providers. Second, I explore the dynamics of access for subsidized areas, and find clear evidence that subsidized carriers gradually builtout to targeted areas.

Given the established narrative, hailing broadband as necessary driver of economic growth, provision of such a good under this regime is a first-order policy concern. This study informs the efficacy of large government subsidies to achieve this universal service priority. The results of this paper suggest that government intervention is effective in providing broadband to areas that are not traditionally commercially viable. However, the results indicate that a higher subsidy amount may be needed to adequately target increasingly more costly areas. More work is needed to identify: (1) whether subsidies that expand broadband induce consumers to take up service, and (2) the extent to which there are associated labor economic effects from expanded access consistent with the canonical narrative surrounding expansion. A thorough analysis of the efficacy of broadband expansion necessitates consideration of these outcomes.

References

Akerman, Anders, Ingvil Gaarder, and Magne Mogstad, "The Skill Complementarity of Broadband Internet*," *The Quarterly Journal of Economics*, November 2015, *130* (4), 1781–1824.

Angrist, Joshua David and Jörn-Steffen Pischke, *Mostly harmless econometrics: an empiricist's companion*, Princeton: Princeton University Press, 2009. OCLC: ocn231586808.

Atasoy, Hilal, "The Effects of Broadband Internet Expansion on Labor Market Outcomes," *ILR Review*, April 2013, *66* (2), 315–345.

Bhuller, Manudeep, Andreas Ravndal Kostol, and Trond Christian Vigtel, "How Broadband Internet Affects Labor Market Matching," IZA DP 12895.

Briglauer, Wolfgang, Niklas Dürr, and Klaus Peter Gugler, "A Retrospective Study on the Regional Benefits and Spillover Effects of High-Speed Broadband Networks: Evidence from German Counties," *SSRN Electronic Journal*, 2019.

Calonico, Sebastian, Matias D Cattaneo, and Max H Farrell, "Optimal bandwidth choice for robust bias-corrected inference in regression discontinuity designs," *The Econometrics Journal*, May 2020, *23* (2), 192–210.

_ , Matias D. Cattaneo, Max H. Farrell, and Rocío Titiunik, "Rdrobust: Software for Regression-discontinuity Designs," *The Stata Journal: Promoting communications on statistics and Stata*, June 2017, *17* (2), 372–404.

Carare, Octavian, Chris McGovern, Raquel Noriega, and Jay Schwarz, "The willingness to pay for broadband of non-adopters in the U.S.: Estimates from a multistate survey," *Information Economics and Policy*, March 2015, *30*, 19–35.

Choi, Eleanor Jawon, "Does the Internet Help the Unemployed Find Jobs?," *SSRN Electronic Journal*, 2011.

Conkling, Thomas S., "Crowd-Out or Affordability? The Lifeline Expansion's Effect on Wireless Service Spending: Effects of the Lifeline Wireless Expansion," *Journal of Policy Analysis and Management*, March 2018, *37* (2), 357–383.

Denzer, Manuel, Thorsten Schank, and Richard Upward, "Does the Internet Increase the Job Finding Rate? Evidence from a Period of Internet Expansion," IZA DP 11764 August 2018.

Dettling, Lisa J., "Broadband in the Labor Market: The Impact of Residential High-Speed Internet on Married Women's Labor Force Participation," *ILR Review*, March 2017, *70* (2), 451–482.

_ , Sarena Goodman, and Jonathan Smith, "Every Little Bit Counts: The Impact of High-Speed Internet on the Transition to College," *The Review of Economics and Statistics*, May 2018, *100* (2), 260–273.

Faulhaber, Gerald R. and Christiaan Hogendorn, "The Market Structure of Broadband Telecommunications," *The Journal of Industrial Economics*, March 2003, *48* (3), 305–329.

George Zuo and Daniel Kolliner, "Wired and Hired: Employment Effects of Subsidized Broadband Internet for Low-Income Americans," Technical Report October 2019.

Gürtzgen, Nicole, Andrr Nolte, Laura Pohlan, and Gerard J. van den Berg, "Do Digital Information Technologies Help Unemployed Job Seekers Find a Job? Evidence from the Broadband Internet Expansion in Germany," *SSRN Electronic Journal*, 2018.

Hausman, Jerry A., "Regulated costs and prices in telecommunications," in "Emerging Telecommunications Networks," Edward Elgar Publishing, 2003, p. 1983.

Hjort, Jonas and Jonas Poulsen, "The Arrival of Fast Internet and Employment in Africa," *American Economic Review*, March 2019, *109* (3), 1032–1079.

Imbens, G. and K. Kalyanaraman, "Optimal Bandwidth Choice for the Regression Discontinuity Estimator," *The Review of Economic Studies*, July 2012, *79* (3), 933–959.

Imbens, Guido W. and Thomas Lemieux, "Regression discontinuity designs: A guide to practice," *Journal of Econometrics*, February 2008, *142* (2), 615–635.

Kuhn, Peter and Hani Mansour, "Is Internet Job Search Still Ineffective?," *The Economic Journal*, December 2014, *124* (581), 1213–1233.

_ **and Mikal Skuterud**, "Internet Job Search and Unemployment Durations," *American Economic Review*, February 2004, *94* (1), 218–232.

LaRose, Robert, Sharon Strover, Jennifer L. Gregg, and Joseph Straubhaar, "The impact of rural broadband development: Lessons from a natural field experiment," *Government Information Quarterly*, January 2011, *28* (1), 91–100.

Lee, David S and Thomas Lemieux, "Regression Discontinuity Designs in Economics," *Journal of Economic Literature*, June 2010, *48* (2), 281–355.

McCrary, Justin, "Manipulation of the running variable in the regression discontinuity design: A density test," *Journal of Econometrics*, February 2008, *142* (2), 698–714.

Richmond, William, Scott Rader, and Clinton Lanier, "The "digital divide" for rural small businesses," *Journal of Research in Marketing and Entrepreneurship*, October 2017, *19* (2), 94–104.

Singer, Hal J., "Do Municipal Broadband Networks Stimulate or Crowd Out Private Investment? An Empirical Analysis of Employment Effects," in Lorenzo Pupillo, Eli Noam, and Leonard Waverman, eds., *Digitized Labor*, Cham: Springer International Publishing, 2018, pp. 251–261.

Whitacre, Brian, Sharon Strover, and Roberto Gallardo, "How much does broadband infrastructure matter? Decomposing the metro–non-metro adoption gap with the help of the National Broadband Map," *Government Information Quarterly*, July 2015, *32* (3), 261–269.

Wilson, Kyle, "Does Public Competition Crowd Out Private Investment? Evidence from Municipal Provision of Internet Access," *SSRN Electronic Journal*, 2016.

Figures

Figure 1: Access to broadband over time.

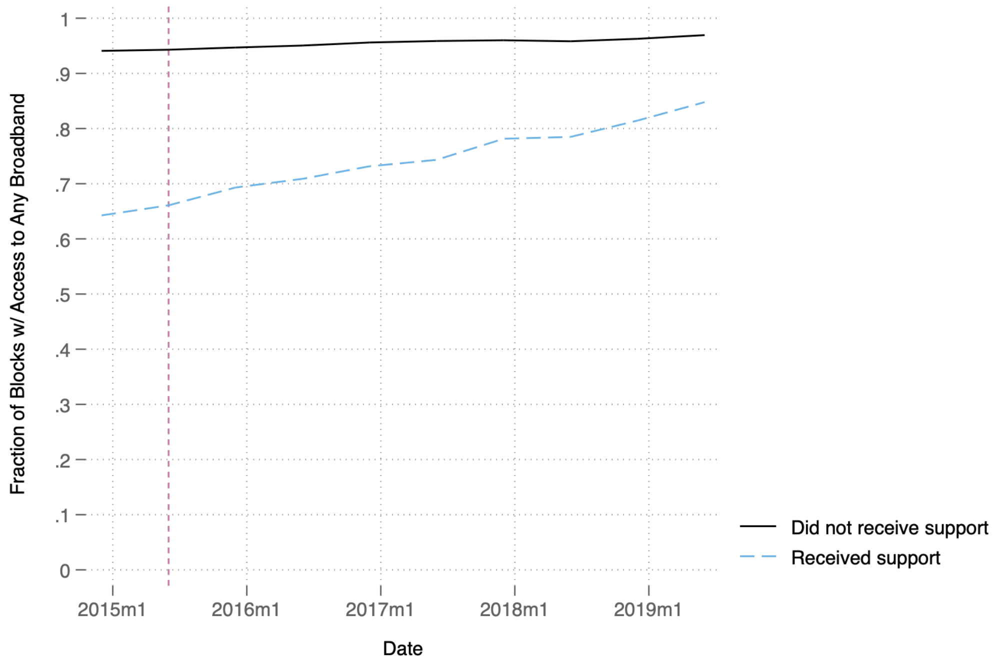


Figure 2: Access to 10 Mbps Down/1 Mbps Up over time.

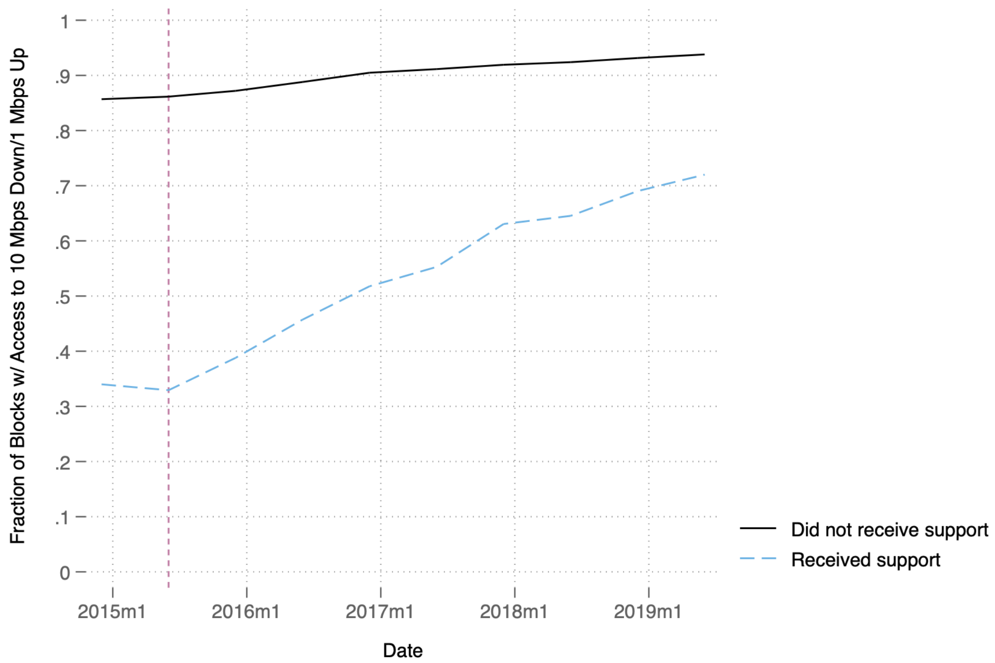


Figure 3: Distribution of Cost-Per-Active Subscriber

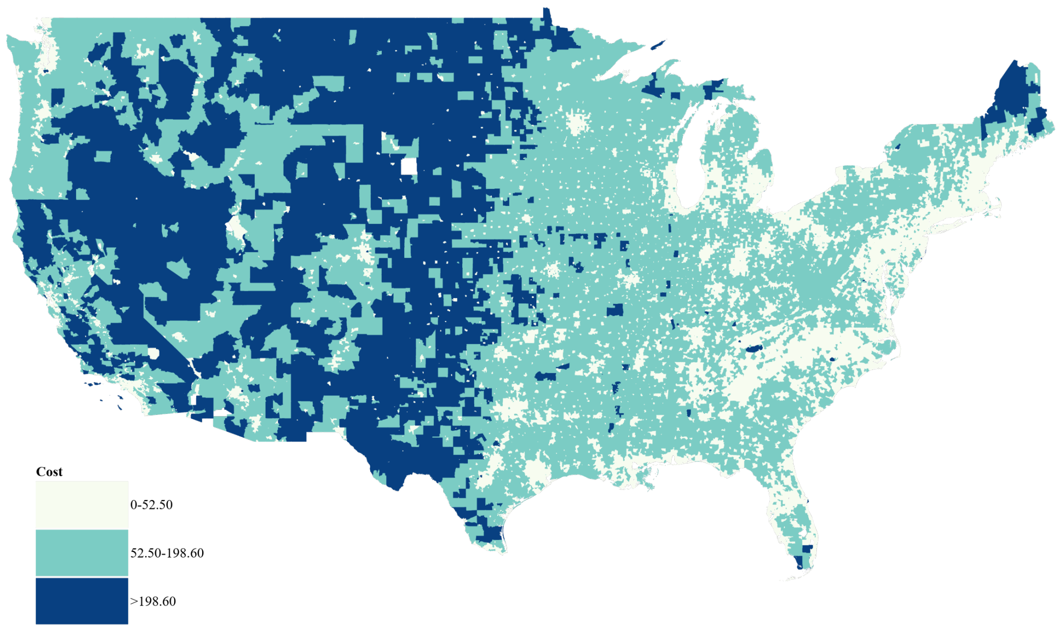


Figure 4: First-Stage - Probability of Receiving Model-Based Support (Descriptive)

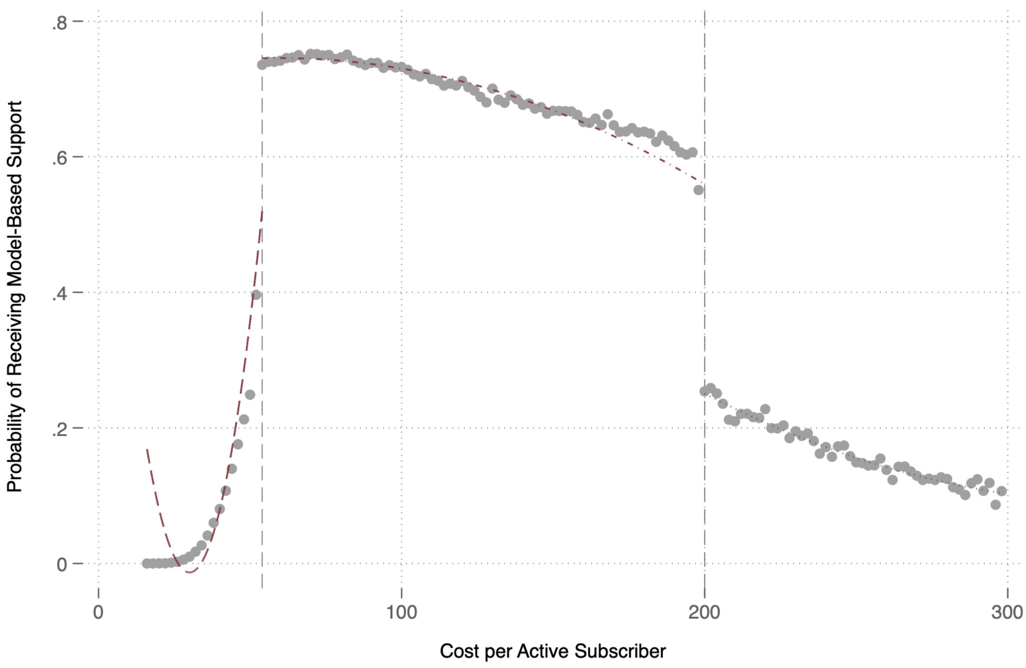


Figure 5: First-Stage - Probability of Receiving Model-Based Support

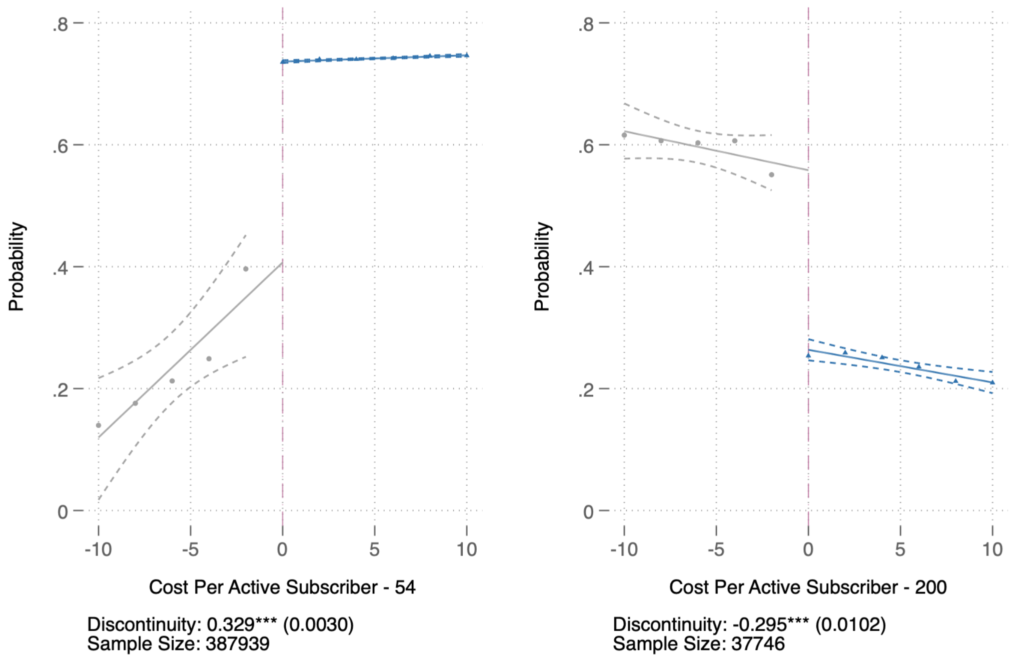


Figure 6: Distribution of cost per active subscriber around each threshold

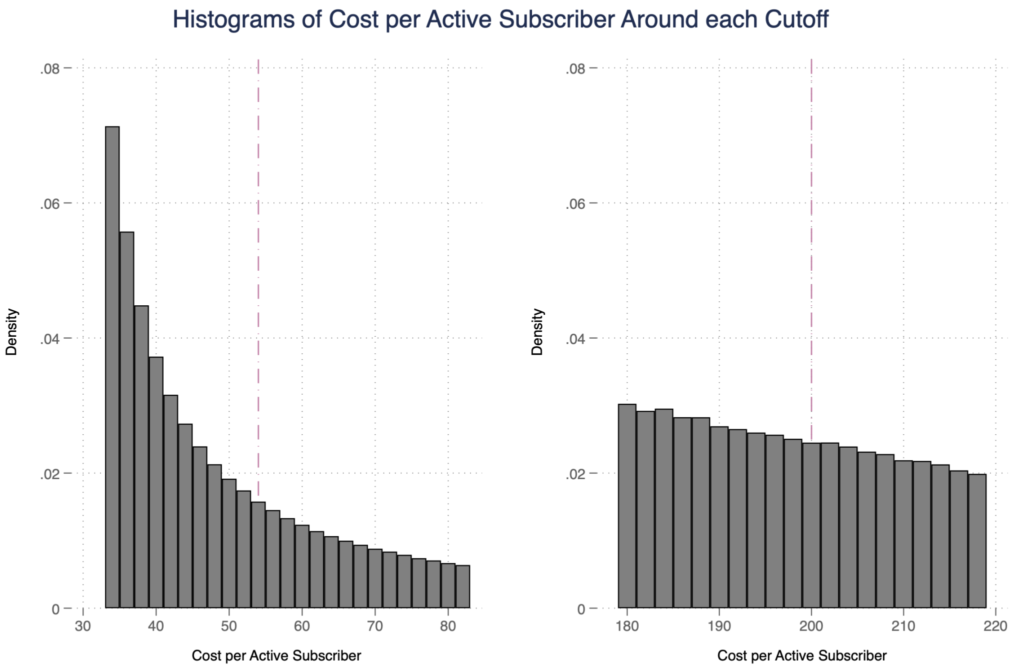


Figure 7: McCrary's Density Test

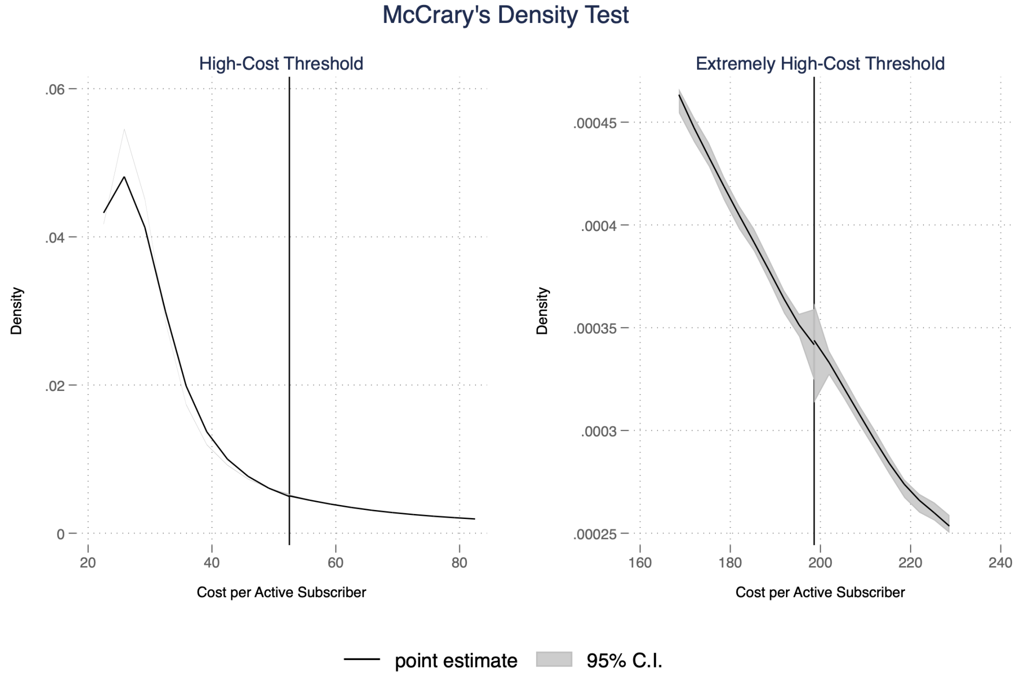


Figure 8: Outcomes Prior to Treatment - 10/1

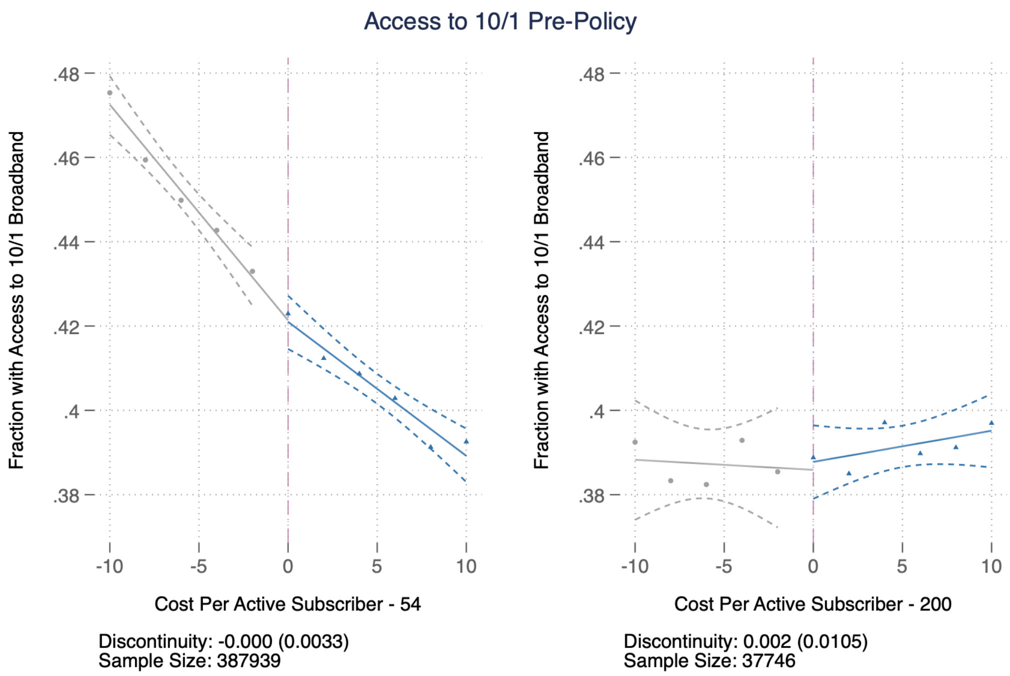


Figure 9: Outcomes Prior to Treatment - 25/3

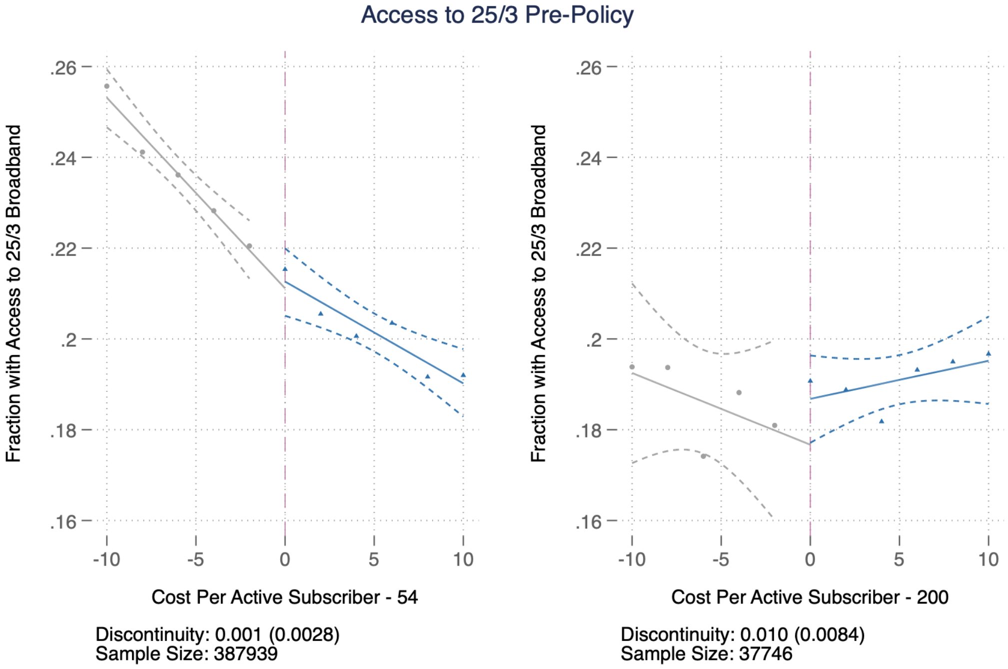


Figure 10: Reduced Form - Probability of Access to Broadband

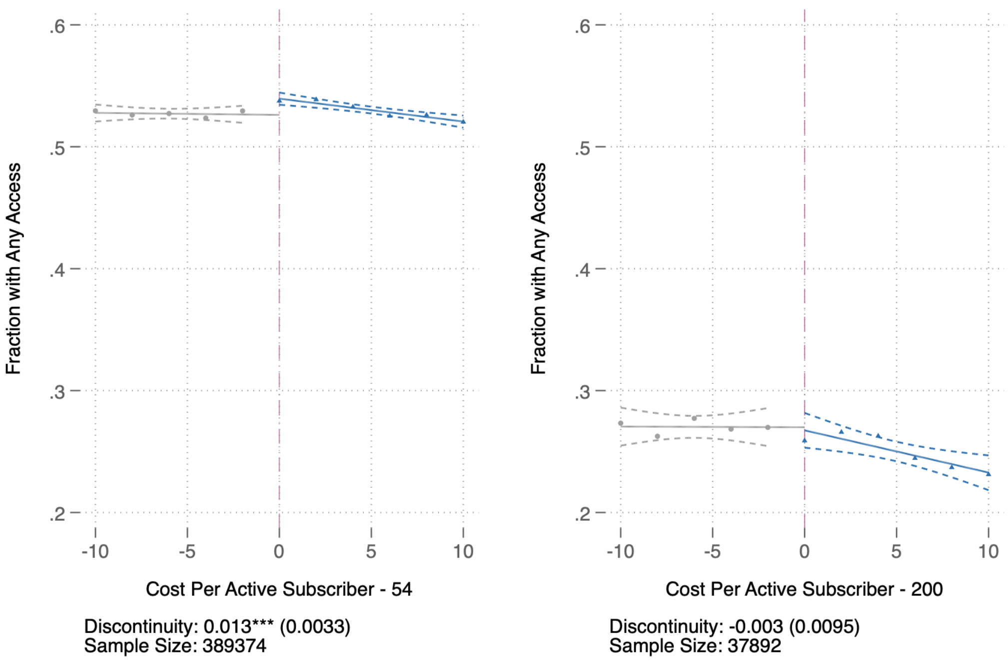


Figure 11: Reduced Form - 10 Mbps Down/1 Mbps Up

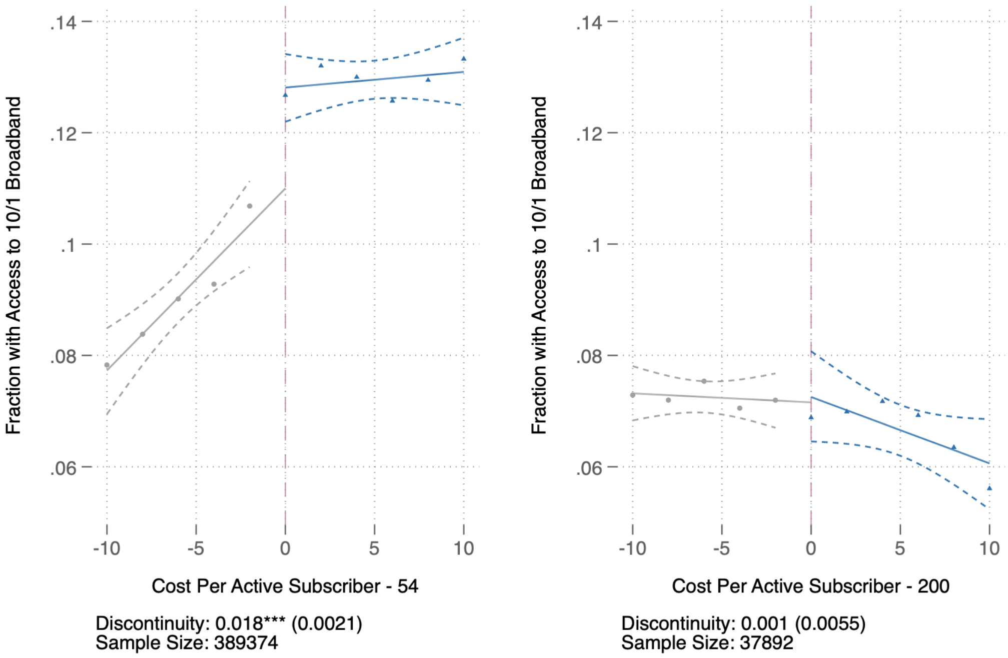


Figure 12: Reduced Form - 25 Mbps Down/3 Mbps Up

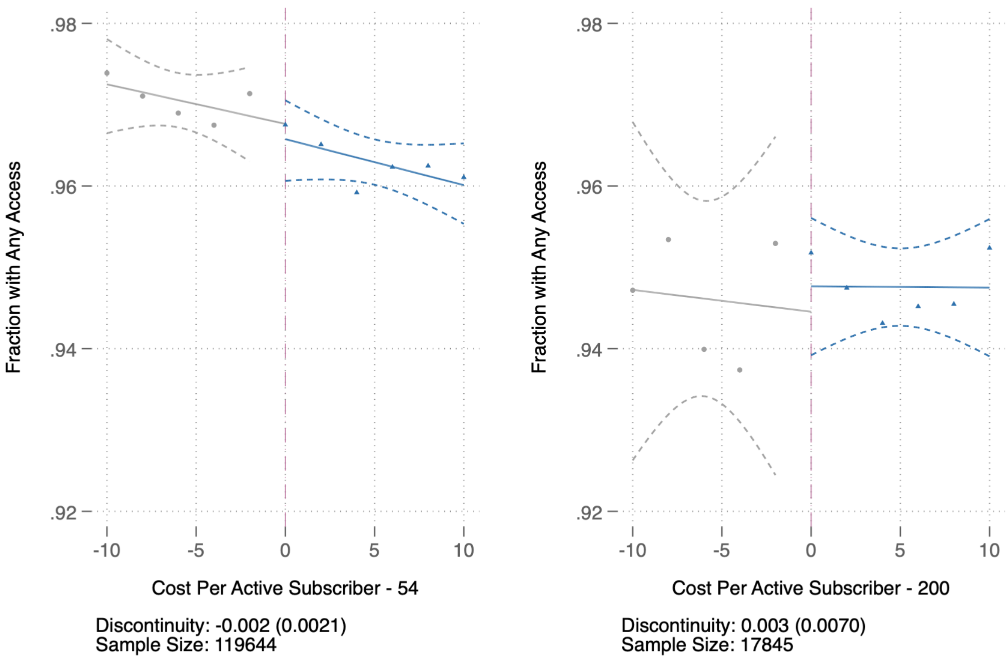


Figure 13: Reduced Form - Effect on Access to DSL Technology

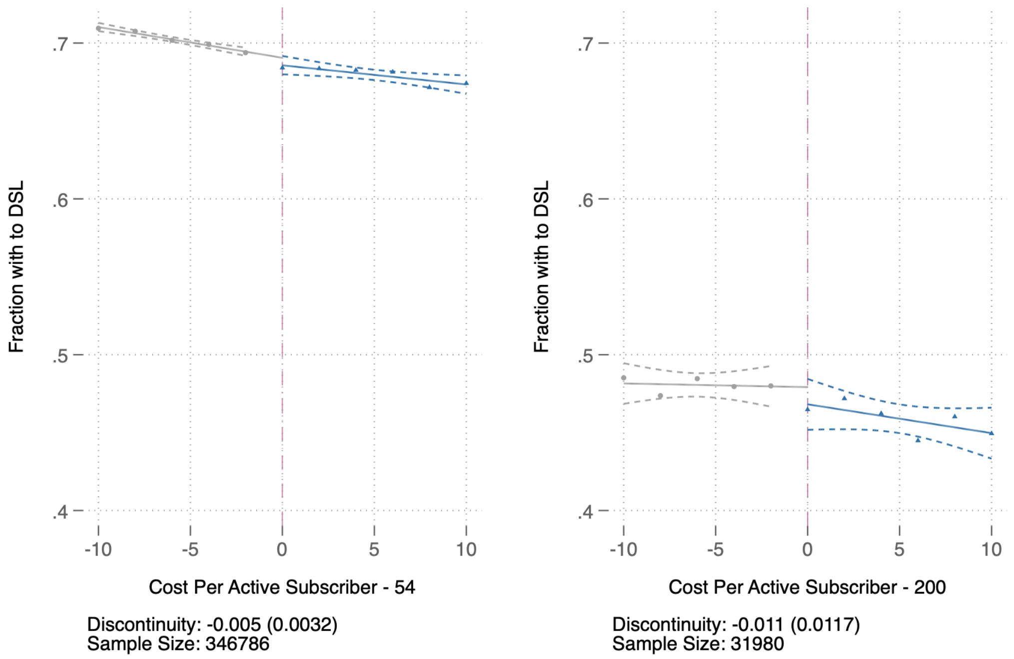


Figure 14: Reduced Form - Effect on Access to Cable Technology

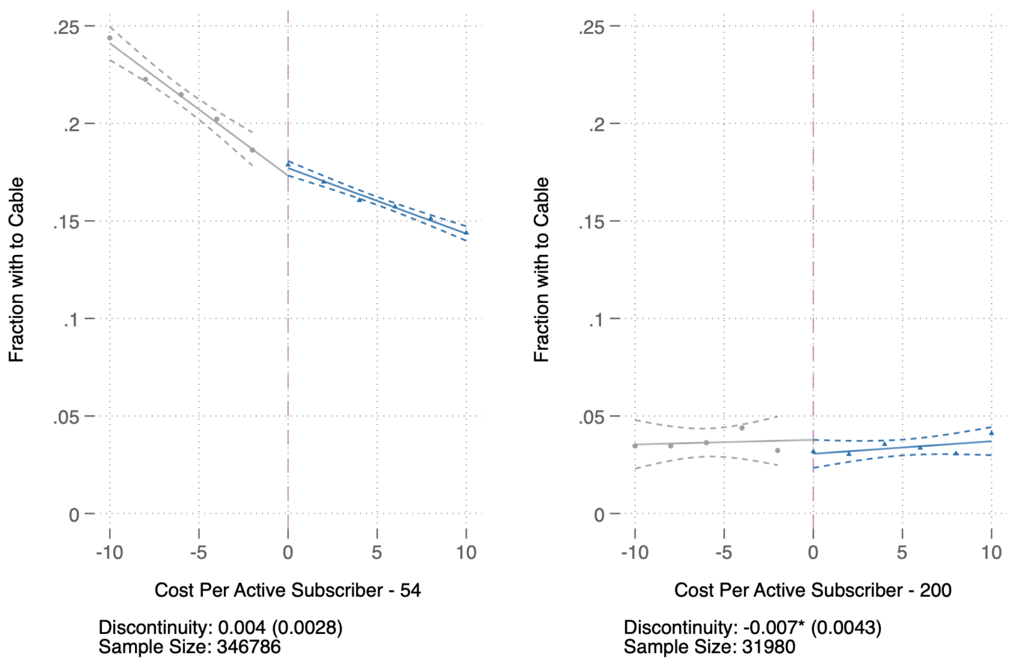


Figure 15: Reduced Form - Effect on Number of Providers

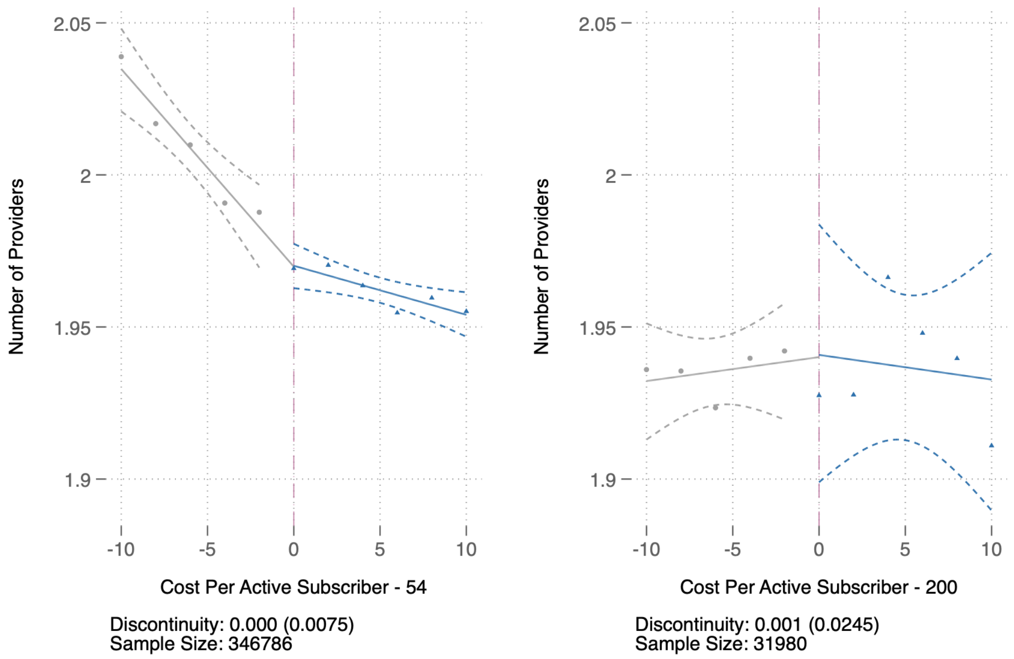
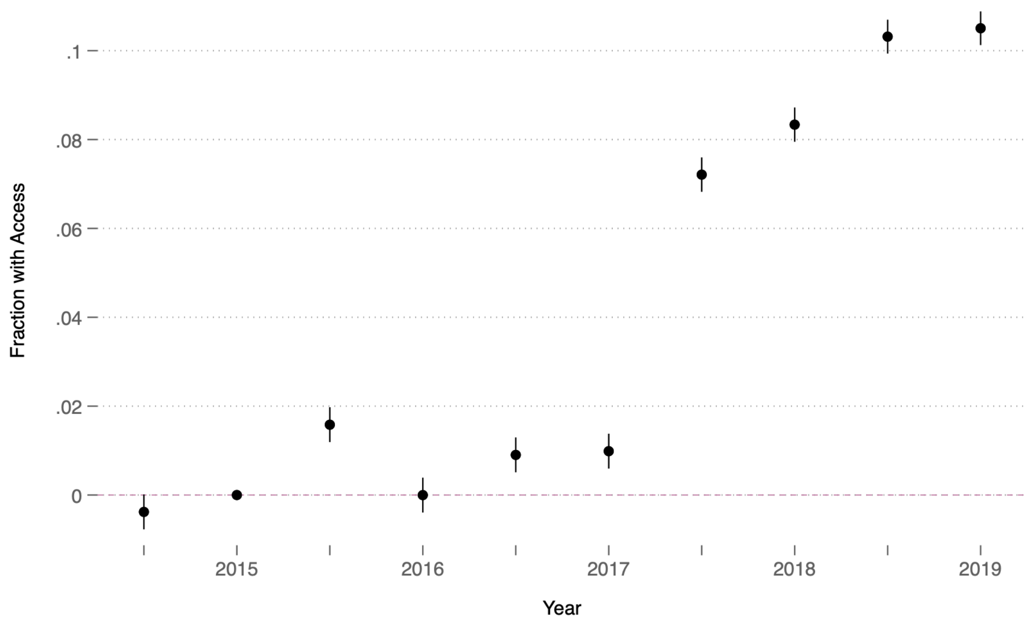
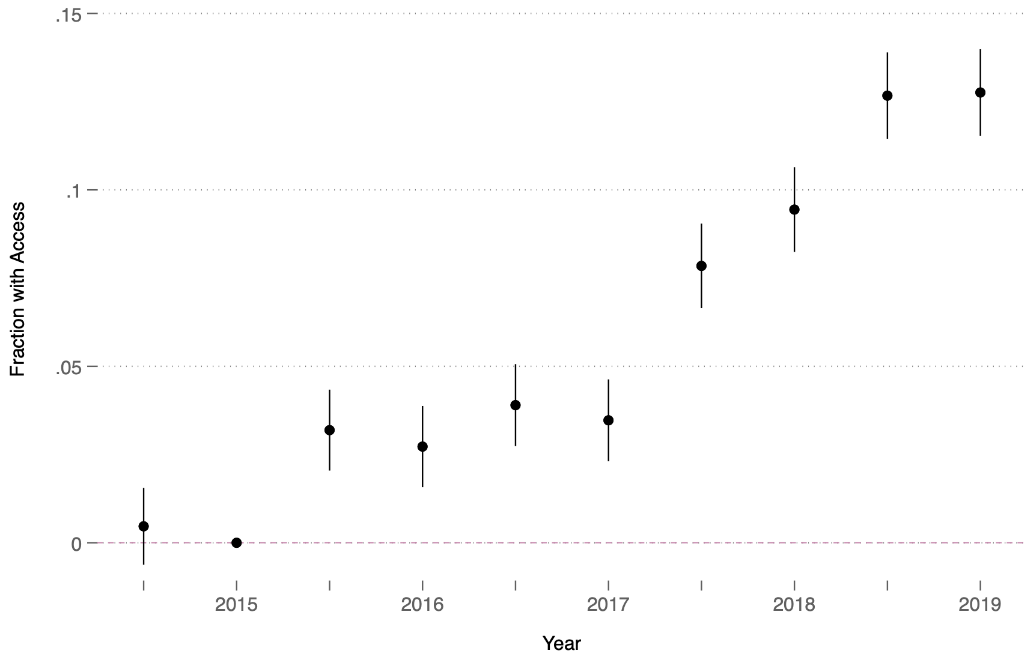


Figure 16: Expansion Evidence - High-Cost Threshold



[a] Dynamics in broadband access are estimated for a $10 bandwidth of the running variable, and using just price cap carriers.

Figure 17: Expansion Evidence - Extremely High-Cost Threshold



[a] Dynamics in broadband access are estimated for a $10 bandwidth of the running variable, and using just price cap carriers.

Figure 18: Falsification Check - Extensive Margin *ROR* Areas

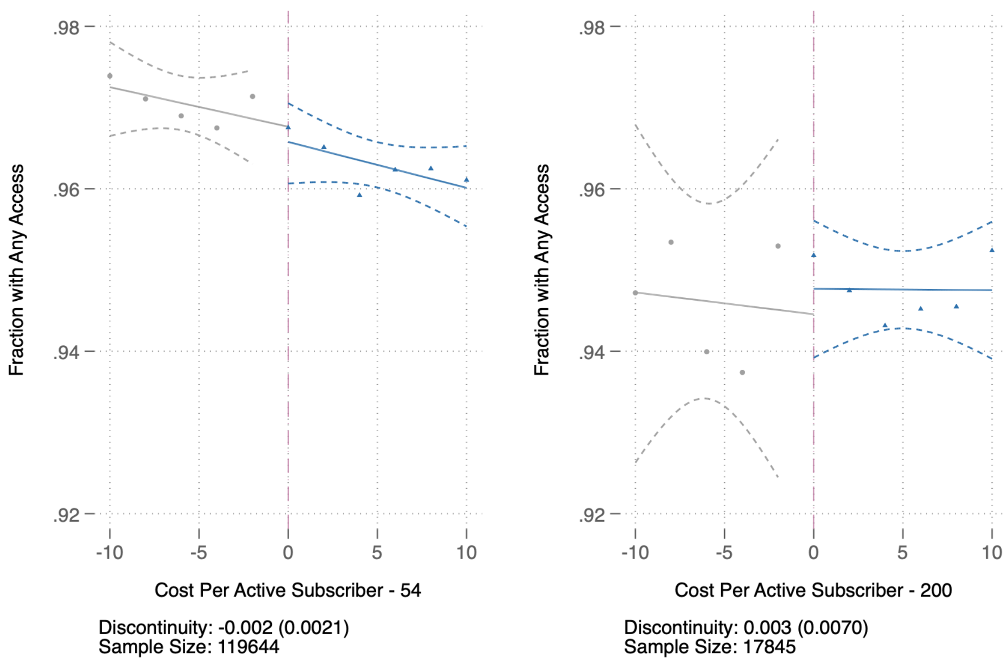


Figure 19: Falsification Check - 10 Mbps Down/1 Mbps Up *ROR* Areas

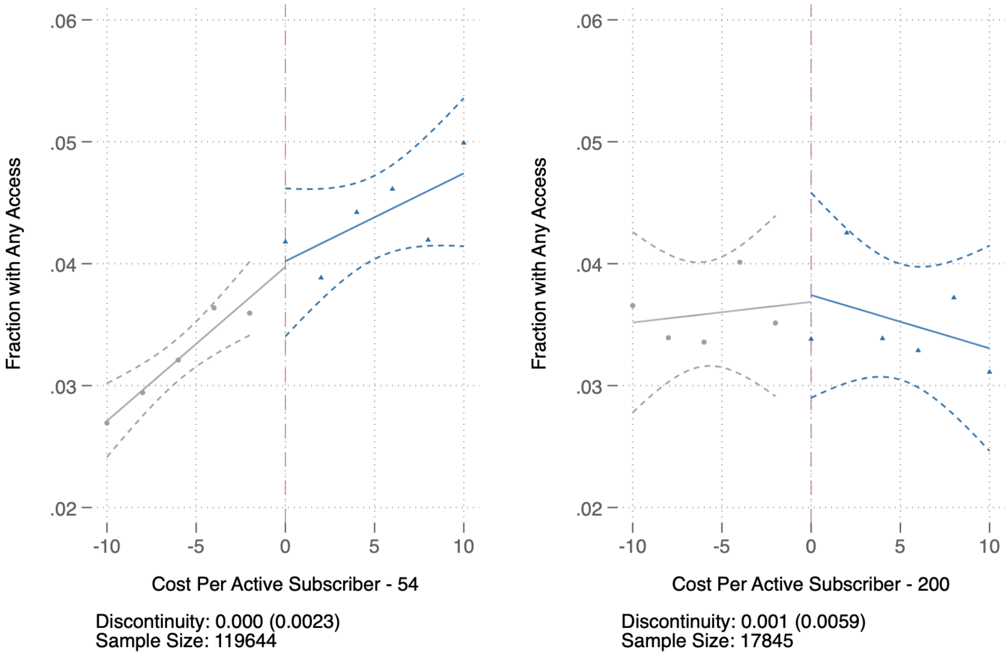
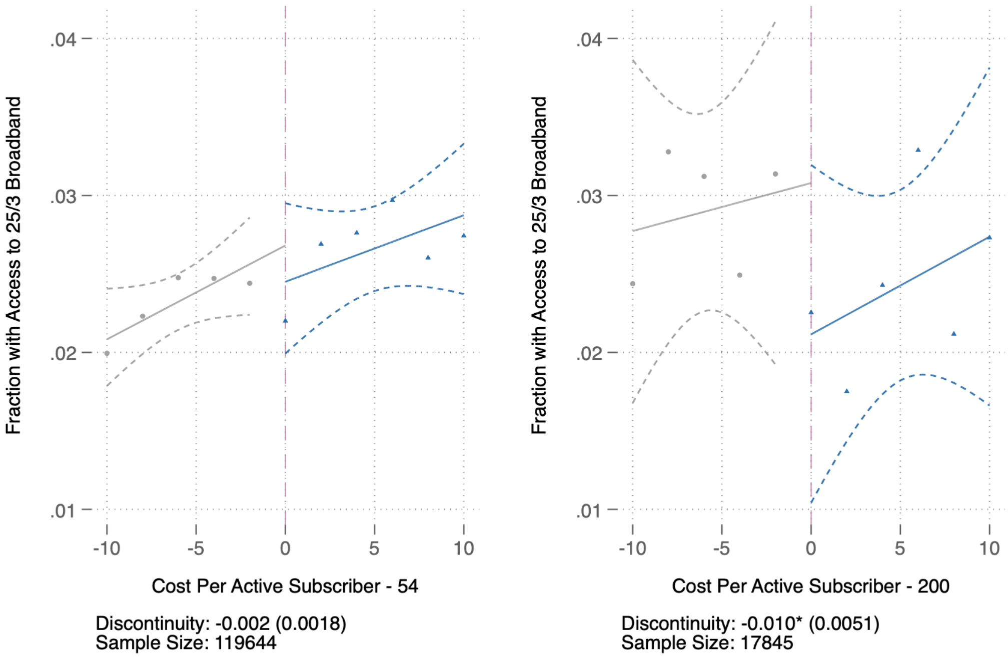


Figure 20: Falsification Check - 25 Mbps Down/3 Mbps Up *ROR* Areas



Tables

Table 1: Summary Statistics by Cost per Active Subscriber

	Cost Category					
	< $52.50		$52.50 – 198.60		> $198.60	
	Pre-Policy	*Post-Policy*	*Pre-Policy*	*Post-Policy*	*Pre-Policy*	*Post-Policy*
Cost per Active Subscriber	30.25	30.25	95.68	95.72	432.10	431.94
	(7.50)	(7.50)	(38.18)	(38.14)	(429.85)	(429.69)
Supported by Model	0.01	0.01	0.50	0.50	0.08	0.08
	(0.11)	(0.11)	(0.50)	(0.50)	(0.28)	(0.28)
Consumer Service Offered	0.96	0.97	0.77	0.83	0.71	0.78
	(0.20)	(0.18)	(0.42)	(0.38)	(0.46)	(0.42)
Maximum Advertised Download Speed	127.43	439.27	45.45	151.51	33.38	120.18
	(184.04)	(413.04)	(138.77)	(310.43)	(127.06)	(288.85)
Maximum Advertised Upload Speed	53.56	145.07	19.85	62.69	19.57	85.14
	(174.24)	(309.03)	(115.23)	(215.15)	(116.17)	(257.37)
Access to 10 Mbps Down/1 Mbps Up	0.00	0.00	0.02	0.03	0.02	0.03
	(0.07)	(0.07)	(0.13)	(0.18)	(0.14)	(0.17)
Access to 25 Mbps Down/3 Mbps Up	0.00	0.00	0.00	0.01	0.00	0.01
	(0.03)	(0.05)	(0.05)	(0.11)	(0.06)	(0.09)
Observations	6,978,375	62,910,655	6,978,375	62,910,655	6,978,375	62,910,655

Table 2: First-Stage - Probability of Receiving Model-Based Support at Each Threshold

	Dependent Variable: Supported by the CAF II Model					
Bandwidth	+/-10	+/-10	+/-20	+/-20	+/-30	+/-30
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: High-Cost Threshold					
$1\{C_i \geq 0\}$	0.190***	0.384***	0.253***	0.486***	0.314***	0.568***
	(0.00222)	(0.00363)	(0.00142)	(0.00205)	(0.00114)	(0.00151)
Obs	634660	251207	1671948	561127	4567191	933096
	Panel B: Extremely High-Cost Threshold					
$1\{C_i \geq 0\}$	-0.224***	-0.444***	-0.244***	-0.508***	-0.259***	-0.529***
	(0.00981)	(0.0120)	(0.00617)	(0.00776)	(0.00487)	(0.00622)
Obs	42341	19571	89501	41394	137915	64108
Eligible Sample	No	Yes	No	Yes	No	Yes

Heteroskedastic robust errors in parentheses. Eligible sample refers to restricting the sample to just blocks that were previously unserved by a *price cap* carrier and areas that are not *rate-of-return* regulated.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: 2SLS Estimates - Broadband Access

Dependent Variable	Consumer	Consumer	CAF Benchmark	CAF Benchmark	FCC Benchmark	FCC Benchmark
	(1)	(2)	(3)	(4)	(5)	(6)
				Panel A: High-Cost-Threshold - $52.50		
Supported	0.0519	0.0766	0.0425***	0.0419***	-0.0160	-0.0183*
	(0.0317)	(0.0598)	(0.0128)	(0.0119)	(0.0084)	(0.0093)
Obs				1,686,515		
				Panel B: Extremely High-Cost Threshold - $198.60		
Supported	0.0042	0.0054	0.0065	0.0067	0.0074	0.0092
	(0.0149)	(0.0140)	(0.0064)	(0.0069)	(0.0051)	(0.0058)
Obs				1,072,250		
Polynomial Order	1	2	1	2	1	2

Consumer is an indicator equal one if a census block has broadband access. CAF Benchmark is an indicator equal one if a census block has access and their maximum download/upload speed is equal to 10 Mbps down and 1 Mbps up. FCC Benchmark is an indicator equal one if a census block has access and their maximum download/upload speed is equal to 25 Mbps down and 3 Mbps up. Standard errors are calculated using heteroskedasticity robust nearest neighbor variance estimates. Optimal bandwidth are calculated using MSE-optimal bandwith selectors that are regularized via the Stata package rdrobust (Calonico et al., 2017). I use the default inputs unless otherwise specified. The sample is restricted to just blocks that were previously unserved by a price cap carrier and areas that are not rate-of-return regulated. All estimates use data from June 2019.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: 2SLS Estimates - Technology & Number of Competitors

Dependent Variable	DSL	DSL	Cable	Cable	No. Providers	No. Providers
	(1)	(2)	(3)	(4)	(5)	(6)
				Panel A: High-Cost-Threshold - $52.50		
Supported	0.0295	0.0445	0.0197	0.0068	-0.4160*	-0.5610
	(0.0926)	(0.1390)	(0.0616)	(0.0930)	(0.1740)	(0.290)
Obs					1,686,515	
				Panel B: Extremely High-Cost Threshold - $198.60		
Supported	0.0052	0.0340	0.0292	0.0449	-0.0055	-0.0469
	(0.0489)	(0.0553)	(0.0219)	(0.0300)	(0.0765)	(0.1470)
Obs					1,072,250	
Polynomial Order	1	2	1	2	1	2

DSL is an indicator equal one if a census block has broadband access using DSL technology. Cable is an indicator equal to one if a census bloack has broadband access using cable technology. Standard errors are calculated using heteroskedasticity robust nearest neighbor variance estimates. Optimal bandwidth are calculated using MSE-optimal bandwith selectors that are regularized via the Stata package rdrobust (Calonico et al., 2017). I use the default inputs unless otherwise specified. The sample is restricted to just blocks that were previously unserved by a price cap carrier and areas that are not rate-of-return regulated. All estimates use data from June 2019.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: 2SLS Estimates - Broadband Access Price Cap Sample

Dependent Variable	Consumer	Consumer	CAF Benchmark	CAF Benchmark	FCC Benchmark	FCC Benchmark
	(1)	(2)	(3)	(4)	(5)	(6)
				Panel A: High-Cost-Threshold - $52.50		
Supported	-0.0139	-0.0912	0.0576*	0.0599**		
	(0.0507)	(0.1570)	(0.0234)	(0.0222)		
Obs				1,686,652		
				Panel B: Extremely High-Cost Threshold - $198.60		
Supported	0.0306	0.0926*	-0.0082	-0.0150		
	(0.0265)	(0.0400)	(0.0167)	(0.0220)		
Obs				1,072,250		
Polynomial Order	1	2	1	2	1	2

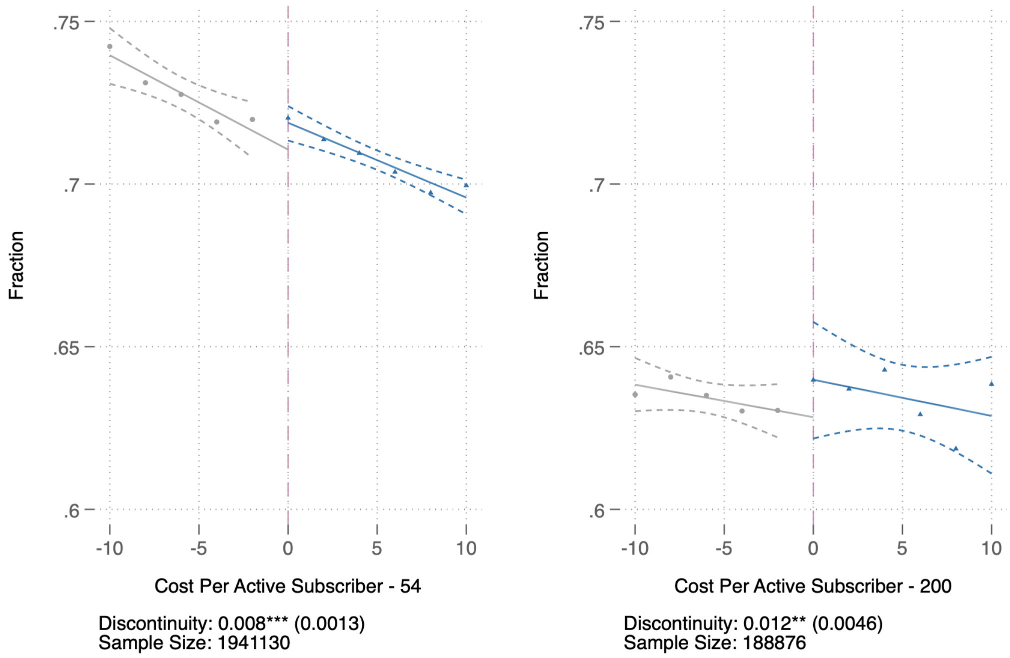
Consumer is an indicator equal one if a census block has broadband access. CAF Benchmark is an indicator equal one if a census block has access and their maximum download/upload speed is equal to 10 Mbps down and 1 Mbps up. FCC Benchmark is an indicator equal one if a census block has access and their maximum download/upload speed is equal to 25 Mbps down and 3 Mbps up. Standard errors are calculated using heteroskedasticity robust nearest neighbor variance estimates. Optimal bandwidth are calculated using MSE-optimal bandwith selectors that are regularized via the Stata package rdrobust (Calonico et al., 2017). I use the default inputs unless otherwise specified. The sample is restricted to just blocks that were previously unserved by a price cap carrier and areas that are not rate-of-return regulated. All estimates use data from June 2019.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

9 Appendix

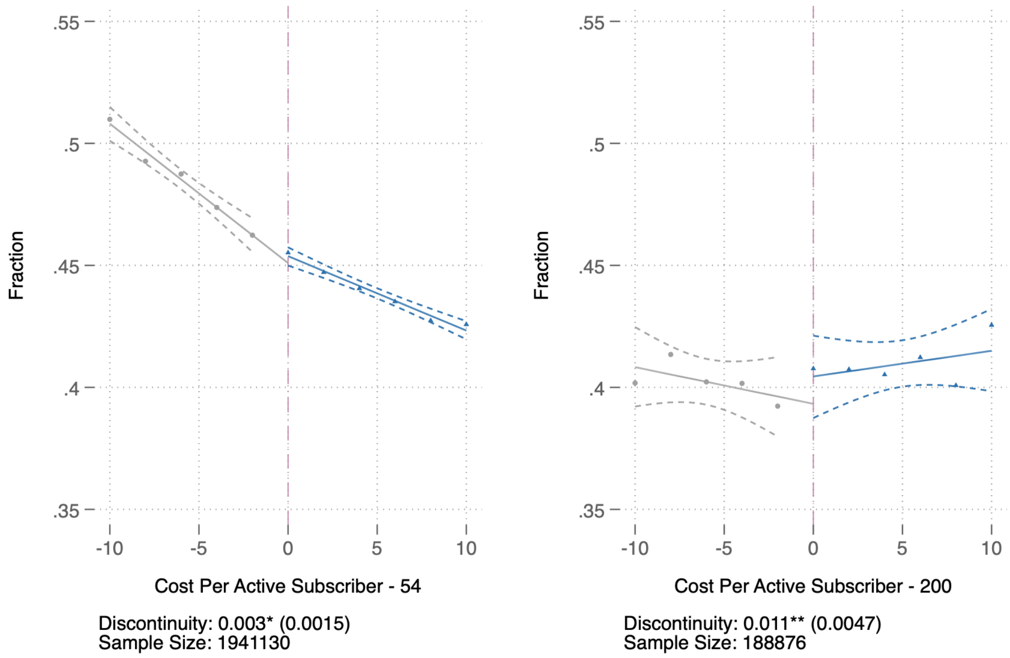
9.1 Alternative Broadband Specifications

Figure 21: Reduced Form - Probability of Access to 10 Mbps Down/1 Mbps Up



[a] Access to 10 Mbps down/1 Mbps up where a block is considered served if the maximum advertised download and uploads speed are at least the benchmark.

Figure 22: Reduced Form - Probability of Access to 25 Mbps Down/3 Mbps Up



[a] Access to 25 Mbps down/3 Mbps up where a block is considered served if the maximum advertised download and uploads speed are at least the benchmark.

9.2 Expansion Evidence

Figure 23: Expansion Evidence - *Price Cap* Sample

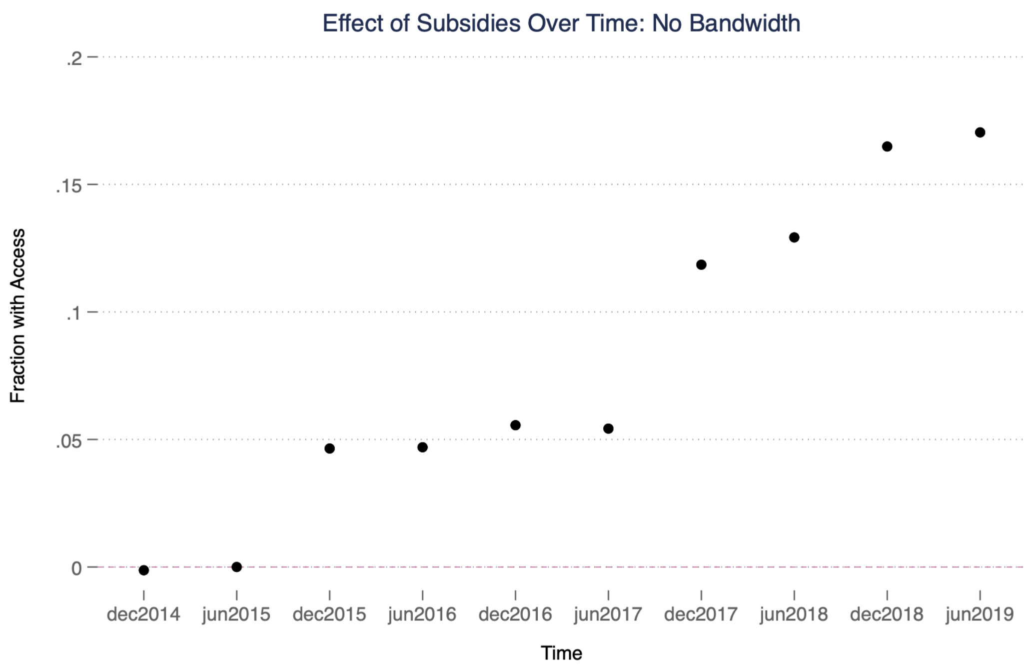


Figure 24: Expansion Evidence - High-Cost Threshold $10 Bandwidth

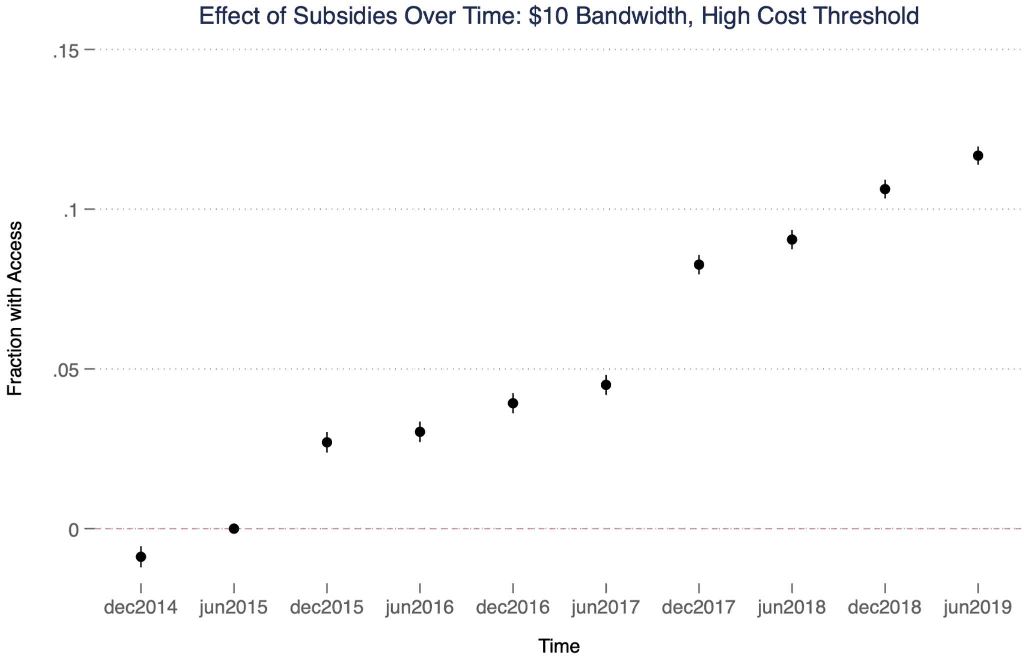


Figure 25: Expansion Evidence - Extremely High-Cost Threshold $10 Bandwidth