Digital redlining: the relevance of 20th century housing policy to 21st century broadband access and education

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Abstract

Despite its increasing importance for educational practices, broadband is not equally accessible among all students. In addition to oft-noted last-mile barriers faced by rural students, there can be wide variation in in-home access between proximate urban and suburban neighborhoods ostensibly covered by the same telecommunications infrastructure. In this paper, we investigate the connection between these disparities and earlier redlining practices by spatially joining two current measures of broadband access with Depression-era residential security maps that graded neighborhoods for real estate investment risk from "Best" to "Hazardous" based in part on racist and classist beliefs. We find evidence that despite internet service providers reporting similar technological availability across neighborhoods, access to broadband in the home generally decreases in tandem with historic neighborhood risk classification. We further find differences in in-home broadband access by race/ethnicity and income level, both across and within neighborhood grades. Our results demonstrate how federally developed housing policies from the prior century remain relevant to the current digital divide and should be considered in discussions of educational policies that require broadband access for success.

Keywords: redlining, broadband access, digital divide, educational access, HOLC

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Introduction

The sudden shift to online schooling during the COVID-19 pandemic quickly demarcated and, in some cases, exasperated existing race- and income-aligned disparities in broadband access (Ong, 2020). While limited access to the internet can make it difficult to engage in modern society along a number of dimensions (Dharma et al., 2010), students with poor broadband connectivity can face particular barriers to their educational progress. Prior to the pandemic, approximately 30% of all public K-12 students lacked the ability to connect to the internet in their homes (Chandra et al., 2020), and approximately 17% of teenage students reported being unable to finish homework due to poor internet connectivity (Anderson & Perrin, 2018). After shifting to remote instruction in the spring of 2020, many districts responded to poor broadband access by supplying their students with internet-connected devices and in-home hot spots as well as by repurposing school buses to serve as mobile WiFi connection points (Levin, 2020). Despite these and other mitigation efforts, there remain broad concerns about differential learning loss among K-12 student populations due, in part, to disparate technological access (Kuhfeld et al., 2020).

At the higher education level, access to high-speed broadband has been associated with more robust college application behaviors (Dettling et al., 2018) and increased enrollment in distance education courses (Goodman et al., 2019; Skinner, 2019). Enrollments in online courses have been steadily increasing over the past decade (Xu & Xu, 2020), culminating in 37.2% of all college students taking at least some of their courses online and 17.6% enrolling exclusively in distance education courses just prior to the pandemic (U.S. Department of Education, National Center for Education Statistics, 2021). For students living in education deserts, online coursework may represent the only way to access higher education (Hillman, 2016; Klasik et al., 2018). Studies conducted during the COVID-19 pandemic, when almost all higher education students shifted to taking their courses online (Marsicano et al., 2020), found that the reliability of internet connectivity was positively correlated with both students' ability to complete online college course work (Armstrong-Mensah et al., 2020) and the educational value of the college online experience (Zalat, 2021). Because it is likely that both K-12 and higher education in the post-pandemic era will include ever-increasing reliance on online interactions (Darling-Hammond et al., 2020; Lockee, 2021), it is important to understand and mitigate disparities in broadband access as a matter of educational equity.

Much of the prior research on the digital divide has focused on differences between urban/suburban and rural areas (Copps, 2009; LaRose et al., 2007; West & Karsten, 2016). This concern is warranted as last-mile digital connections can be costly and difficult to maintain (Scheibe et al., 2006). Nonetheless, there is evidence of broadband access disparities within denser urban and suburban areas that are explained by neighborhood and demographic segmentation rather than geographic barriers (Alliance, 2017; Irving et al., 1999). In this study, we conceptualize access to high-speed broadband internet as part of a student's geography of opportunity (de Souza Briggs, 2005; Green et al., 2017; Tate IV, 2008), which is shaped by three tenets: first, that the "intersection of race and property creates an analytical tool through which we can understand social (and consequently school) inequity," (Ladson-Billings & Tate IV, 1995, p. 48); second, that the racial and socioeconomic segregation of neighborhoods is related to the segregation of educational resources and opportunities (Green et al., 2017); and third, that differences in geographies of opportunity are not the inevitable result of natural social processes (de Souza Briggs, 2005).

Focusing on the historical links between race- and income-based neighborhood segregation and access to other educational resources (Orfield, 1994; Pearman, 2019), we explore the connection between broadband access and the actions of a number of federal agencies created to provide relief to banks and homeowners during the Great Depression. These agencies, which included the Home Owners' Loan Corporation (HOLC) and the Federal Housing Administration (FHA), helped formalize real estate appraisal methods that entrenched residential segregation and, in the process, produced a number of residential security or redlining maps that classified neighborhoods in cities across the country based in part on racist beliefs (Jackson, 1987; Michney & Winling, 2020; Rothstein, 2017; Stuart, 2003; Winling & Michney, 2021; Woods II, 2012). Demonstrating urban theorist Edward Soja's notion that "once spatial injustice is inscribed into the built environment, it is difficult to erase," (2010, p. 41), scholars in multiple disciplines have shown the continued relevance of these neighborhood classifications and other segregationist policies to a range of social (Aaronson et al., 2020; Mitchell & Franco, 2016; Zhang & Ghosh, 2016), health (Beck et al., 2020; Nardone, Casey, Morello-Frosch, et al., 2020; Nardone, Casey, Rudolph, et al., 2020), and educational (Goldring & Swain, 2014; Lukes & Cleveland, 2021; Orfield, 2013; Pearman, 2019; Pearman & Swain, 2017; Reardon, 2016; Vigdor & Ludwig, 2007) inequities more than a half century after they were legally ended.

Based on the twin histories of redlining housing practices and differential access to telecommunications technologies required for full participation in our modern educational systems, we ask with this study: do we observe differences in broadband access related to historical redlined neighborhood boundaries and, if so, is there further heterogeneity in access by a person's race/ethnicity or income? We investigate these questions with complementary data on broadband access from the Federal Communications Commission (FCC) and the American Community Survey (ACS). Our first measure from the FCC shows whether internet service providers (ISPs) report offering various broadband technologies (e.g., cable modem, optical/fiber to the home) to at least one household in an area. Our second measure from the ACS summary household file reports the number of persons who have in-home broadband access, both in the aggregate and within demographic subgroups. Using georeferenced maps from *Mapping Inequality* project (Nelson et al., 2020), we assign both sets of broadband measures to neighborhoods across the country based on historical boundary lines and fit multilevel Bayesian regressions to estimate differences in access across neighborhood classifications.

We do not find strong evidence that ISPs provide service at different rates across neighborhood grade classifications as measured by their self-reported data to the FCC. Across the most commonly offered broadband technologies, changes in reported ISP service offerings between December 2014 and June 2019 occur in tandem across neighborhood grades. Using ACS measures, however, we find across-grade differences in in-home broadband access, with those living in historically lower-graded neighborhoods reporting less in-home broadband access than those living in neighborhoods that had received higher grades. We also find differences by racial/ethnic group, with Black and Hispanic persons as well as those defined by the census as “other race” reporting lower in-home broadband access than white and Asian persons within the same neighborhood classification. Furthermore, Black and Hispanic persons living in the highest graded neighborhoods were likely to report lower broadband access than white and Asian persons living in the lowest graded neighborhoods. We find similar within- and between-classification grade differences by income level, with more than 92 percent of those making $75,000 or more per year having in-home broadband access compared to less than 67 percent of those who make less than $20,000 per year.

Our results suggest that despite the appearance of relatively equal ISP penetration within many communities, there remain neighborhood-based differences in in-home broadband access correlated with past racist and classist housing practices. Two implications for education policy as they pertain to students’ geography of opportunity follow from our results. First, framings of the digital divide that fall along the rural/urban dimension (Pereira, 2016; West & Karsten, 2016), though important, leave out within-urban and suburban area differences that can affect students who live within the same school zone or local college area. Second, an ISP offer of broadband service does not equate to universal access and may instead exacerbate current inequities among students attending the same school (Pearman, 2019). While broadband policy affects nearly all individuals, it is particularly important for students who rely on the internet for homework, research, and online coursework that small area digital inequities are properly addressed. We argue that understanding the connection between past housing policy and current infrastructural inequities provides clarity about the state’s affirmative responsibility in ameliorating the digital divide among all students.

Background

Disparities in educational opportunity have long been linked to racial segregation in both schools (Reardon, 2016; Reardon et al., 2019) and housing (Goldring & Swain, 2014; Lukes & Cleveland, 2021; Orfield, 2013; Vigdor & Ludwig, 2007). Despite the Supreme Court’s rejection of the doctrine of “separate but equal” for schools in *Brown v. Board of Education* and subsequent directions that schools should be desegregated with "all deliberate speed" (*Brown v. Board of Education of Topeka, 347 U.S. 483* , 1954; *Brown v. Board of Education of Topeka, 349 U.S. 294*, 1955), later rulings in cases like *Milliken v. Bradley* (*Milliken v. Bradley, 418 U.S. 717*, 1974) effectively halted many urban school district desegregation plans based on arguments that residential segregation was due to private preference, with the implication that insofar as school segregation resulted from *de facto* situations there was little room for government intervention (Orfield, 1994). Many dispute that residential segregation is completely a matter of private choice, however, and point to a history of *de jure* government housing policies that effectively segregated white persons in neighborhoods and school districts away from immigrants and persons of color (Orfield, 1994, 2013; Rothstein, 2012, 2017). In this paper, we focus specifically on federal housing programs of the New Deal era, tracing the exclusionary property ownership and residential segregation technologies developed by administrators of the HOLC and the FHA (Michney & Winling, 2020; Rothstein, 2012, 2017; Satter, 2009; Winling & Michney, 2021) to current differences in students' geographies of opportunity as they relate to broadband access (de Souza Briggs, 2005; Green et al., 2017; Tate IV, 2008).

New Deal-era housing policy and the codification of residential segregation

Attempting to mitigate the negative effects of the Great Depression in the final year of his administration, President Hoover signed the Federal Home Loan Bank Act of 1932 (Federal Home Finance Agency, 2011), an act which created the Federal Home Loan Bank (FHLB) system and its governing board. The FHLB's board, or FHLBB, chartered a number of federally-owned banks that offered membership and low interest loans to private banks experiencing liquidity freezes due to instability in the housing market. This legislation paved the way for the flurry of New Deal acts under the Roosevelt administration that created the HOLC, the FHA, and the Mutual Mortgage Insurance Company (MMIC) (Federal Home Finance Agency, 2011; Jackson, 1987; Rothstein, 2017).

As part of its mission to support home ownership, the federal government used the FHLBB agencies, which included the HOLC, and later the FHA to institute two key influences on home finance: (1) increased use of affordable long-term amortized mortgages, which replaced home loans that typically had been short-term interest-only loans; and (2) nation-wide use of standardized appraisal methods for real-estate valuation and credit-risk indexing (Fahey et al., 1938; Rothstein, 2017; Stuart, 2003; Woods II, 2012). The HOLC was tasked with underwriting the purchase and refinancing—often at a discount—of existing at-risk urban and suburban home loans for the "relief of debt-burdened home owners" who faced foreclosure (Home Owner's Loan Act, H.R. 5240, 73rd Congress, 1933; Jackson, 1987; McMichael, 1951, p. 331).[1] As part of their work, the HOLC's appraisal department developed a "nation-wide scientific appraisal procedure and standard appraisal formula" (Fahey et al., 1938, p. 72) for mortgage-risk assessment and property valuation. These standards were used to assess the property value and credit risk associated with each loan under consideration for refinance as well as the total risk of the securities held by each lending institution. Established a year after the HOLC, the FHA expanded the federal government's role in housing policy by underwriting mortgages for new construction that were backed by the MMIC (Jackson, 1987; Stuart, 2003). Quickly, the HOLC's and FHA's appraisal efforts were centralized in order to streamline processes among these related agencies (Fahey, Webb, Catlett, et al., 1937; Fahey, Webb, Stevenson, et al., 1937; Light, 2011; McDonald, 1937; Woods II, 2012).

Under the aegis of the FHLBB and FHA, the new scientific real estate standards grew from a cross-pollination of ideas between federal housing agencies, academic research institutions, and private real estate organizations. Richard T. Ely and his Institute for Research in Land Economics and Public Utilities, housed first at the University of Wisconsin and later at Northwestern University, represents one important point of connection among these groups (Light, 2011; Weiss, 1989; Winling & Michney, 2021). Several of Ely's students and associates at the Institute were members of the National Association of Real Estate Boards and early FHA personnel who were highly involved in the systematization of appraisal methods (Stuart, 2003). Two examples at the FHA include Ernest Fisher, director of economics and statistics, and Frederick Babcock, director of underwriting and author of *The Appraisal of Real Estate* (1924) and the FHA's *Underwriting Manual* (1936), which offered standardized appraisal techniques. Also influential in these efforts was Homer

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[1] Jackson (1987) notes that the "Emergency Farm Mortgage Act, passed almost a month [before the act that established the HOLC], was intended to reduce rural foreclosures" (p. 196).

Hoyt, an economist for the FHA's division of economics and statistics and the FHLBB's division of research and statistics as well as a member of the University of Chicago Social Science Research Committee. Both his dissertation, *One hundred years of land values in Chicago: The relationship of the growth of Chicago to the rise of its land values, 1830-1933* (1933), and subsequent study, *The structure and growth of residential neighborhoods in American cities* (1939), greatly influenced methods for assigning property value (Harriss, 1951; Hoyt, 1933; Winling & Michney, 2021).

Ostensibly scientific in their desire to professionalize the real estate industry, these texts implicitly and, in many instances, explicitly revealed the racist and classist beliefs of their authors. This includes the *Underwriting Manual*, which considered and ranked races of property owners and neighborhood inhabitants, and Hoyt's work, which expressly provided hierarchical indices of race/ethnicity to consider when assigning property values. One particular outcome of these discriminatory beliefs on appraisal techniques was that racially segregated neighborhoods became a norm that signaled stability whereas integrated neighborhoods in all but a very few exceptional circumstances signaled neighborhood decline (Hoyt, 1939). For Institute affiliates, stability, which encouraged long-term investors rather than short-term speculators, was extremely important. Lack of uniformity in a neighborhood—whether due to variation in housing quality or the demographic make-up of residents—meant instability and was to be avoided lest it negatively affect investments (Stuart, 2003; Winling & Michney, 2021). As noted by Fishback et al. (2021), though such racist and classist beliefs "did not begin with the FHA or the HOLC" (p. 7), their application in federal housing policy was new and reflected in both agencies' procedures and products.

The residential security or redlining maps in which neighborhoods across a number of metropolitan areas were color coded to reflect mortgage credit-lending risk represent one such product (Jackson, 1987). Using Hoyt's guidelines, the cooperation of the HOLC's appraisal department, and the knowledge of local appraisers, the FHLBB's division of research and statistics assigned neighborhoods credit risk ratings based on a variety of factors, including the present market value of its properties, estimated cost to improve or replace them, average rental values, and the demographic make-up of its residents (Stuart, 2003).[2] Once collated, these factors were use to place neighborhoods into one of four categories or grades: A (green) "best," B (blue) "still desirable," C (yellow) "definitely declining," and D (red) "hazardous." Despite a sheen of objectivity, appraisal and risk assessment methods developed by the federal housing agencies assessed higher risk and reduced values for properties situated in neighborhoods with non-white and immigrant residents, with "Negro" presence being the factor that increased credit risk the most and non-Jewish, American-born white presence the factor that increased it least (Hoyt, 1933; Jackson, 1987; Nelson et al., 2020; Rothstein, 2017).

Due to the efforts of the HOLC, other FHLBB administrative agencies, and the FHA, the federal government was able to mitigate the housing crisis of the Great Depression (Rothstein, 2017). Nevertheless, it did so by choosing who would and who would not be supported, making that decision in part on the race and citizenship status of those who applied as well as those living in the neighborhood. Federal housing policies begun in the 1930s supported the partition of communities such that white Americans were more likely to own equity-accruing single family homes while immigrants and Black Americans were more likely to reside in often substandard multi-family and rental housing (Hillier, 2005; Nelson et al., 2020; Rothstein, 2017).

Subsequent research has shown the lingering effects of these federal housing policies on families and communities across the country. Neighborhoods given the lowest grade are more likely to be classified as majority-minority and low-to-moderate income neighborhoods today (Mitchell & Franco, 2016). From their analyses, Aaronson et al. (2020) conclude that the "[HOLC] maps account for between 15 to 30 percent of the overall gap in share African American and home ownership over the 1950 to 1980 period and 40 percent of the gap in house values" (p. 31). Health researchers have found that gestational age, and perinatal mortality measured over a 10 year period from 2006–2015 in California tend to be higher in neighborhoods with lower grades (Nardone, Casey, Rudolph, et al., 2020) and that emergency room visits due to asthma are also higher in redlined census tracts (Nardone, Casey, Morello-Frosch, et al., 2020). Lukes &

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[2] The joint authorship between these two governmental agencies can be seen on many of the residential security maps that have been scanned and shared by the *Mapping Inequality* project (Nelson et al., 2020).

Cleveland (2021) find that schools and districts in “D” graded neighborhoods receive less money per pupil, have less diverse student populations, and have lower average test scores compared to their counterparts in “A,” “B,” and “C” neighborhoods. We add to this growing literature of the downstream effects of Depression-era federal housing policy by investigating the relationship between redlined neighborhood demarcations, disparities in broadband access, and differential educational opportunities for students partitioned across the digital divide.

Broadband access and its connection to place and education

Despite its increasing importance across our society (Dharma et al., 2010), high speed broadband internet remains an “inherently local phenomenon” (Mack, 2020), a resource not openly accessible but rather offered as a limited commodified product. Though broadband has outgrown its roots in highly advanced scholarly and technical communities, its use remains significantly stratified due to geographical, political, social, and infrastructural barriers (Farlie, 2005).

Research that explores the urban/rural digital divide generally traces geographical constraints of broadband, whereby less-populated areas are offered fewer quality internet service options than urban and suburban areas (Copps, 2009; LaRose et al., 2007; Prieger, 2013; Townsend et al., 2013; West & Karsten, 2016; Wood, 2008). Though shrinking, this disparity endures in part due to provider size and focus, with larger companies serving large and more densely populated—and thus more profitable—metropolitan areas while smaller companies that serve smaller communities are unable to meet costs of new and higher quality infrastructure (LaRose et al., 2007; Wood, 2008). This divide is compounded by consumer-level economic barriers, with companies wanting adoption projections to sufficiently outweigh costs before making infrastructural investments (Hollifield & Donnermeyer, 2003). In addition to issues pertaining to geography and affordability, low technological skills can impede broadband adoption in communities where expanded access is not accompanied by opportunities for training or other supports (Powell et al., 2012).

These disparities persist not only among rural/urban divides but also within and across urban and suburban areas where disparate economic conditions influence provider investment and readiness of technological support. A National Telecommunications and Information Administration (NTIA) report from the late 1990s revealed that there were often differences in telephone, internet (via dial-up modem), and computer access between urban and "central city" areas as well as across racial/ethnic demographic groups and income levels within those areas (Irving et al., 1999). Specifically, high income, more highly educated, and white households—called "information rich" in the report—were much more likely to disclose having in-home internet access than lower income, lower education level, Black, and Hispanic households—the "information poor." A more recent investigative report using Federal Communications Commission (FCC) Form 477 data demonstrated how an internet service provider (ISP) in Cuyahoga County, Ohio, was much more likely to offer its newest and fastest broadband technologies in suburban middle- and high-income census blocks than in high-poverty census blocks within Cleveland city limits (Alliance, 2017).

Such disparities in access matter as students now describe broadband access as a direct and pertinent educational need (Powell et al., 2012). In addition to take-home assignments and school/parent communication that necessitate home connection (Powell et al., 2012), broadband connectivity within K-12 schools often determines the types and quality of materials teachers and students will be able to use (Fox et al., 2012; Kormos, 2018). One example of this is a students' ability to access Advanced Placement (AP) and foreign language courses that, for some schools, are only available through distance learning (Fox et al., 2012; Hudson, 2011). Related, those in online credit recovery programs may face additional challenges if they lack stable internet connections (Heinrich et al., 2019). Each has downstream implications for students in terms of academic achievement, college readiness and access, and labor market preparedness.

The need for quality broadband becomes even more pronounced in the transition from high school to college, when internet resources often play an integral role in how students acquire information when making their application decisions (Burdett, 2013). From the initial search stage to matriculation to later success while enrolled, students often require fast and consistent internet connections in order to submit admissions and financial aid applications, complete course assignments, and conduct research (Dettling et al., 2018; Perna, 2010). Many also need broadband to attend class as colleges expand their online offerings (Palvia et al., 2018; Skinner, 2019). A number of studies have shown that in the short term, students often do not perform as well in online courses as they do in face-to-face courses (see Xu & Xu, 2020 for a recent review of the literature); in addition, outcomes in online courses may differ across student subpopulations (Xu & Jaggars, 2014). Though course design and a student's self-directed learning skills may play a role in the difference (Xu & Xu, 2020), it's also possible that some of these differences of outcome—particularly among different student populations—can be attributed to differences in broadband access. In a study comparing dial-up and broadband, Wu & Turner (2006) found evidence that students who relied on slower dial-up connections behaved differently in courses that required learner-to-learner interactions. While average broadband speeds have increased since the time of this study, commensurate increases in the sophistication and bandwidth requirements of online courses may mean that some students with poorer broadband access continue to face additional challenges.

Housing policy, broadband, and the geography of opportunity

The historical record is clear that the overlapping policies and procedures of the HOLC and the FHA supported racial segregation in communities across the United States. Whether cementing existing conditions or encouraging segregation in new housing developments, one outcome was the same: poorer non-white persons had less access to quality housing and the public infrastructure built around it. As lower property values, lower tax bases, and less access to credit compounded over time, neighborhoods deemed "hazardous" by HOLC appraisers in the 1930s remained underdeveloped and undersupported into the twenty-first century (Aaronson et al., 2020).

Returning to the notion of a student's geography of opportunity (de Souza Briggs, 2005; Green et al., 2017; Tate IV, 2008), we are interested in exploring the relationship between historically redlined neighborhoods and current access to broadband. Because of the increasing importance of broadband access to education at all levels—not only during the COVID-19 pandemic, but before and after—we investigate this connection as a potential mechanism for differences seen in student access to and outcomes in online courses as well as traditional classroom settings that rely on internet access for out-of-class work. Better understanding the connection between racist federal housing policies and access to an increasingly necessary educational resource is important not only for gaining a clearer understanding of the history of education in the United States but also for considering targets of and responsibility for remedies.

Data

We estimate broadband access across HOLC-graded neighborhoods using data from two sources: the Federal Communications Commission (FCC) and the American Community Survey (ACS).[3] Whereas the first measures access based on ISP-reported service offerings, the second uses counts of persons in households who have both a computer and in-home broadband access. Each of these measures can be linked to TIGER/Line shapefiles from the United States Census Bureau and then spatially joined with shapefiles of HOLC-graded neighborhood maps provided by the *Mapping Inequality* project (Nelson et al., 2020). We discuss both broadband access data sources and shapefiles in more detail below.

Federal Communications Commission

Our first measure of broadband access is whether an internet service provider (ISP) offers service within a census block group. ISP-reported data on broadband availability by technology type is collected for the FCC form 477 and released to the public twice a year (Federal Communications Commission, 2020). In addition to listing the census blocks in which they offer service, ISPs also provide information about which internet technologies they offer (e.g., cable, DSL, fiber to the home) and various metrics of those technologies such as maximum advertised upload and download speeds.

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[3] In this section of the paper as well as subsequent sections in which we discuss our methods and results, we describe neighborhood boundaries and grades as coming from the HOLC. While this description also aligns with how many others describe the redlining shapefiles we use (Nelson et al., 2020), we use HOLC as shorthand for the complex organizational structures we discuss in earlier sections of the paper that led to these designations and maps.

We use data on the 10 six-month periods from December 2014 to June 2019 in our analyses. We investigate access to the three most common fixed broadband technologies in this period: copper wire-based cable modem (DOCSIS 3.0 and DOCSIS 3.1), telephone line-based digital subscriber line (Asymmetric DSL, ADSL2/ADSL2+, and VDSL), and optical wire-based fiber to the home.[4] We aggregate block data up to the block group level so that we can merge it with TIGER/Line shapefiles. We consider a census block group served by one of these technologies if an ISP offering that technology is listed in the FCC form 477 data for that census block group. Service in an census block group, however, does not guarantee service to all households in the entire block group. The FCC form 477 requires that ISPs need only serve a single household to count as providing service in the geographic area.[5] Due to this limitation of FCC form 477 data, we also consider another measure of broadband access in our analyses.

American Community Survey

Our second measure of broadband access comes from the ACS 5-year summary files (U.S. Census Bureau, 2019). Whereas FCC-derived broadband access measures represent service availability, ACS reports the number of persons who have access to various computing and broadband technologies in their homes. For our study, we investigate the number of persons with in-home access to broadband, both overall and disaggregated by racial/ethnic group and income levels. Data from the ACS cover the years 2015 to 2019. We rely on the 5-year summary files rather than single year files because they provide household information at the census tract level, the lowest geographic level available for these data.[6]

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[4] We do not include satellite technologies in our analyses. Their unique nature means that ISPs who offer broadband via satellite connection can claim nearly universal coverage, which means there is little variation across the sample.

[5] From the FCC website https://www.fcc.gov/general/explanation-broadband-deployment-data:

> A provider that reports deployment of a particular technology and bandwidth in a particular census block may not necessarily offer that particular service everywhere in the census block. Accordingly, a list of providers deployed in a census block does not necessarily reflect the number of choices available to any particular household or business location in that block, and the number of such providers in the census block does not purport to measure competition.

[6] Census tracts represent one geographic level of aggregation higher than census block groups.

TIGER/Line shapefiles

Data elements in both FCC and ACS files are given a geographic identifier that uniquely identifies the element and can be associated with specific geographic areas. We link data elements from each data source to US Census Bureau TIGER/Line shapefiles (United States Census Bureau, n.d.), which provide boundaries for geospatial areas from the national level down to the census block level. We associate FCC and ACS broadband access measures to TIGER/Line shapefiles at the census block group and census tract levels, respectively, using the 2019 boundary files for both measures.

Mapping Inequality project

HOLC neighborhood boundary shapefiles come from the *Mapping Inequality* project (Nelson et al., 2020), a collaborative effort of researchers across four universities that created georeferenced digital scans of HOLC-era residential security zoning maps. Each observation in the publicly available shapefile data represents one HOLC neighborhood and includes, in addition to its spatial boundaries, its HOLC designation (e.g., A, B, C, or D) and short descriptions of the area. Overall, 8,868 neighborhoods in 196 cities across 38 states are represented in the data (see Figure 1). While represented communities are spread throughout the contiguous United States, most are located in the South, Great Lakes Midwest, and New England. In the next section, we describe how we translate broadband measures fit to modern spatial boundaries to HOLC-era neighborhoods.

Methodology

Assigning broadband measures to HOLC neighborhoods

The first step in our analysis requires assigning both measures of broadband access—ISP-reported service availability and ACS household responses—to each HOLC neighborhood. Because modern census boundaries do not perfectly align with HOLC neighborhoods, we approximate current access by (1) spatially joining census shapefiles to HOLC shapefiles, (2) computing weights based on proportions of overlapping areas, and (3) assigning broadband measures to HOLC neighborhoods using these weights to adjust within-neighborhood averages. Though the relative procedures to assign FCC and ACS broadband measures are similar, we describe the process for creating each analysis data set in turn below.

Assigning FCC broadband measures

After linking FCC broadband measures to their corresponding census block group boundaries, we perform a spatial join between the census block group and HOLC shapefiles, each of which have been projected using an area-preserving projection.[7] We use an area-preserving projection so that we are able to accurately measure the area of each HOLC neighborhood covered by each census block group. From these area overlaps, we compute weights, $w_i = \frac{area_{overlap}}{area_{HOLCneighborhood}}$, that we use when assigning each HOLC neighborhood its measure of ISP-reported service by technology.

As an example, say that a given HOLC neighborhood overlaps with three modern census blockgroups—BG1, BG2, and BG3—with the following proportions: BG1 = 50%, BG2 = 20%, and BG3 = 30%, meaning that 50% of the HOLC neighborhood is taken up by BG1, 20% by BG2, and 30% by BG3. Considering one broadband technology classification, Asymmetric DSL (ADSL), let us further say that while FCC form 477 records for December 2015 show at least one ISP that reports providing ADSL service in BG1 and BG2 each, no ISP reports offering that broadband service in BG3. Based on these overlaps and records, we would assign the HOLC neighborhood a value of 0.7 for ADSL access in December 2015 ($(1*0.5)+(1*0.2)+(0*0.3) = 0.7$), which we interpret to mean that during that period, 70% of persons in the neighborhood have access to ADSL technology according to ISP-reported offerings. We perform the same procedure for each broadband technology classification and period in the data. Figure 2 visualizes how HOLC neighborhoods are subdivided into their constituent census block groups for Evansville, IN, one city in our analytic sample.

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[7] We use Coordinate Reference System (CRS) 5070, the NAD83/Conus Albers projection, which works well with the contiguous 48 states. None of the HOLC communities in our sample are located in Alaska or Hawaii.

Assigning ACS broadband measures

To assign ACS measures of broadband access, which represent counts of persons in households with access to a computer and broadband in the home, we again perform spatial joins between census and HOLC shapefiles. While the process is broadly similar, there are a few differences from the procedure we used to assign FCC measures. First, ACS measures are aggregated one step higher at the census tract level which means that we use census tract shapefiles. Second, we compute the proportion of each census tract overlapped by a HOLC neighborhood (the opposite from before when we computed the proportion of the HOLC neighborhood overlapped by the census area). We use this fraction as weight to assign numbers of persons to the HOLC neighborhood.

Using another example, assume that a HOLC neighborhood overlaps two census tracts, T1 and T2, with a coverage of T1 = 60% and T2 = 50%, this time meaning that 60% of T1's and 50% of T2's area is covered by the HOLC neighborhood. From the ACS summary file, we see that 800 out of a total of 1000 persons in T1 have access to a computer and broadband in their home; the numbers are 500 of 600 persons in T2. Using the overlapping areas as weights, we assign 900 total persons with in-home computer access to the HOLC neighborhood, 730 of whom also have access to in-home broadband $((.6 * 800/1000) + (.5 * 500/600))$.[8] In addition to overall household counts, we perform this procedure for each racial/ethnic and income group for which ACS summary files provide data.

Inferential models and estimation

We estimate broadband access by HOLC neighborhood grade across our sample by fitting a series of Bayesian multilevel regression models that allow us to account for the nesting of HOLC neighborhoods in cities, states, and regions of the country (Gelman et al., 2014). We fit two sets of models: one for our FCC measures of ISP-reported technology availability and one for ACS

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[8] Across the sample, weighted assignments almost always result in partial persons. Because integer counts are necessary for our inferential models, we round these fractions up the nearest person (e.g, 802.1 / 1000.7 becomes 803 / 1001 persons). To reduce the degree of error, we only round at the end of all within neighborhood summations, that is, after all contributing weighted census tracts have been summed: $(500.4 + 234.6 + 67.1)/(600.5 + 292.7 + 106.9) = (802.1/1000.1) => 803/1001$.

measures of in-home broadband access.

The first set of models using FCC data assume that the average proportion, y, of a HOLC neighborhood grade within a city with access to a broadband technology, i, follows a Beta distribution,

$$y_i \sim beta(a_i, b_i) \tag{1}$$

in which the shape parameters a_i and b_i are transformed into $a_i = \mu_i \times \phi_i$ and $b_i = (1 - \mu_i) \times \phi_i$, ϕ_i is a dispersion parameter, and μ_i takes the form

$$\mu_i = \text{logit}^{-1}(\beta_0 + \beta^{grade}_{j[i]} + \beta^{period}_{t[i]} + \alpha^{city}_{k[i]} + \alpha^{state}_{l[i]} + \alpha^{region}_{m[i]}) \tag{2}$$

where β_0 is the overall intercept, $\alpha^{city}_{k[i]}$, $\alpha^{state}_{l[i]}$, and $\alpha^{region}_{m[i]}$ are random intercepts to account for correlations within each geographic level in the data, $\beta^{period}_{t[i]}$ is a parameter for each time period in the data (every six months from December 2014 to June 2019), and $\beta^{grade}_{j[i]}$ represent the four HOLC neighborhood classifications.[9] Priors for each set of parameters are assumed to be jointly normally distributed with a mean of 0 and shared variance,

$$\begin{aligned}
\beta^{grade}_{j[i]} &\sim \mathcal{N}(0, \sigma^2_{grade}) && \text{for } j \in A, B, C, D \\
\beta^{period}_{t[i]} &\sim \mathcal{N}(0, \sigma^2_{period}) && \text{for } t \in 1, ..., 10 \\
\alpha^{city}_{k[i]} &\sim \mathcal{N}(0, \sigma^2_{city}) && \text{for } k \in 1, ..., 196 \\
\alpha^{state}_{l[i]} &\sim \mathcal{N}(0, \sigma^2_{state}) && \text{for } l \in 1, ..., 38 \\
\alpha^{region}_{m[i]} &\sim \mathcal{N}(0, \sigma^2_{region}) && \text{for } m \in 1, 2, 3, 4
\end{aligned} \tag{3}$$

with each σ^2 given a $\mathcal{N}_+(0,1)$ prior. While not completely uninformative, these priors are sufficiently weak such that our estimates of broadband access across HOLC neighborhood grades are largely driven by what is observed in the data.

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[9] FCC measures in a few neighborhoods in some periods are 0 (meaning no provision) and 1 (meaning 100% provision). Because the beta distribution's support, $x \in (0,1)$, does not include exact values of 0 or 1, we use the common transform, $(y * (n-1) + .5)/n$, where y is the proportion of interest and n is the sample size, to pull 0s and 1s slightly within the bounds of support.

For the second set of models using ACS measures, we model the number of persons with in-home broadband access using a binomial distribution,

$$n_i \sim binomial(N_i, \theta_i) \tag{4}$$

where n_i is the number of persons in HOLC neighborhood i with in-home broadband access, N_i is the total number of persons, and θ_i is the probability of access.[10] We estimate θ_i in logistic multilevel regression,

$$\theta_i = \text{logit}^{-1}(\beta_0 + \beta^{grade}_{j[i]} + \alpha^{city}_{k[i]} + \alpha^{state}_{l[i]} + \alpha^{region}_{m[i]}) \tag{5}$$

The parameters in this model are given the same priors as the Beta model. Because the ACS data jointly cover the period from 2014 to 2018, there is not a parameter for time in these models.

We fit a total of 21 models using the cmdstanr R package interface to the Stan language (Gabry & Češnovar, 2021; R Core Team, 2021; Stan Development Team, 2021). Six models estimate ISP-reported service by technology: asymmetric DSL, asymmetric DSL 2/2+, very high bitrate DSL (VDSL), cable modem DOCSIS 3.0, cable modem DOCSIS 3.1, and optical/fiber to the home. The remaining 15 models estimate the proportions of persons in households with in-home access to broadband overall, by eight categories of race/ethnicity defined by the ACS: American Indian / Alaska Native, Asian, Black, Hispanic, multiple races, Native Hawaiian / Pacific Islander, other race, and non-Hispanic white; and six intervals of yearly household income: <\$10k, [\$10k, \$20k), [\$20k, \$35k), [\$35k, \$50k), [\$50k, \$75k), and \$75k+. To speed computation, we aggregate all measures to the HOLC grade within each city—for FCC measures, this means averaging coverage; for ACS measures, summing counts. In the next section we report results for μ_i and θ_i as predicted percentages of broadband access across HOLC neighborhood grades.

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[10] For overall estimates and those separated by racial/ethnic subgroup, N_i is the total number of persons with in-home access to a computer. Due to differences in the way the census data are reported, N_i represents the total number of persons in the income band for estimates disaggregated by income.

Results

FCC measures of broadband access

Results from the first set of models using FCC-derived measures of broadband access by technology type are presented in Figure 3. Each facet shows changes in the predicted percentage of the population with access to a specific broadband technology from December 2014 to June 2019. The predicted percentages were computed for each HOLC neighborhood grade in each period from the joint posterior distribution of regression parameters, holding the random parameters for each city, state, and region at their respective means. The dark central lines represent the posterior median percentage for each HOLC neighborhood grade and the shaded areas the 95% credible intervals (2.5% and 97.5% percentiles).

Two patterns emerge across the facets of Figure 3. First, ISP-reported service offers of most broadband technology types increased during the 4.5 years of the sample. Increases range from a little less than 10 percentage points (p.p.) for asymmetric DSL to 35 p.p. for ADSL2/ADSL2+ and optical/fiber to the home. The middle facets show the replacement of older DOCSIS 3.0 cable modem technology with DOCSIS 3.1 technology, which was not widely available until 2016 but quickly rose to be offered to nearly 80% of the sample population. Even so, just over 30% of areas in the sample continued to have access to DOCSIS 3.0 as of June 2019. VDSL access appears to have dropped from December 2014 to December 2015, but mostly recovers by the end of the period.

The second pattern that emerges is that there is very little difference in ISP-reported service by technology type across HOLC neighborhood grades during this window. For five of the six broadband technologies, the posterior distributions for each HOLC neighborhood grade almost entirely overlaps the others. Though having the greatest difference across neighborhoods, VDSL, which comparatively fewer ISPs offered during the time period, still shows significant overlap between adjacent neighborhood grades. Overall, results using FCC form 477 data suggest that broadband access as measured by ISP-reported service shows little difference by HOLC neighborhood category across a range of technology types.

ACS measures of broadband access

Contrary to ISP-reported service offers, however, we find that reports of in-home broadband access from the ACS differ across HOLC neighborhood grades. Among the individuals counted by the ACS and used in our analyses, 12.9% lived in “A” graded neighborhoods, 28.2% in “B,” 37.7% in “C,” and 21.1% in “D.” Figure 4 shows the posterior distributions of the overall percentage of persons with in-home computer and broadband access by HOLC neighborhood grade. The median value of in-home access rises from 87.47% [95% CI: 86.71, 88.18] of those living in the lowest “D” grade neighborhoods, to 88.69% [87.99, 89.34] , 91.04% [90.47, 91.57], and 93.20% [92.75, 93.61] in “C,” “B,” and “A” graded neighborhoods, respectively. On average, moving to the next higher HOLC neighborhood grade represents a 1.2–2.3 percentage point increase in the probability of in-home broadband access. The difference moving from the lowest “D” to the highest “A” graded neighborhood is a 5.7 p.p. increase in access.

Next, we examine differences in in-home access among subpopulations. We again start with a discussion of how persons in our analytic sample are distributed across HOLC neighborhood grades. The top facet of Figure 5 shows the percentage of persons within each racial/ethnic group who live in each HOLC neighborhood grade.[11] For context, the number in parentheses under each label shows the percentage of the full analytic sample represented by persons in the group. Non-Hispanic white persons are the largest group in our sample, comprising 50.15% of our sample. Black and Hispanic persons represent the next largest groups, making up 17.41% and 16.73% of the sample, respectively. Asian persons (6.07%) and those whom the census categorizes as “other” race (5.40%) or multiple races (3.74%) comprise most of the rest of the analytic sample. We include in our analyses persons who identify as American Indian / Alaska Native (0.41%) and native Hawaiian / Pacific Islander (0.10%), but note that persons in these two groups combined represent less than one percent of our sample.

Across all racial/ethnic groups in our sample, most persons (36 to 45%) live within

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[11] See Table A.1 in the appendix for the counts of those assigned to each HOLC neighborhood by race/ethnicity and income category.

neighborhoods that HOLC graded as “C,” while the fewest (5 to 16%) live in “A” neighborhoods. These broad similarities notwithstanding, we find variation across racial/ethnic groups in their respective distributions across HOLC neighborhoods. While approximately 47% of non-Hispanic white persons live in “A” or “B” HOLC neighborhoods, only 27 to 31% of persons who identify as Black, Hispanic, Native Hawaiian / Pacific Islander, or as another race live in one of these top two graded neighborhoods. On the other side of the HOLC scale, 18% of non-Hispanic white persons live in “D” neighborhoods compared to 20 to 28% of all other racial/ethnic groups.

The second facet of Figure 5 shows broadly similar living patterns by household income levels. Across all income levels, most persons live in “C” neighborhoods (35 to 41%) while the fewest live in “A” neighborhoods (8 to 17%). As household income level increases, however, persons are more likely to live in “A” or “B” neighborhoods (from 31 to 48%) and less likely to live in those designated with a “D” grade (from 29 to 18%). Persons in households making $75,000 or more a year (40.26%) comprise the largest income group in our sample whereas those making less than $10,000 a year are the smallest (8.09%). The remaining four income groups each comprise between 10 and 16% of our sample. Though limitations of the ACS summary data files prevent our ability to compute the cross-tabulations of race/ethnicity and income, we can say that our sample is mostly comprised of non-Hispanic white persons with significant numbers of Black and Hispanic persons and that among all those in our sample, approximately one in ten live in households with yearly incomes below $10,000, five of ten between $10,000 and $75,000 a year, and four out of ten above $75,000.[12]

Results from our second set of models that use ACS data to estimate in-home computer and broadband access across HOLC neighborhood grades by race/ethnicity are shown in Figure 6.[13] Each line offers the full posterior distribution for the subgroup, with the center dot representing the median posterior value and the thick and thin horizontal lines showing the 50% and 95% posterior credible intervals, respectively. Green, blue, yellow, and red lines represent separate

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[12] Appendix Figure A.1, which presents distributions as counts rather than percentages, makes these sample size differences across groups more apparent.

[13] Tables A.2, A.3 in the appendix present the same estimates used in Figures 6, 7 in tabular form.

percentages of access for each HOLC neighborhood grade. While over 80% of all people have a broadband connection in their home, we find variation in access both across race/ethnicity and HOLC neighborhood grades.[14] For all but the smallest groups (American Indian / Alaska Native and Native Hawaiian / Pacific Islander), access increases as the HOLC neighborhood grade improves. These increases are similar to those seen in the overall models, with differences in median values typically ranging from 1 to 2 p.p. at each step or about 4 to 5 p.p. moving from the lowest "D" grade neighborhoods to the highest "A" grade neighborhoods. As exceptions to the pattern, American Indian / Alaska Natives show about the same degree of access in both "A" and "B" neighborhoods (94%), with decreasing access moving into "C" and "D" neighborhoods. Native Hawaiian / Pacific Islanders also break the pattern in that those who live in "B" neighborhoods have lower access (98%) than those who live in "C" neighborhoods (99%). The sample sizes for these latter groups, however, are sufficiently small that their estimates should be interpreted with caution, a point which we will return to later in the discussion of our results.

In addition to differences within racial/ethnic subgroups, we find further heterogeneity in access between subpopulations. Among the larger subpopulations, Asian persons have both the highest broadband access overall, with median values that range from approximately 95 to 97%, as well as the least difference between persons living in neighborhoods with different HOLC grades. At somewhat lower values, non-Hispanic white persons (92 to 96%) and those who identify with multiple races (93 to 95%) have roughly similar access. Those identified as "other" race (90 to 94%), Hispanic persons (88 to 93%), and Black persons (87 to 90%) have the lowest estimated likelihood of access across neighborhoods. Across all racial/ethnic groups, Native Hawaiian / Pacific Islander persons have the greatest access, hovering around 99%. These high rates may be due in part to the fact that, in addition to their small numbers in the data set, persons in our sample identifying as Native Hawaiian / Pacific Islander are found mostly in large, West Coast cities which tend to have better broadband access than other Midwestern and Southern communities in the sample.

Finally, we find further evidence of differential broadband access when comparing results

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[14] Throughout this section, we report median values (θ_{50}) for concision.

within the same HOLC neighborhood grade across racial/ethnic groups. Focusing on the largest three racial/ethnic groups in our sample—non-Hispanic white, Black, and Hispanic—Figure 6 shows that while approximately 96% of non-Hispanic white persons living in "A" graded neighborhoods have in-home computer and broadband access, only 93% of Hispanic persons and 90% of Black persons do. At the other end of the HOLC grading scale, 93% of non-Hispanic white persons living in "D" neighborhoods have access while only 88% of Hispanic and 87% of Black persons do. Taking into account the full posterior distributions, while approximately 90% of Hispanic persons living in "A" neighborhoods are estimated to have equal or better in-home broadband access than non-Hispanic white persons living in "D" neighborhoods, we estimate that nearly all Black persons living in "A" neighborhoods are less likely to have in-home broadband access than non-Hispanic white persons living in the "D" neighborhoods.[15] Our results in Figure 6 show similar patterns in comparisons across other groups.

Figure 7 presents estimates for in-home broadband access disaggregated by income level. We find that differences in access by income level are more consistent in pattern within income band—access generally increases in tandem with HOLC grade—and more extreme between bands. Within each income band, we estimate greater access as a person moves up in HOLC neighborhood grade though average differences between grades decrease as incomes increase. At the bottom end of the income distribution, those households making less than $20,000 a year (representing two income bands) have access that ranges from just over 50% in "D" neighborhood grades to between 64 and 67% in "A" neighborhoods. Within the top income band—those making over $75,000 per year—the range between "A" and "D" grades is less than 4 p.p. and overall access is much higher at 92 to 95%. Compared to differences between racial/ethnic subpopulations, we find greater separation between income levels. Except for the overlapping distributions between the bottom two income groups, those living in "D" neighborhoods are more likely to have broadband access than those in the income band just below who live in "A" neighborhoods. Above the $20,000 mark, moving from an "A" neighborhood in one income band to a "D" neighborhood in the next income

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[15] We calculate these percentages as $Pr(\theta_{NHW_D} - \theta_{(H|B)_A} > 0)$, which is otherwise expressed as $\frac{1}{N}\sum_i^N \mathbb{1}(\theta_i^{NHW_D} - \theta_i^{(H|B)_A} > 0)$, where N is the number of posterior draws.

band is associated with a 3 to 5 p.p. increase in the likelihood of in-home broadband access. We contextualize these and other results in the next section.

Discussion

Using FCC and ACS data, our results offer differing accounts of broadband access in urban and suburban communities that were formerly divided by HOLC into neighborhoods of varying desirability. Fitting models using FCC data we find almost no difference in ISP-reported service availability across HOLC neighborhood grades and a number of common broadband technologies over time. Conversely, our estimates using ACS data show disparities in-home broadband access across HOLC neighborhood grades. Furthermore, we find heterogeneity in access between racial/ethnic groups and various household income levels, both within and across HOLC neighborhood grades. We conclude that despite equitable *potential* access to broadband among former HOLC communities in terms of ISP service, *real* access to broadband differs at the intersection of neighborhood with race/ethnicity and income level. While some racial/ethnic groups and those with higher household incomes have greater broadband access overall, we find that otherwise demographically similar persons with the same ISP options may nevertheless have different likelihoods of in-home broadband access due to neighborhood characteristics that are correlated with New Deal-era housing policy.

One limitation of our study is that we are not able to provide estimates for intersections of race/ethnicity and income within HOLC neighborhood grade. Though our analytic framework would support it, we are limited by the structure of ACS data in which there is a trade-off between geographic specificity and the level of detail available about individuals in the data. Because we must use spatial joins to place modern census estimates within historical HOLC neighborhood boundaries, we use the smallest available geographic areas to reduce potential error. At the census tract level, however, estimates of in-home broadband access are provided only along univariate (e.g., race/ethnicity) dimensions. We are also limited by the broad racial/ethnic categories provided by ACS. Though such aggregations are likely tied to concerns of confidentiality, we would prefer not to use categories such as "multiple races" and "other race" as these categories both *other* (literally in the case of the latter group) and are sufficiently imprecise as to cover likely heterogeneity across the racial/ethnic groups included in these categories. We also note similar imprecision of racial and ethnic terms generally, for example the term *Hispanic*, an ethnicity that ACS lists as a racial category and one that may not accurately reflect broader Latinx identities.

From a methodological standpoint, a second limitation of our study lies in how we assign persons to HOLC neighborhoods. We assume an equal distribution of persons in the neighborhood. When a HOLC neighborhood intersects with, for example, 50% of a census tract, we assume 50% of persons in the tract live within the HOLC neighborhood boundaries. We make this assumption for overall counts and each racial/ethnic group and income level. As an extension, we also assume that in-home broadband access is similarly equally distributed within census tracts, meaning that if half of persons within a census tract have broadband in their home, we assume that half the portion assigned to a HOLC neighborhood has access. This is an assumption that we cannot test with the data we have. However, if persons with broadband access are missorted, we expect that our sorting procedure has assumed higher rates of access in lower grade HOLC neighborhoods and lower rates in higher grade HOLC neighborhoods. In this case, any bias in our estimates due to missorting is likely to produce more conservative (smaller) estimates of differences in in-home broadband access between HOLC neighborhoods.

Prior research has shown that access to broadband (and telecommunications infrastructure more generally) differ by location (Copps, 2009; Grubesic, 2006; West & Karsten, 2016) and by race/ethnicity and income level (Irving et al., 1999). We add to this literature by providing evidence that more strongly connects differences in access to much earlier public policies that officially ended long before the advent of broadband technologies. More specifically, our paper fits within a larger body of literature that demonstrates the residual negative effects that redlining housing policies have had on a wide range of social and health outcomes (Aaronson et al., 2020; Beck et al., 2020; Lukes & Cleveland, 2021; Mitchell & Franco, 2016; Nardone, Casey, Rudolph, et al., 2020; Zhang & Ghosh, 2016).

As education scholars, we are particularly concerned with how differences in broadband access may affect students' geographies of opportunity (de Souza Briggs, 2005; Green et al., 2017; Tate IV, 2008). As our results show, even persons from the same racial, ethnic, or income group had different likelihoods of broadband access in connection with the historical rating of their neighborhood. Discussions of the digital divide are often presented within an urban versus rural dichotomy (Copps, 2009; LaRose et al., 2007; Pereira, 2016; West & Karsten, 2016), in which rural students are left without the same levels of broadband access as those who live in more urban areas. While this disparity rightly deserves the attention of policymakers, our results demonstrate the importance of considering similar digital divides within proximate urban and suburban neighborhoods. In his review of the literature on gentrification and academic achievement, Pearman (2019) notes that while some studies find evidence that "gentrifying families are better equipped to place pressure on neighborhood institutions to improve their services" (p. 145), it is not always the case that the benefits of these improvements are felt equally among all students in the area. The differences in access that we find between racial/ethnic groups and different income levels within the same HOLC neighborhood grades suggest that greater ISP provision of broadband technologies is one such example. A recent report on differential access to newer broadband technologies across neighborhoods in Cleveland, OH, provides further evidence that market-based approaches used by ISPs are unlikely to support all equally (Alliance, 2017). Administrators and policymakers, therefore, must not conflate broadband infrastructure with broadband access: students living a block away from their school or university may be as disconnected from broadband as their more distant rural peers, thus experiencing an equally poor geography of opportunity.

We are also interested in the connection between broadband access and prior public policy because it suggests who might bear responsibility for ameliorating current inequities. Rothstein (2017) argues that because the federal government, through the policies and practices of the FHLBB, the HOLC, and the FHA, had a direct hand in housing segregation, residential segregation effectively moved from a *de facto* to *de jure* condition. As a result, the federal government bears responsibility for providing remedies for the negative outcomes associated with residential segregation. We find this argument compelling. In terms of making broadband access more equitable for students of all ages, one such remedy might be a more robust, place-based, and permanent version of the FCC's COVID-19 Emergency Broadband Benefit, which provides monthly subsidies for broadband service to those unable to afford market rates.[16] Whatever the particular remedy, however, our study provides evidence that disparities in broadband access are not merely the result of consumer preferences, but can be linked to racist policies of the past, the effects of which persist to this day.

Conclusion

When schools at all levels quickly shifted to remote learning in the spring of 2020, districts and higher education institutions across the country saw a clearer picture of how many of their students—even those living in urban and suburban neighborhoods—lacked sufficient access to broadband. In this paper we provide evidence that links these infrastructural disparities with New Deal-era housing policies that purposefully segregated communities throughout the country. Despite seeming parity in ISP-reported provision of broadband, we find much heterogeneity in in-home broadband access, overall, by race/ethnicity and income level, and within and across different neighborhood grades. While access to the internet through a quality broadband connection is increasingly important for accessing many public services (Dharma et al., 2010), its importance for education specifically cannot be understated. Future research with less aggregated data should further explore the intersections of place, race, and income—geographies of opportunity—as they relate to broadband access in order to craft better and more targeted policies to support educational success. In the meantime, policies to support access to quality broadband among students should expand and focus not only on rural/urban digital divides but also those within urban and suburban neighborhoods unfairly marked by prior federal policies.

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[16] https://www.fcc.gov/broadbandbenefit

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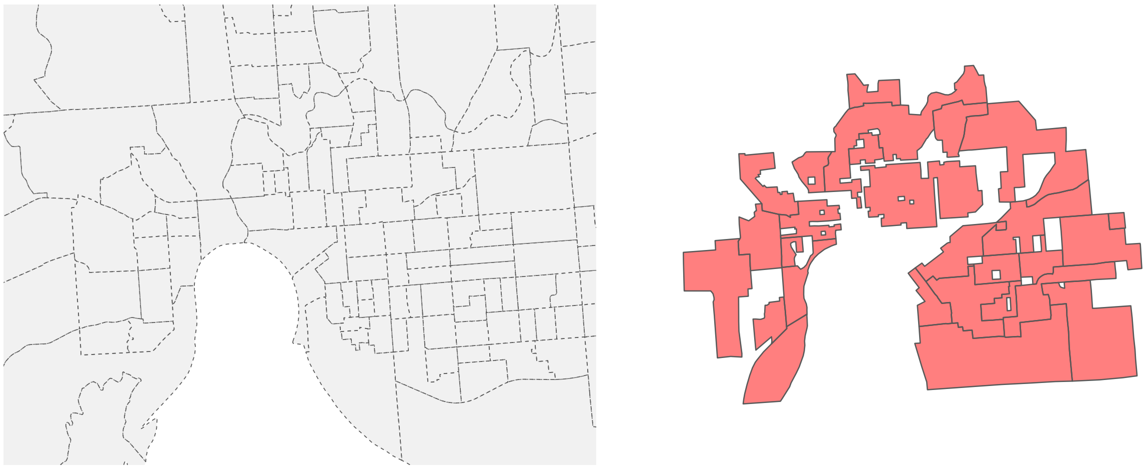
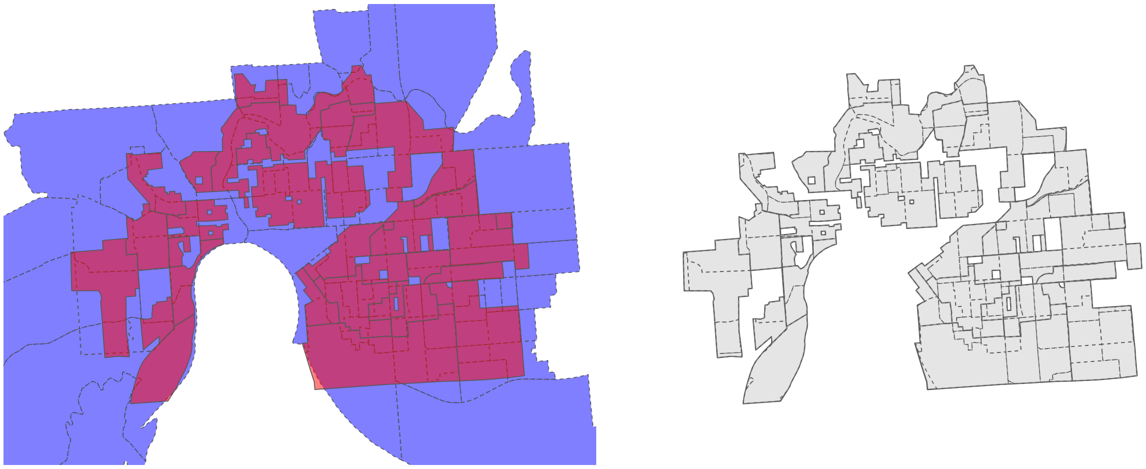
Figure 1: Location of communities in the sample. Each dot represents a community with HOLC-era residential security or redlining maps that have been georeferenced by the *Mapping Inequality* project. Represented communities are spread throughout the contiguous United States, though most are located in the South, Great Lakes Midwest, or New England.


(A) Census block groups

(B) HOLC neighborhoods


(C) Overlap of census block groups and HOLC areas

(D) Census block group portions inside HOLC neighborhoods

Figure 2: Overlapping census block groups and HOLC neighborhoods for Evansville, Indiana. To assign FCC form 477-based broadband access measures to HOLC neighborhood grades, we start with (A) census block group and (B) HOLC neighborhood spatial data files, all of which are projected using area-preserving projections. Because these spatial units do not perfectly align—with HOLC neighborhoods crossing census block group boundaries (C)—we perform an intersecting spatial join (D) and compute HOLC neighborhood broadband access averages that are weighted by the relative proportions of the intersecting block groups. We perform a similar procedure using census tracts and ACS data to estimate the number of persons across demographic groups in each HOLC grade with computer and broadband access.

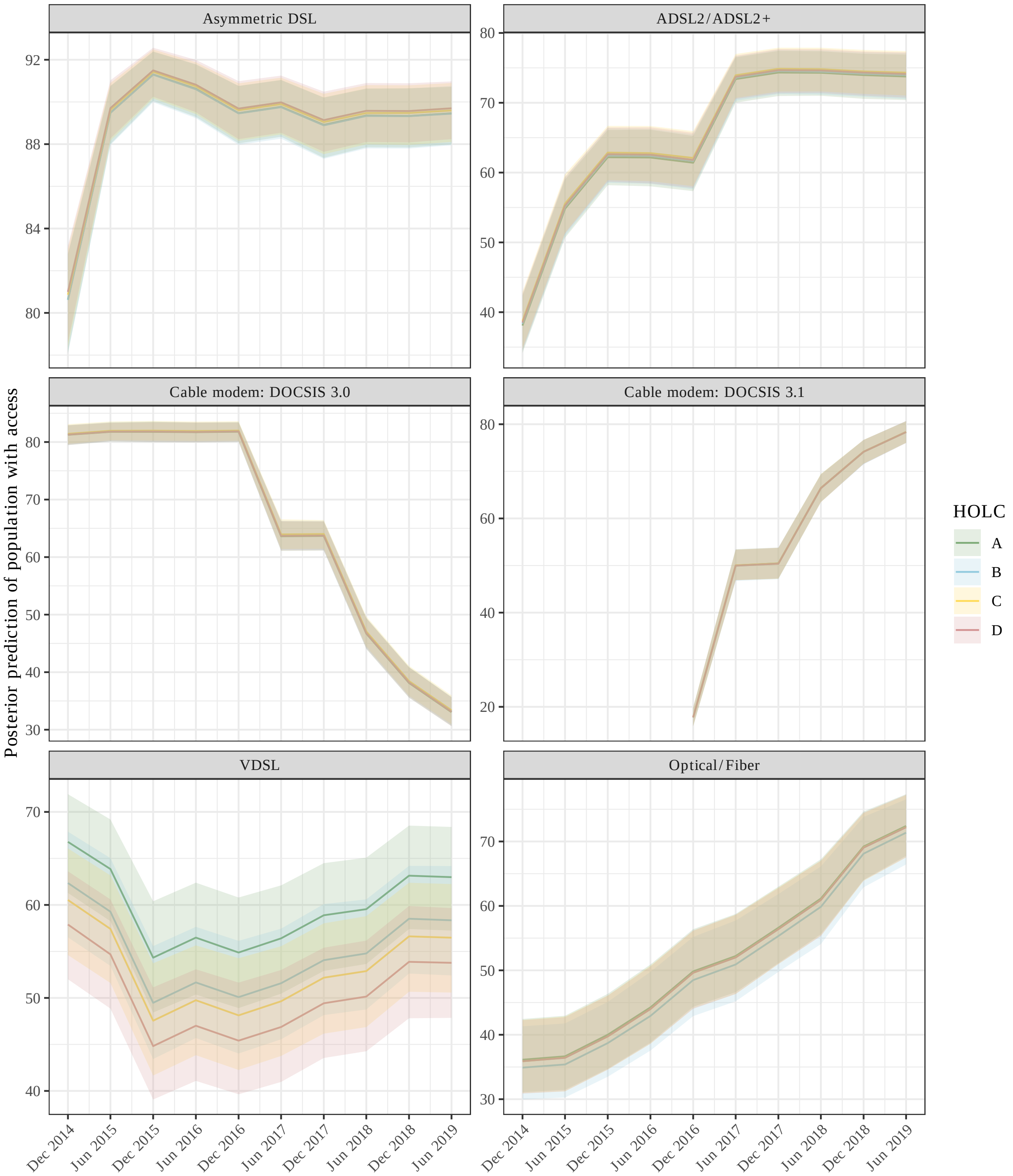


Figure 3: Estimated changes in the percentages of those with broadband access by technology from December 2014 to June 2019 as defined by ISP service availability. Percentages are computed for each HOLC neighborhood classification using the posterior parameters estimated from Equation 1 (holding city, state, and region values at their respective means across levels), with center lines representing the median posterior value and 95% credible intervals shown with the shaded area.

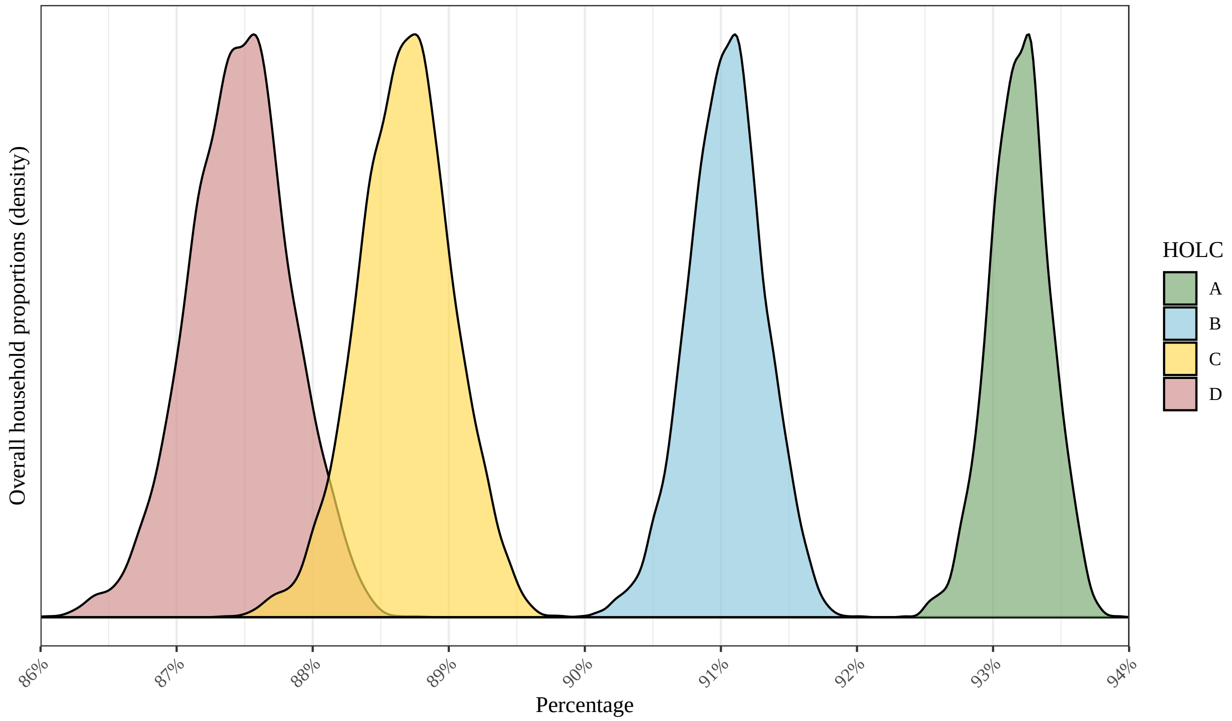


Figure 4: Distribution of estimated percentages of persons with access to a computer and broadband in their household in the period from 2015–2019. Percentages are computed for each HOLC neighborhood classification using the posterior parameters estimated from equation 4 (holding city, state, and region at their respective means across levels)

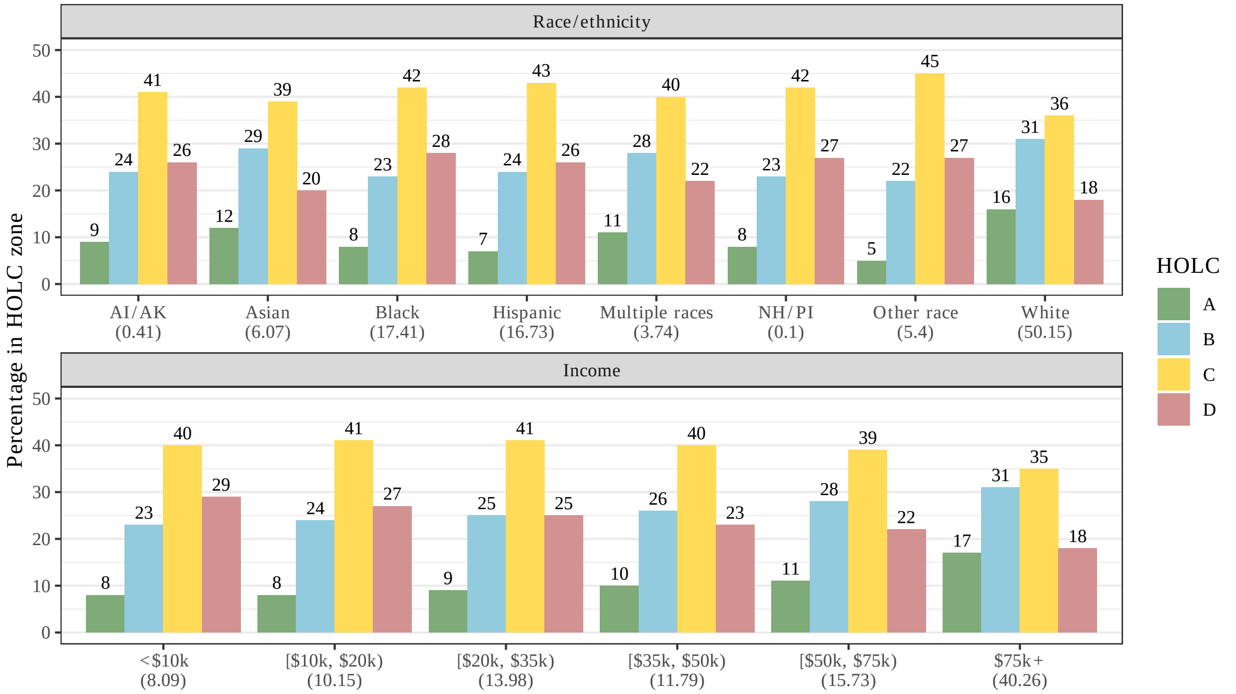


Figure 5: Distribution of persons from ACS data across HOLC neighborhoods by group. Each bar and accompanying value represents the within-group percentage of persons in the sample who live within a HOLC neighborhood grade classification. The percentage that the group represents of the total is in parentheses below the group name. *AI/AK*: American Indian / Alaska Native; *NH/PI*: Native Hawaiian / Pacific Islander.

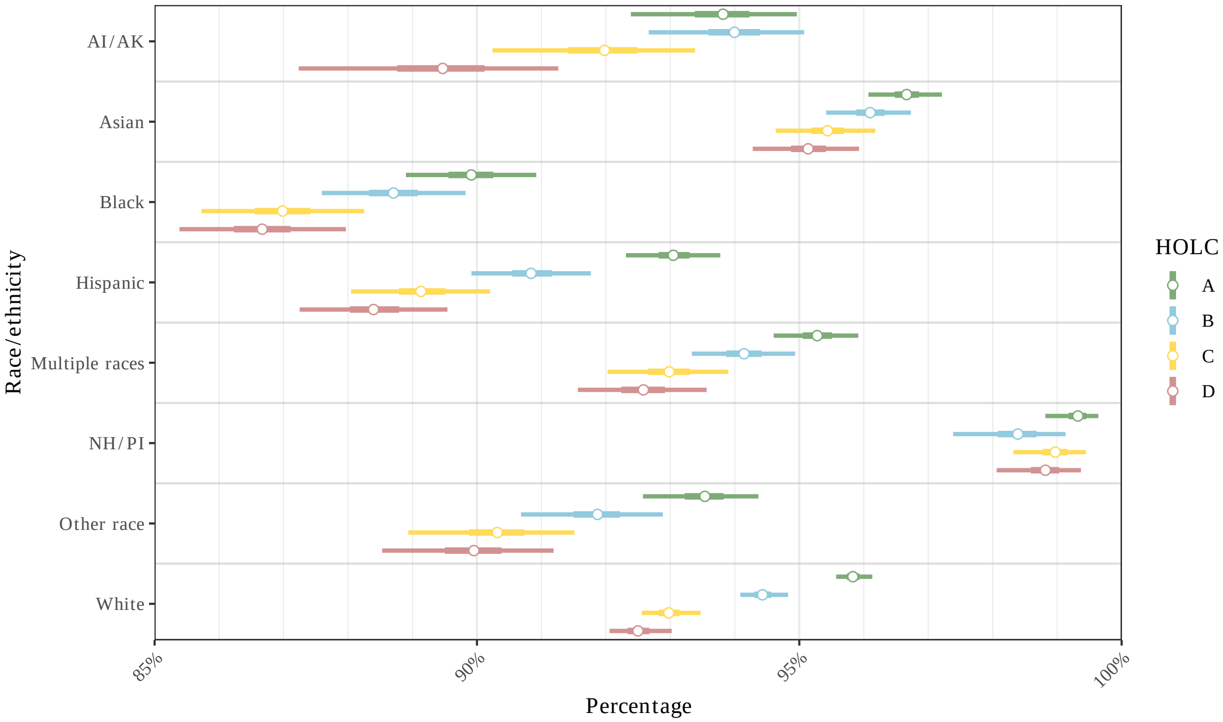


Figure 6: Estimated percentages of persons by race/ethnicity with access to a computer and broadband in their household in the period from 2015–2019. Percentages are computed for each HOLC neighborhood classification using the posterior parameters estimated from equation 4 (holding city, state, and region at their respective means across levels), with center lines representing the median posterior value and 95% credible intervals shown with the shaded area. *AI/AK*: American Indian / Alaskan Native; *NH/PI*: Native Hawaiian / Pacific Islander.

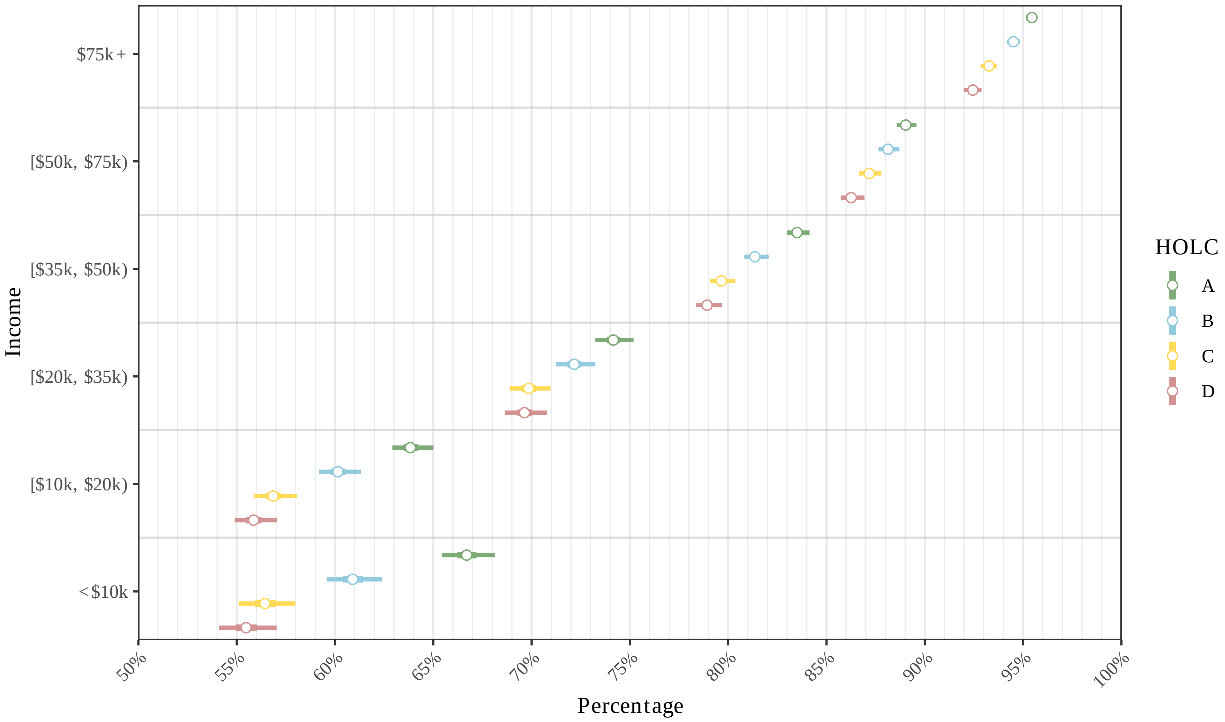


Figure 7: Estimated percentages of persons by income level with access to broadband in their household in the period from 2015–2019. Percentages are computed for each HOLC neighborhood classification using the posterior parameters estimated from equation 4 (holding city, state, and region at their respective means across levels), with center lines representing the median posterior value and 95% credible intervals shown with the shaded area.

Table A.1: Descriptive statistics of sample

	A		B		C		D	
	Broadband/Total	%	Broadband/Total	%	Broadband/Total	%	Broadband/Total	%
Overall	**1463378/1567072**	**93.38**	**3143251/3429831**	**91.64**	**4096158/4582225**	**89.39**	**2253930/2566697**	**87.81**
Race/ethnicity								
AI/AK	10848/12232	88.69	28877/32450	88.99	47712/55274	86.32	29884/35974	83.07
Asian	235002/244024	96.30	568894/594446	95.70	744889/786705	94.68	373722/397884	93.93
Black	383330/436547	87.81	1168999/1347720	86.74	2041963/2408063	84.80	1349124/1608944	83.85
Hispanic	356290/388981	91.60	1205169/1347955	89.41	2103214/2382061	88.29	1265178/1455255	86.94
Multiple races	129571/136201	95.13	322922/342956	94.16	462464/499394	92.61	245859/268049	91.72
NH/PI	2323/2447	94.93	6512/7403	87.96	11938/13344	89.46	7792/8577	90.85
Other race	85521/94279	90.71	357312/403064	88.65	713471/817459	87.28	419924/485863	86.43
White	2580977/2684572	96.14	4896193/5151823	95.04	5564258/5947954	93.55	2709495/2927634	92.55
Income								
<$10k	57940/88655	65.35	151790/251735	60.30	246997/442138	55.86	172351/319529	53.94
[$10k, $20k)	72027/113392	63.52	197177/328839	59.96	318989/562626	56.70	210030/377703	55.61
[$20k, $35k)	127984/174270	73.44	345021/481945	71.59	539672/775923	69.55	324834/471738	68.86
[$35k, $50k)	135911/164220	82.76	343108/425100	80.71	511727/645488	79.28	290283/371655	78.11
[$50k, $75k)	214298/242128	88.51	522033/595777	87.62	731827/843602	86.75	395109/461348	85.64
$75k+	867441/905589	95.79	1618232/1700016	95.19	1801081/1916643	93.97	895023/961754	93.06
Region								
Midwest	346		775		1308		808	
Northeast	281		702		935		542	
South	240		470		659		519	
West	173		385		479		246	
N	1040		2332		3381		2115	

Notes. Data for this table come from the ACS 2015-2019 summary files. Numbers in the top panel represent estimates of the number and percentage of persons in households with access to a computer and broadband by HOLC neighborhood zone. The bottom panel gives the counts of unique neighborhoods in the sample, within census region and overall. *AI/AK*: American Indian / Alaskan Native; *NH/PI*: Native Hawaiian / Pacific Islander.

Table A.2: Percentage of persons in households with access to a computer and broadband across HOLC neighborhood zones: by race/ethnicity

	AI/AK	Asian	Black	Hispanic	Multiple races	NH/PI	Other race	White
HOLC zone								
A	93.8	96.7	89.9	93	95.3	99.3	93.5	95.8
	[92.4, 95]	[96.1, 97.2]	[88.9, 90.9]	[92.3, 93.8]	[94.6, 95.9]	[98.8, 99.6]	[92.6, 94.4]	[95.6, 96.1]
B	94	96.1	88.7	90.8	94.1	98.4	91.9	94.4
	[92.7, 95.1]	[95.4, 96.7]	[87.6, 89.8]	[89.9, 91.8]	[93.3, 94.9]	[97.4, 99.1]	[90.7, 92.9]	[94.1, 94.8]
C	92	95.4	87	89.1	93	99	90.3	93
	[90.2, 93.4]	[94.6, 96.2]	[85.7, 88.3]	[88, 90.2]	[92, 93.9]	[98.3, 99.4]	[88.9, 91.5]	[92.6, 93.5]
D	89.5	95.1	86.7	88.4	92.6	98.8	90	92.5
	[87.2, 91.3]	[94.3, 95.9]	[85.4, 88]	[87.3, 89.5]	[91.6, 93.6]	[98.1, 99.4]	[88.5, 91.2]	[92.1, 93]

Notes. Each column presents results from a separate regression model. The median value of the full posterior distribution is presented, with 95% credible intervals in square brackets below. Percentage estimates were computed for each HOLC zone parameter ($\beta^{zone}_{A,B,C,D}$) using average parameter values across region, state, and city. *AI/AK*: American Indian / Alaskan Native; *NH/PI*: Native Hawaiian / Pacific Islander.

Table A.3: Percentage of persons in households with access to a computer and broadband across HOLC neighborhood zones: by income

	<$10k	[$10k, $20k)	[$20k, $35k)	[$35k, $50k)	[$50k, $75k)	$75k+
HOLC zone						
A	66.7	63.8	74.2	83.5	89	95.4
	[65.5, 68.1]	[62.9, 65]	[73.2, 75.2]	[83, 84.1]	[88.6, 89.6]	[95.2, 95.7]
B	60.9	60.1	72.2	81.4	88.1	94.5
	[59.6, 62.4]	[59.2, 61.3]	[71.2, 73.2]	[80.8, 82.1]	[87.6, 88.7]	[94.2, 94.8]
C	56.4	56.8	69.9	79.6	87.2	93.3
	[55.1, 58]	[55.9, 58.1]	[68.9, 71]	[79.1, 80.4]	[86.7, 87.8]	[92.8, 93.7]
D	55.5	55.9	69.6	78.9	86.3	92.4
	[54.1, 57]	[54.9, 57.1]	[68.7, 70.8]	[78.3, 79.7]	[85.7, 86.9]	[92, 92.9]

Notes. Each column presents results from a separate regression model. The median value of the full posterior distribution is presented, with 95% credible intervals in square brackets below. Percentage estimates were computed for each HOLC zone parameter ($\beta^{zone}_{A,B,C,D}$) using average parameter values across region, state, and city.

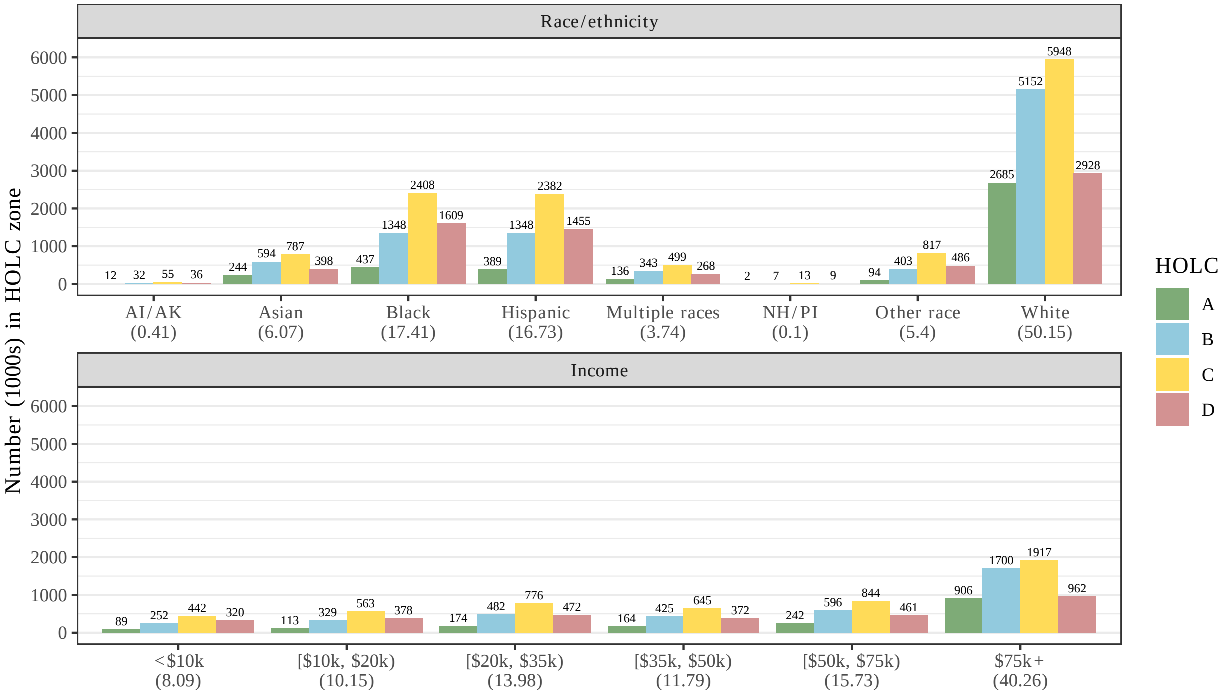


Figure A.1: Distribution of persons from ACS data across HOLC neighborhoods by group. Each bar and accompanying value represents the within-group count (in 1000s) of persons in the sample who live within a HOLC neighborhood grade classification. The percentage that the group represents of the total is in parentheses below the group name.