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Who gets access to fast broadband? Evidence from Los Angeles County

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A R T I C L E I N F O

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A B S T R A C T

Regulatory and market changes in residential (fixed) broadband have raised concerns about Internet Service Providers (ISPs) prioritizing investments in the most profitable areas, thus relegating low-income and minority communities to fewer broadband options and legacy networks. This study examines these concerns for Los Angeles (LA) County during the 2014–18 period. The analysis uses rollout data collected by the California Public Utilities Commission (CPUC) in combination with demographic information from the American Community Survey (ACS). Because the spatial distribution of broadband investments cannot be directly observed, competition and the availability of FTTH services are used as proxies. The findings indicate that competition and fiber-based services are less likely in low-income areas and minority communities, with the most severe deficits observed in census block groups that combine poverty and a large share of Black residents. We outline alternative policy tools to address intracity inequalities in broadband investments in the conclusion.

1. Introduction

High-quality, affordable broadband is as critical to the social and economic vitality of communities as transportation and electricity were in the 20th century. However, the private sector is responsible for most of broadband investments in the US. This raises fundamental questions about potential underinvestment in areas of low expected returns. Further, market consolidation and the relaxation of rules governing industry organization have intensified concerns that network upgrades to fast broadband services are not reaching distressed urban communities (Blevins, 2019; Crawford, 2013). Underinvestment in broadband therefore threatens to amplify urban inequality by depriving communities of the basic infrastructure for commerce, education and civic engagement (Mossberger, Tolbert, & Franko, 2012).

This study probes for evidence that broadband infrastructure investments in Los Angeles (LA) County during the 2014–18 period have favored affluent areas, thus relegating low-income and minority communities to fewer broadband options and legacy networks. Similar patterns have been documented by advocacy groups in several other US cities. A study by the National Digital Inclusion Alliance (NDIA) suggests that AT&T has failed to upgrade Internet and video services in low-income communities in Cleveland, OH, and Dallas, TX (NDIA, 2019). Similar findings have been reported for Goochland County, VA, where the Center for Public Integrity found that low-income neighborhoods are significantly less likely to have Internet service at broadband speeds (Holmes & Wieder, 2016). Despite the media attention generated by these and other reports, the issue has received surprisingly little attention in the academic literature.

In order to explore the intracity patterns of broadband investments for the 2014–18 period we create a longitudinal dataset that combines information on residential (fixed) Internet service availability for every census block in LA county with demographic information from the American Community Survey (ACS). Because the spatial distribution of broadband investments cannot be directly observed, we use competition intensity and the availability of residential fiber services (FTTH) as proxies. With this dataset, we use two empirical strategies to estimate how income and racial composition affect broadband service rollout: first, a pooled logistic regression with error clustering, which allows for isolating the effect of income and race from other factors shown in previous studies to affect broadband deployment; second, a fixed effects estimation that further controls for unobserved heterogeneity across our units of observation.

The findings from these two strategies are consistent and support the hypothesis that network upgrades in the 2014–18 period are associated with income *and* racial factors. Perhaps the most remarkable finding is that the largest deficits are observed in areas that combine low income and a high share of Black residents. This finding is consistent with previous studies of urban segregation in Los Angeles, which emphasize the

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clustering of multidimensional poverty in formerly redlined neighborhoods, particularly in the South Los Angeles area (Matsunaga, 2008). These communities have historically been bypassed by investments in health facilities, transportation, education and other public goods. Whereas Internet adoption could theoretically compensate for such deficits (for example by facilitating remote work, telehealth services and remote learning), lagging investments in next-generation broadband threaten to aggravate community distress and inhibit socioeconomic development.

These findings raise multiple policy questions. Whether and how federal law requires deployment of communication facilities on a nondiscriminatory basis is the subject of much debate among legal scholars (Baynes, 2004). Interestingly, antidiscrimination provisions in federal and state law have rarely been tested in the courts - possibly due to the lack, until recently, of appropriately disaggregated information about service availability and adoption. This strengthens the case for improving the collection and reporting of broadband data at the federal and state levels.[1] Further, the findings also bear on the debate over the classification of broadband as an information service (and therefore more lightly regulated under Title I of the Communications Act) or as an essential communication service (and thus subject to the more stringent obligations of Title II). We elaborate on the implications of our findings for these debates and the policy tools available to redress intracity gaps in broadband investments in the conclusion.

Our findings also inform scholarship about smart cities and digital inequality. Weak competition and lack of high-quality services may partly account for the racial/ethnicity gaps in residential broadband adoption (after controlling for income and other characteristics) that prior studies have identified but struggled to explain (e.g., Campos-Castillo, 2015; Fairlie, 2004; Flamm & Chaudhuri, 2007). Further, and in the context of the current COVID-19 pandemic, our findings call for increased attention to the unintended amplification of inequalities in education, health and job opportunities that results from differences in connectivity opportunities available to residents.

2. What drives broadband infrastructure deployment and why it matters?

2.1. The determinants of broadband investments

From the early days of the transition from dial-up to broadband Internet in the mid-1990s, questions have been raised about the spatial distribution of investments in network upgrades to high-speed services, and about investment lags in low-income communities and rural areas. Congress addressed this question in the Telecommunication Act of 1996, establishing a broad mandate that communication services be made available "to all people of the United States, without discrimination on the basis of race, color, religion, national origin, or sex".[2] This broad policy mandate resulted in several federal initiatives to expand broadband services across the US, including the Connect America Fund and the e-rate program.

The Act also mandated the FCC to collect broadband deployment data to establish "whether advanced telecommunications capability is being deployed to all Americans in a reasonable and timely fashion".[3] Until 2010, however, the FCC collected such data at the ZIP-code level, thus limiting precise measurement of the sociodemographic patterns and market parameters affecting investment decisions made by ISPs. Despite this limitation, several early studies addressed the nexus between broadband availability, socioeconomic factors and service adoption.

In one of these early studies, Gillett and Lehr (1999) use county-level data to analyze the factors driving investments in cable modem services. Their findings suggest that these services concentrate in high-income and high-density urban areas, which the authors attribute to the expected diffusion pattern of new information technologies. In a similar study, Prieger (2003) finds evidence of a rural gap in broadband availability. However, after controlling for cost factors, competition intensity, and demographic variables that affect broadband demand, the author does not find evidence that income or racial/ethnicity factors influence broadband investments. Grubesic and Murray (2005) similarly find that broadband competition is significantly weaker in rural areas.

Other studies have used more restricted datasets to address similar questions. For example, Prieger and Hu (2008) use a unique dataset of DSL subscribers at the ZIP+4 level for two incumbent operators across five states in the Midwest region.[4] Their findings suggest that household income is a significant driver of investments in DSL infrastructure. However, after controlling for income and other demand factors, race and ethnicity are not found to affect DSL rollout. Similarly, Kolko (2010) combines ZIP code level availability data with geolocated household-level information from a proprietary dataset. Using households as the unit of observation, the regression estimates suggest that income is a strong predictor of broadband supply.

With funding from the American Recovery and Reinvestment Act of 2009, federal and state governments began collecting broadband deployment data at the census block level. This change in data granularity significantly improved researchers' ability to tease out the determinants of investments in broadband infrastructure. The existing data collection procedure is far from perfect, and both researchers and oversight agencies have exposed numerous flaws (e.g., GAO, 2018; Grubesic, 2012; Turner, 2016). In the case of fixed residential services, the most significant shortcoming is that an entire census block is considered served if a provider is able to serve a single household in that block. Further, ISPs are allowed to report availability in blocks where they could potentially offer services "within a service interval that is typical for that kind of connection—that is, without an extraordinary commitment of resources."[5] As reported by the Government Accountability Office (2018), this leads to significant availability overstatement, which affect in particular areas with large census blocks.

Despite these shortcomings, the availability of more granular data has significantly contributed to scholarship about the relationship between broadband investments, competition intensity, community demographics and residential adoption. For example, Whitacre, Strover, and Gallardo (2015) use a regression decomposition strategy to examine the extent to which differences in broadband availability explain the rural-urban adoption gap. Their findings suggest that supply variations account for over a third of the observed rural gap in residential broadband adoption. Using a matching estimator strategy, Prieger (2015) finds that, despite widespread availability of fixed residential services nationwide, Black and Hispanic households tend to have fewer broadband choices.[6]

The availability of deployment data at the census block level has also shifted the research focus from the federal or state to the local level. As a result, digital inequality scholarship has moved beyond the traditional demographic factors, exploring how idiosyncratic community factors and municipal policies affect broadband investment and adoption patterns. For example, Rhinesmith and Reisdorf (2017) combine FCC deployment data with information from the ACS to analyze the spatial

[1] See FCC (2019). Establishing the Digital Opportunity Data Collection, WC Docket No. 19–195, released August 6, 2019.

[2] 47 U.S.C. § 151.

[3] 47 U.S.C. § 706.

[4] The ZIP+4 level is significantly more geographically disaggregated than the five-digit ZIP code level.

[5] FCC Report and Order and Second Further Notice of Proposed Rulemaking, WC Docket Nos. 19–195, 11–10, p. 3.

[6] Interestingly, the reverse is true for mobile broadband, though it must be noted that current data collection procedures for wireless broadband are notoriously imprecise (see GAO, 2018).

distribution of broadband competition and service quality differences across the Kansas City metro area. Their findings highlight the value of local policy efforts to address deficits in broadband investments in low-income communities. Similarly, Grubesic, Helderop, and Alizadeh (2019) examine the deployment of Google Fiber in Provo, UT, and Austin, TX, using a novel empirical strategy that contrasts results obtained with FCC data with results from a query-based data collection effort at the residential address level. Interestingly, their findings indicate that fiber deployment in Provo and Austin has favored areas with fewer minority residents but lower median incomes, which the authors partly attribute to the presence of a large population of college students in both cities.

2.2. Connecting digital inequality and urban segregation

The ability to quantitatively explore how disparities in broadband provision manifest at the local level has opened multiple opportunities to connect digital inequality scholarship with the broader literature on urban segregation and broader debates about fairness in the provision of essential public goods. Two particularly useful concepts from this literature are "cumulative adversity" and "concentration effects," both of which refer to the intergenerational accumulation of socioeconomic disadvantages in urban neighborhoods that combine poverty and a large concentration of underrepresented minorities (Quillian, 2012; Sampson & Wilson, 1995; Wilson, 1987). Drawing from studies in various urban settings, these scholars point to the compounding of disadvantages in specific urban clusters, which is both caused by and contributes to underinvestment in critical infrastructure such as transportation, health facilities and sanitation.

For example, Massey (1990) argues that the multiplicative effects of poverty and racial segregation in the housing market during the postwar era has resulted in inner-city communities that are more prone to deteriorating infrastructure, violence, fractured social networks, and more limited access to quality public goods. This cycle has had a particularly negative impact on Black residents, who regardless of actual income are significantly more likely to live in less affluent neighborhoods, and therefore with fewer access opportunities to quality education, transportation and other critical resources.

Several studies have examined these clustering effects in the Los Angeles area. Matsunaga (2008) finds that South Los Angeles and the adjacent downtown neighborhoods represent areas of concentrated poverty with disproportionately large shares of Hispanic and Black residents. In these areas, deficits in transportation, housing, education, and other public goods combine with poverty to perpetuate community distress. Kneebone and Holmes (2016) show that these trends have exacerbated since the Great Recession. Others examining concentration effects in Los Angeles focus on the resource environment as a source of environmental and health injustice. For example, Wolch, Wilson, and Fehrenbach (2005) find that families in low-income, majority Black and Hispanic areas such as South LA have significantly more limited access to parks while other studies report similar deficits with respect to healthy food options (Lewis et al., 2005).

Drawing on this body of literature, we examine whether the same patterns of infrastructure underinvestment exist in the case of broadband. In other words, we probe for evidence of concentration effects whereby formerly redlined areas of Los Angeles that combine low income and a disproportionate share of underrepresented minorities are less likely to receive investments and network upgrades to fast broadband services. A key component to these investments is fiber. As several scholars argue, there is no viable path to a faster and more robust Internet for households and businesses without significant investments that bring fiber infrastructure closer to the end-user (Crawford, 2018; Grubesic et al., 2019). Even the new generations of ultrafast mobile technologies (e.g., 5G) depend on fiber backhaul deployment to connect base stations to the public Internet.

Our analysis pays particular attention to historically Black areas in LA county for two main reasons. First, as (Perry, 2020) argues, the legacy of urban segregation and redlining in Los Angeles has largely affected Black residents. Second, Black residents are significantly more spatially segregated than other racial/ethnic minorities. Consider an analysis based on the dissimilarity index proposed by Massey and Denton (1988), which represents the percentage of one demographic group who would need to relocate to another neighborhood to achieve equal distribution across an urban area. In 2018, the Black-non Black dissimilarity index for Los Angeles was 0.7, compared to 0.5 for Hispanics and Asians. Therefore, though representing a relatively small minority in LA County (relative to Asians and in particular Hispanics), and despite significant changes in the racial composition of LA neighborhoods in the past decade (Clark, Anderson, Östh, & Malmberg, 2015), Blacks remain spatially concentrated and overrepresented in areas affected by the legacy of racial discrimination in the postwar era.

3. Data and methods

This study draws from two data sources. The first is the California Public Utilities Commission (CPUC), which annually collects information from ISPs about service availability, speed and transmission technology at the census block level. This data collection initiative is separate from the data collected by the FCC through Form 477. Further, the CPUC performs several additional validity checks, the most important being that service availability is validated through a provider-supplied list of customers showing their address and subscribed speeds (CPUC, 2016). This validation procedure significantly reduces the overstatement of availability found in FCC data.

It is important to note that our analysis is limited to the availability of residential (wired) broadband services, and thus excludes mobile broadband and fixed terrestrial wireless alternatives. A thorough discussion about whether fixed and wireless broadband are truly separate markets is beyond the scope of this study. Our premise, following the FCC's latest broadband deployment report (FCC, 2020), is that consumers continue to use both services concurrently and in distinct ways, thus suggesting complementarity rather than substitution.

Using the CPUC residential broadband deployment data, we create a series of new variables, including the total number of unique ISPs offering broadband speeds and the number of ISPs offering fiber services (e.g., FTTH) in each census block.[7] We use these variables as proxies for investments in residential broadband, which cannot be directly observed. The dependent variables to be estimated are thus:

1) whether broadband competition exists in a particular census block (indicated by the presence of two or more ISPs offering broadband speeds);
2) whether residential fiber services are available in a particular census block (indicated by the technology and speed reported by ISPs servicing that block).

We combine this data with sociodemographic information from the American Community Survey (ACS). With a current sample size of about 3.5 million households, the ACS allows for reliable estimates at the census block group level, which on average contains about 40 census blocks (or about 1500 residents). To join these datasets at the same geographical scale, we aggregate the block-level CPUC data to the block group level. Despite the fact that in a highly urbanized metro area such as Los Angeles the typical census block is relatively small (about 30,000 square feet), this aggregation inevitably results in overestimation of service availability. Our results should thus be interpreted as upper bound estimations. Further, as is the case for most spatial statistical

[7] Following the FCC definition we consider broadband an Internet access service with advertised speeds of at least 25Mbps for data download and 3Mbps for data upload (FCC, 2015).

inquiries involving aggregate data, we acknowledge that our results are vulnerable to the Modifiable Areal Unit Problem (MAUP), defined as the sensitivity of estimates to zonation (i.e., the arbitrary nature of block group boundaries) and scale (i.e., the size of block groups) (see Fotheringham & Wong, 1991; Green & Flowerdew, 1996; Oberwittler & Wikström, 2009).

Our full dataset contains 32,135 observations, which correspond to 6427 block groups observed over five years from 2014 to 2018. For each observation, we estimate the probability of observing our two outcomes of interest (the presence of broadband competition and the availability of fiber services), conditional on a series of demographic factors that previous studies have shown to affect broadband investments (Flamm & Chaudhuri, 2007; Hauge & Prieger, 2010; Whitacre et al., 2015). These include population density, racial composition, median household income (logged), housing value (logged), median age, education (percentage of population with bachelor's degree or higher), the percentage of households with children under 18 years old, and the percentage of English-only households.

In order to test for the concentration effects discussed in the previous section, we create an interaction between the share of Black residents in a block group and whether the block group is low income, using the bottom quartile of median household income as a proxy for low income. Broadly speaking, this term tests the hypothesis that, above and beyond the separate effect of income and race factors, broadband investments lag in areas that combine poverty and a disproportionately large share of Black residents. Table 1 contains additional details about the model variables.

The empirical analysis is based on two reduced-form modelling strategies. The first is a fixed-effects panel data specification that estimates the effect of race and income on the two outcomes of interest (broadband competition and fiber availability), conditional on demographic factors. The regressors are lagged one period in order to account for the prolonged investment cycle involved in broadband network deployment.Formally, the model is:

$$Pr\left(Y_{it} = 1 | X'_{it-1}, \beta, \alpha_i\right) = \frac{1}{1 + e^{-\alpha_i - x_{it-1}\beta}}$$

$$Y_{it} = 1\left[X'_{it-1}\beta + \alpha_i + \varepsilon_{it} > 0\right]$$

where Y_{it} is the binary outcome of interest for census block group i in year t, X'_{it-1} is the vector of (lagged) block group characteristics, α_i is the time-invariant error term for block group i, ε_{it} is the logistically distributed, time-varying error term and β is the vector of coefficients that are estimated through maximum likelihood.

This strategy best approximates the effect of income and racial factors on the spatial distribution of broadband investments by controlling for time-invariant unobserved differences across blocks groups (such as topography and local rules for civil works) known to affect broadband rollout (Greene, 2003). These unobserved differences between block groups are particularly relevant in Los Angeles County, which contains 88 incorporated cities over a 4083 square-mile area with considerable variation in topography. Results from a Hausman test confirm that the fixed-effects specification is preferred over a random-effects specification.

At the same time, this empirical strategy results in considerable information loss, primarily because the fixed-effects estimator only uses information from block groups for which changes in the outcome variables are observed during the study period. For example, there are 4834 block groups (from a total of 6427) for which no change in fiber availability status is observed between 2014 and 2018 (in order words, fiber service was either available or unavailable in these blocks throughout the entire period). These observations are thus dropped from the fiber model estimations, thus resulting in significant information loss.

We therefore use a second estimation strategy that, while not controlling for unobserved heterogeneity across block groups, uses information from all observations. These second set of estimates are based on a pooled logit specification with robust standard errors clustered at the block group level. While this strategy essentially ignores the panel structure in the data, the clustered errors account for correlation between errors from repeated observations across periods (Wooldridge, 2001). Results for both empirical strategies are reported and discussed in the following sections.

Table 1
List of variables and sources.

Type	*Variable name*	*Variable explanation*	*Source*
Dependent Variable	Broadband Competition	Whether block group has more than one ISP offering broadband speeds (YES = 1)	CPUC
	Availability of Fiber-to-the-Home Services	Whether FTTH services are available in block group (YES = 1)	CPUC
Independent Variable of Interest	Concentration Effects of % Black and Low-Income	Interaction between Black residents (%) and low-income block group (YES = 1)	ACS
Covariates	Population Density	Population per square mile in block group	ACS
	% Black	Percent of block group population that is Black	ACS
	% Non-white Hispanic	Percent of block group population that is non-white Hispanic	ACS
	% Asian	Percent of block group population that is Asian	ACS
	Median Age	Median age of block group population	ACS
	% English-only Households	Percent of block group households that report speaking English only	ACS
	Presence of Children	Percent of block group households with at least one child (individuals less than 18 years old)	ACS
	% Bachelor or Higher	Percent of block group population with a bachelor's degree or higher	ACS
	Median Income (log)	Block group median household income (logged)	ACS
	Housing Value (log)	Block group housing value (logged)	
	Low Income Area	Whether the block group median household income falls in the bottom quartile (YES = 1)	ACS

4. Results

4.1. Descriptives and trends in broadband infrastructure rollout

During the 2014–18 period there is evidence of a significant expansion in fixed residential services in LA County. The share of residents served by at least two ISPs offering broadband speeds increased from 65.5% in 2014 to 90.4% in 2018. This represents an additional 2.5 M residents who can choose from high-speed residential plans offered by competing ISPs. Similarly, the share of residents served by FTTH services increased from 26.4% in 2014 to 49.7% in 2018, thus suggesting robust investments in gigabit-level services (Fig. 1 left panel).

At the same time, other results raise concerns about weakening competition and investments. First, the rate of expansion of broadband competition appears to be trending down (Fig. 1 right panel). This is somewhat to be expected as competition approaches full population coverage, and likely reflects (at least in part) topography and regulatory challenges in deploying service to the less than 10% of residents who lack broadband choice. By contrast, the slowdown in residential fiber rollout raises questions as coverage remained below 50% in 2018.

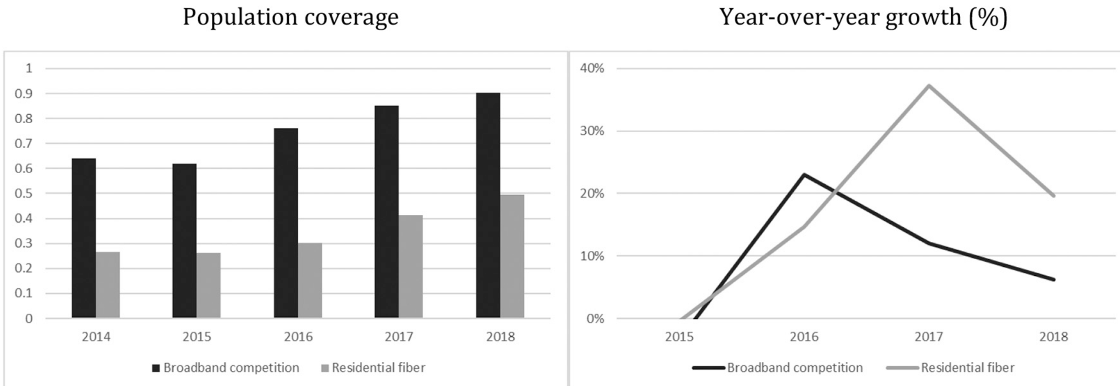

Fig. 1. Trends in broadband competition and residential fiber availability, 2014–2018.

Whether this reflects a temporary slowdown or a long-term trend remains to be seen. The most recent FCC Broadband Deployment report (FCC, 2020) notes that homes passed by fiber grew nationally by 16% in 2019. At the same time, industry analysts note that large operators have scaled-down fiber efforts to favor 5G deployment (Falcon, 2019), though other reports suggest that new entrants are filling in the void (FCC, 2020).

Second, there is evidence that the residential internet access market is increasingly characterized by duopoly competition. Between 2014 and 2018 the share of residents able to choose between three or more competing ISPs dropped by about half from 10% to 5.7%. Further, considering the share of residents who lived in areas where the number of ISPs increased, decreased or remained unchanged between 2014 and 18, the data shows that 11.5% of residents (about 1.2 M) saw a reduction in the number of local competitors. Several studies have noted similar trends nationally, pointing to lack of regulatory incentives that promote effective broadband competition in the US in comparison to other advanced countries (Flamm & Varas, 2018; Frieden, 2009).

As a prologue to the presentation of results in the next section, a table of summary statistics is presented below (Table 2:).

4.2. Broadband competition

4.2.1. Pooled logit results

We begin by examining results from the pooled logit models for broadband competition, our first proxy variable. Model 1 estimates the likelihood of competition in a block group controlling for population density and household characteristics. As noted, while this empirical strategy ignores the panel structure of the data, standard errors are clustered at the block group level to account for correlation between observations across periods. The results are presented in Table 3.

We observe that most control variables take the expected sign. Perhaps surprising is that education level (bachelor's degree or higher) and population density are not significant predictors of broadband competition, while the share of Asian residents has a positive effect. We return to these results in the next section.

Turning to our main variables of interest, we find that the probability of observing competition decreases with the share of Black residents while increasing with household income and housing value. To quantify the magnitude of these effects, Fig. 2 offers a visual representation of the results based on conditional predictions across the range of values for these two variables. As shown (left panel), the probability of competition between two or more ISPs in a census block group is about 77% in areas with a small share of Black residents, dropping to about 68% in traditional Black neighborhoods. Similarly (right panel), in low-income block groups the probability of broadband competition falls below 70%, climbing above 80% in the more affluent areas (notice the effect is nonlinear by construction of the logged income variable). Although competition levels are relatively high overall, the results suggest that low-income and Black residents have fewer broadband options, which is typically associated with lower quality services and higher prices.

In order to test for the concentration effects discussed in section 2.2., Model 2 introduces a term that captures the interaction between the share of Black residents and whether the block group is low income, using first (bottom) median household income quartile as a proxy. The results reveal several interesting patterns. First, the bottom income quartile variable absorbs the effect of median household income, thus suggesting that underinvestment is clustered in high-poverty areas. Further, the interaction term also absorbs the effect of Black, which in Model 2 is not significant. At the same time, the interaction term is highly significant, thus validating the hypothesis that competition is particularly lacking in areas that combine poverty and a large

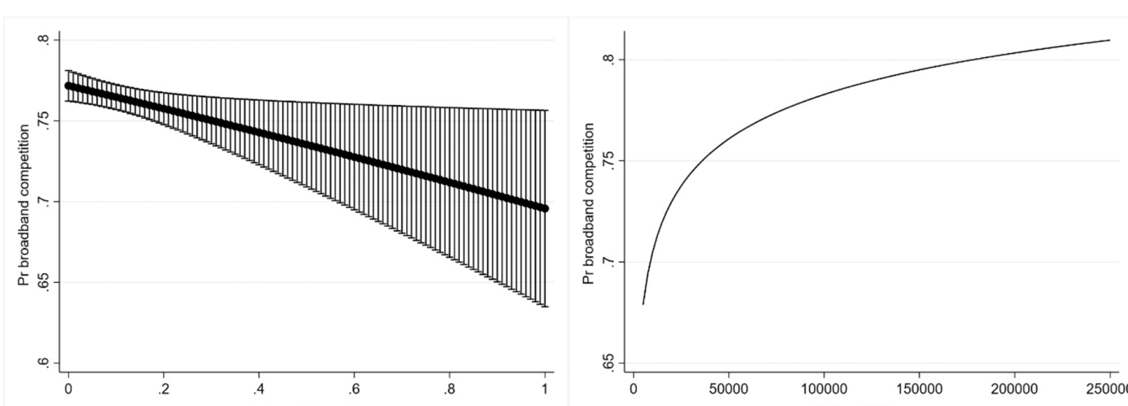

Fig. 2. Predicted probability of broadband competition by HH income and share of Black residents (95% confidence intervals).

concentration of Black residents.

To illustrate these interaction effects, Fig. 3 replicates the left panel plot in Fig. 2 (probability of broadband competition along the share of Black residents), but divides block groups into low income (bottom quartile) and not low income (that is, the remaining three quartiles). In other words, the figure compares the likelihood of broadband competition between low-income and more affluent areas along the share of Black residents in each block group. As shown, while the probability of observing competition is higher and relatively similar in affluent areas regardless of the share of Black residents, the same probability falls rapidly in poor communities as the share of Black residents increases. Notably, it falls below 50% in low-income block groups that concentrate large Black populations.

4.2.2. Fixed-effects logit results

The results above suggest that intracity variations in investments in fast broadband are associated with race and income factors. These results however do not account for unobserved differences across block groups that may affect broadband rollout. This include important cost factors such as topography and permitting laws as well as other demand factors not captured in the pooled logit models. By contrast, Table 4 presents results from the fixed effects estimations, which as discussed take advantage of the panel structure of the data to control for unobserved, time invariant heterogeneity across units of observation.

The fixed effects estimations generally validate the findings from the pooled logit models, with minor differences in coefficients for the control variables. While the predictor variables in Models 3 and 4 are identical to those in Models 1 and 2, it is worth noting that results from Models 3 and 4 are based on a smaller sample of 8464 observations (2206 block groups observed over 4 periods), which corresponds to block group where competition status changed (in either direction) over the study period. Note for example that education and the presence of children in the household are now, as expected, positively correlated with broadband competition, while the share of Asian residents is no longer significant.

Turning to our main variables of interest, we observe that household income no longer has an independent effect on broadband competition, although housing value remains a strong predictor, which suggests a correlation between broadband investments and areas that experienced faster gentrification (and thus stronger growth in housing values) during the study period. The dummy variable for low income areas (bottom income quartile) remains significant, thus suggesting an independent effect on the likelihood of broadband competition (model 4). Notably, the interaction term between bottom income quartile and the share of Black residents, which captures the concentration effects discussed above, remains negative and significant at $p < 0.01$. This validates the hypothesis that new broadband investments are not reaching historically Black, low-income communities.

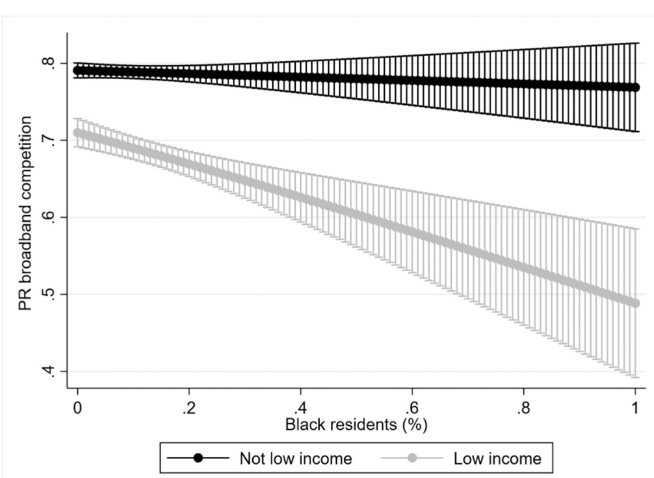

Fig. 3. Predicted probability of broadband competition by HH income and share of Black residents (95% confidence intervals).

4.3. Fiber availability

4.3.1. Pooled logit results

Results for fiber availability, our second proxy variable, generally point in a similar direction. As expected, the probability of observing fiber availability decreases with the share of Black residents. The results also indicate that fiber is more likely to be available in the more affluent areas. However, contrary to the results for broadband competition discussed above, the interaction term between the share of Black residents and bottom income quartile is not significant (Model 6), suggesting that race and income independently (but not jointly) affect the probability of observing fiber availability.

Fig. 4 quantifies the effect magnitude of racial and income factors based on the predicted probability of observing fiber along the range of values for the two variables of interest (the share of Black residents and median household income). As shown, the probability of fiber availability is about three times lower in majority Black block groups relative to comparable areas with fewer Black residents (left panel). Similarly, while in the more affluent areas the likelihood of observing fiber are approaching 1 in 2, in the less affluent areas they stand at about 1 in 5 (right panel).

4.3.2. Fixed-effects logit results

The fixed effects estimations for fiber availability are presented in Table 6. The results are qualitatively similar to those in Table 5, with some variations in effect size and statistical significance. Interestingly, we observe that while the positive effect of the Asian and Hispanic variables disappears, the share of Black residents remains a strong negative predictor of fiber services. In turn, household income has a positive independent effect in Model 7, which is nonetheless absorbed by the introduction of the interaction term in Model 8. Overall, the fixed effects estimates validate the main hypothesis about broadband investments being associated with income and racial factors, with particularly adverse effects found for low-income Black communities.

5. Discussion and limitations

This study examines the correlation between demographic factors and broadband service rollout in LA County over the 2014–18 period, using competition and fiber availability as proxy variables. Using two different empirical strategies, we find consistent evidence that racial and income factors are associated with the spatial distribution of broadband investments. In particular, we find that competition between two or more ISPs offering services at broadband speeds is less likely in low-income areas as well as in areas with a large share of Black residents. Similarly, these areas are also less likely to be served by residential fiber services capable of delivering gigabit-level speeds.

In addition, the study explores concentration effects that generate particularly adverse outcomes for areas that combine these demographic attributes. As noted, many scholars have linked the legacy of racial discrimination in the postwar era to the spatial concentration of economic distress in particular neighborhoods (Massey & Fischer, 1999; Sampson, 2017). A key barrier to social mobility in these communities is the low quality of the public goods provisioned to residents, including public transportation, public safety, and public education. If—as many have argued—information is the foundation of the modern economy, deficits in the provisioning of high-quality broadband can be expected to have a similarly adverse impact on the opportunities afforded to small businesses and residents in these areas. Overall, our findings suggest that these concentration effects exist and adversely affect broadband infrastructure in predominantly Black, low-income neighborhoods.

Unfortunately, the lack of reliable data about broadband prices and

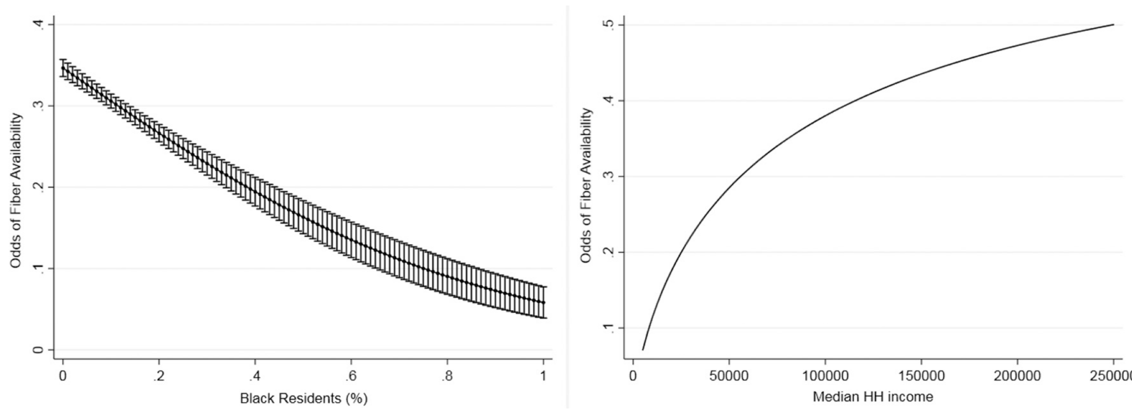

Fig. 4. Predicted probability of fiber availability by HH income and share of Black residents (95% confidence intervals).

actual service speeds (as opposed to advertised speeds) limits our ability to quantify the direct impact of these broadband infrastructure gaps. However, both basic economic principles and evidence from other studies suggest that the implications of weak competition and underinvestments in next-generation broadband infrastructure are potentially far-reaching (see Kongaut & Bohlin, 2017). For example, studies suggest that deficits in network infrastructure are likely to limit the ability of firms in distressed communities to use broadband to compensate for deficits in other inputs, such as transportation and financing. Forman, Goldfarb, and Greenstein (2005) show that geographical isolation promotes broadband adoption by allowing firms to substitute for higher transportation costs. Further, Prieger (2019) finds evidence that broadband promotes small-business formation in low-income and minority areas by compensating for constraints in local banking availability. These and other studies indicate that disparities in the provision of broadband are likely to deepen urban inequality.

At the same time, there are several limitations to this study that warrant caution in the interpretation of results. The most relevant is the potential for omitted variable bias in the estimation models. While our fixed effects modelling strategy effectively accounts for unobserved variations in time invariant factors (such as local terrain) across block groups, this strategy is not immune to bias from time-varying factors that affect broadband investment incentives. An example of such a factor is business demand for broadband, which correlates with incentives to deploy fiber in a particular community. Because the presence of technology-intensive firms also correlates with community demographics, this omission potentially biases our estimation results.

Another question that deserves further attention is why similar deficits in broadband buildout are not found for areas with large Hispanic populations. One possible answer relates to the spatial distribution of Hispanics across block groups in LA county, which is significantly more homogeneous than the distribution of Black residents (recall the results from the dissimilarity index as well as the variable descriptives in Table 2). This makes the potential effect of the Hispanic variable harder to detect. Further, because the fixed effects estimations capture changes in predictors over time, differences in the rate of neighborhood gentrification across racial lines may also account for these results.Ultimately, further studies are needed to untangle this question.

6. Policy implications and conclusions

Addressing deficits in the local availability of critical infrastructure is a key government mandate. This is reflected in several provisions in federal and state law that set forth policies to ensure the deployment of

Table 2
Summary statistics.

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Broadband Competition	0.751	0.433	0	1
Fiber Availability	0.348	0.476	0	1
Population density	13,740.6	11,455.1	0.205	148,004.1
Black (% pop)	0.085	0.148	0	1
Hispanic (% pop)	0.466	0.303	0	1
Asian (% pop)	0.137	0.166	0	1
Bachelor or higher (% pop)	0.303	0.22	0	1
Median age	37.5	7.85	13.6	80.8
HH with children <18 (%)	0.397	0.161	0	1
English-only HH (%)	0.429	0.244	0	1
Median HH income	68,140	36,456	4987	250,000
Housing value	508,189	271,340	10,400	2,000,000
First income quartile	0.244	0.43	0	1

Table 3
Pooled logit estimation for broadband competition.

	Broadband competition (yes = 1)	
VARIABLE	Model 1	Model 2
Population density	4.45e-06	5.20e-06*
	(2.89e-06)	(2.92e-06)
Black (% pop)	−0.430**	−0.139
	(0.179)	(0.194)
Hispanic (% pop)	0.168	0.148
	(0.213)	(0.213)
Asian (% pop)	1.297***	1.279***
	(0.223)	(0.223)
Bachelor or higher (% pop)	−0.144	−0.151
	(0.251)	(0.252)
Median age	−0.0148***	−0.0142***
	(0.00438)	(0.00438)
HH with children <18 (%)	−0.312*	−0.233
	(0.176)	(0.176)
English-only HH (%)	0.997***	1.040***
	(0.194)	(0.195)
Median HH income (log)	0.195***	−0.00832
	(0.0466)	(0.0616)
Housing value (log)	0.161**	0.175**
	(0.0740)	(0.0742)
First income quartile (yes = 1)		−0.182***
		(0.0670)
First income quartile X Black (% pop)		−0.895***
		(0.240)
Constant	−3.563***	−1.540
	(1.111)	(1.194)
Observations	28,273	28,273

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$

Table 4
Fixed effects logit estimation for broadband competition.

	Broadband competition (yes = 1)	
VARIABLE	Model 3	Model 4
Population density	2.57e-05*	2.56e-05
	(1.77e-05)	(1.77e-05)
Black (% pop)	−1.271	−0.795
	(0.982)	(0.996)
Hispanic (% pop)	0.838	0.807
	(0.745)	(0.746)
Asian (% pop)	−0.0567	−0.0742
	(0.929)	(0.930)
Bachelor or higher (% pop)	2.462***	2.468***
	(0.740)	(0.740)
Median age	−0.0636***	−0.0642***
	(0.0103)	(0.0104)
HH with children <18 (%)	2.450***	2.453***
	(0.329)	(0.330)
English-only HH (%)	−0.231	−0.222
	(0.620)	(0.620)
Median HH income (log)	0.0468	0.100
	(0.0826)	(0.106)
Housing value (log)	7.389***	7.416***
	(0.312)	(0.313)
First income quartile (yes = 1)		0.239**
		(0.113)
First income quartile X Black (% pop)		−1.228***
		(0.392)
Observations	8464	8464
Number of block groups	2206	2206

Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$

Table 5
Pooled logit estimation for fiber availability.

	Fiber availability (yes = 1)	
VARIABLE	Model 5	Model 6
Population density	−5.81e-06*	−4.62e-06
	(3.19e-06)	(3.21e-06)
Black (% pop)	−1.414***	−1.372***
	(0.180)	(0.187)
Hispanic (% pop)	2.525***	2.512***
	(0.215)	(0.214)
Asian (% pop)	2.410***	2.360***
	(0.218)	(0.218)
Bachelor or higher (% pop)	−0.389	−0.345
	(0.243)	(0.243)
Median age	−0.00779*	−0.00619
	(0.00453)	(0.00454)
HH with children <18 (%)	0.243	0.373**
	(0.167)	(0.167)
English-only HH (%)	3.396***	3.407***
	(0.213)	(0.213)
Median HH income (log)	0.695***	0.431***
	(0.0502)	(0.0620)
Housing value (log)	0.0521	0.0705
	(0.0769)	(0.0781)
First income quartile (yes = 1)		−0.413***
		(0.0682)
First income quartile X Black (% pop)		−0.148
		(0.282)
Constant	−11.81***	−9.190***
	(1.116)	(1.177)
Observations	28,273	28,273

Robust standard errors in parentheses
*** $p < 0.01$.
** $p < 0.05$
* $p < 0.1$

communication facilities regardless of race, income and other demographic factors.A key takeaway from our findings is that broadband buildout in LA County during the 2014–18 period did not adhere to these policy standards. The steady pace of fiber deployment in affluent areas stands in contrast to the slow rollout in less affluent and minority communities. Similarly, while affluent residents can choose from broadband offerings by competing providers, in many low-income communities broadband speeds are offered by a single provider (typically the incumbent cable TV provider).

At the federal level, several programs exist to promote broadband rollout, most notably the Connect America Fund which since 2011 has provided about $4.5B in annual funding for underserved areas.However, the program guidelines favor high-cost areas, which result in subsidies being directed almost exclusively to rural and sparsely populated areas at the expense of poorly served urban communities. Interestingly, the same is true for California's own broadband infrastructure program, the California Advanced Services Fund (CASF), created in 2007 to promote network deployment in "unserved and underserved areas in the state". As of April 2020, about 90% of the roughly $310 M in awarded funds have gone to broadband infrastructure projects in rural areas.[8]

The challenge of promoting network buildout in distressed urban areas is compounded by the contested nature of policy oversight over broadband deployment. Such oversight spans multiple layers of policy authority, and is characterized by legacy legislation that does not reflect current market trends. Consider for example California's Digital Infrastructure and Video Competition Act of 2006 (DIVCA), which gives broad authority for the CPUC to "promote the widespread access to the most technologically advanced cable and video services to all California communities in a nondiscriminatory manner, regardless of their socioeconomic status".[9] However, the FCC has explicitly ruled that local cable franchising authorities (such as the CPUC) may not exercise this authority to regulate broadband, despite the fact that broadband services are provided over the same infrastructure, and that consumers are rapidly abandoning traditional video and cable services in favor of Internet-based video services.[10]

Some local jurisdictions (including the City of Los Angeles) have attempted to use their control over utility poles, public rights of way, municipal buildings, and other assets that are critical to the rollout of 5G wireless services as levers to negotiate network build-out commitments with broadband operators. However, these attempts have been met with resistance from federal authorities, for example in the FCC's 2018 preemption of local authority over pole attachment rules.[11] And earlier the same year, the FCC reversed course by reclassifying broadband as an information service under Title I of the Communications Act, a shift that signaled its reluctance to extend nondiscrimination obligations (which apply to common carriers under Title II) to the rollout of broadband services.

In response to these policy changes, many local governments are exploring alternatives based on the public-utility model. While there are many variations of this model (Menon, 2016), it is typically structured around a municipally-owned wholesale fiber network that serves

[8] Own calculations based on CPUC data available at www.cpuc.ca.gov.

[9] DIVCA (2006) Section 5810 (a).

[10] FCC Third Report and Order, FCC 19–80, adopted on August 1, 2019.

[11] Accelerating Wireline Broadband Deployment by Removing Barriers to Infrastructure Investment, FCC Docket No. 17–84, Third Report and Order and Declaratory Ruling, 33 FCC Rcd 7705.

Table 6
Fixed effects logit estimation for fiber availability.

	Fiber availability (yes = 1)	
VARIABLE	Model 7	Model 8
Population density	−2.69e-06*	−1.42e-06
	(2.29e-05)	(2.30e-05)
Black (% pop)	−3.669***	−3.136**
	(1.239)	(1.258)
Hispanic (% pop)	−0.439	−0.441
	(0.952)	(0.952)
Asian (% pop)	0.571	0.620
	(1.166)	(1.163)
Bachelor or higher (% pop)	2.515***	2.576***
	(0.927)	(0.928)
Median age	−0.0824***	−0.0826***
	(0.0137)	(0.0137)
HH with children <18 (%)	4.117***	4.117***
	(0.413)	(0.413)
English-only HH (%)	−1.140	−1.090
	(0.803)	(0.804)
Median HH income (log)	0.314***	0.146
	(0.108)	(0.137)
Housing value (log)	11.81***	11.81***
	(0.465)	(0.465)
First income quartile (yes = 1)		−0.0704
		(0.142)
First income quartile X Black (% pop)		−1.256***
		(0.480)
Observations	6227	6227
Number of block groups	1593	1593

Standard errors in parentheses
*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$

government needs while also leasing capacity to private operators who operate the retail access network. Until recently, this model was limited to relatively small cities, or in some cases consortia of cities (such as in Utah's UTOPIA network). However, in January 2020 New York City unveiled an ambitious plan to build an open access fiber network across the entire city, leveraging multiple city assets. This fiber network will be overlaid with a wireless access network capable of providing fast and affordable broadband service in every neighborhood, but the plan explicitly prioritizes low-income areas where competition and FTTH rollout have lagged in comparison to the more affluent neighborhoods.[12]

It remains to be seen whether the municipal network model can be successfully replicated at scale in large metro areas. Regardless, ambitious projects such as New York City's point to growing frustration among local policymakers with federal and state policies that have failed to catalyze broadband investments in distressed urban communities. In 2018, California passed AB 1999 which eliminated the last set of restrictions on municipal broadband.[13] Municipalities seeking to redress disparities in the provisioning of broadband now have a broader toolset at their disposal, and the findings of this study suggest that a more proactive role for local governments may indeed be warranted.

Author statement

Hernan Galperin: Conceptualization, methodology, writing, original draft preparation. Thai Le: Dataset preparation, data analysis, writing. Kurt Wyatt: Dataset preparation, data analysis, writing.

[12] The New York City Internet Mater Plan. Available at www.nyc.gov/tech.
[13] AB 1999 lifted restrictions to publicly-owned broadband networks in unincorporated areas in the state.

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Declaration of Competing Interest

None.

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