Internet Inequity in Chicago: Adoption, Affordability, and Availability

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Lack of access to high-quality Internet connectivity affects how people participate in all aspects of life, from education to work to recreation; disparities in Internet access thus carry over into many other aspects of life. Historically, the discussions on Internet inequity centers mainly around the rural vs. urban divide in the United States. The Covid-19 pandemic has also brought the prevalence of Internet inequity in urban areas to the broader collective attention. To further the study of this issue, this paper characterizes the state of Internet equity in Chicago, focusing on different dimensions of Internet equity, including availability, affordability, and adoption. To this end, we combine multiple existing datasets to understand the digital divide in Chicago and the contributing factors. Our findings show disparity in broadband adoption rates across neighborhoods in Chicago: Broadband adoption varies between 58–93% across community areas, with low access areas mostly concentrated in South and West Chicago. Furthermore, adoption rates are positively correlated with income and education level and negatively correlated with age. The former highlights the need to provide affordable Internet access, while the latter suggests introducing technology training programs, especially for the elderly. We also find disparity in broadband availability—with the number of ISP options in a census block significantly varying across the city, indicating infrastructure equity issues.

1 INTRODUCTION

Internet access has become critical to ensure equitable opportunity in workforce participation, education, health, and other domains, especially in the post-pandemic world. Historically, the question of Internet equity generally has focused on bridging the "digital divide" between urban and rural areas; that is, on bringing broadband service to the (mostly) rural areas that have none. For example, the recently approved Federal Broadband Equity, Access, and Deployment (BEAD) funding, which promises $42.5 billion to expand high-speed Internet access, with priority given to the connection of "unserved" areas, many of which are rural [23]. More attention, however, is also needed to understand and address Internet equity in areas that already meet the FCC standard of "served", because many residents of these mostly urban areas do not, in fact, have broadband connections at home. It has long been known that there exist many barriers to Internet adoption, from access to affordability [28]; thus, policy efforts to bridge the digital divide must also focus on areas that are technically "served" by Internet infrastructure, even in large urban centers.

Accurately identifying the urban digital divide and the contributing factors is an important first step towards mitigating it; doing so can subsequently inform the policy interventions that might reduce the divide. As cities around the United States are working towards understanding gaps in Internet equity, our city officials in Chicago asked us for input into how to quantify the digital divide in Chicago. Specifically, they asked us: *What is the Internet connectivity across different neighborhoods in Chicago and how does it relate to socio-economic factors as well as broadband availability?.*

Recent work has pointed towards the existence of a digital divide in urban areas, but an analysis that quantifies this at a neighborhood level is missing. Given that income, unemployment, institutional resources, and social capital are known to

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be unequally distributed at the neighborhood level—and the influence these characteristics have on both individual and collective outcomes—having an understanding of neighborhood-level inequity in Internet connectivity is paramount [30].

Towards this goal, our work seeks to understand the following questions: (1) What is the current state of Internet inequity in Chicago; specifically which geographies need the most attention and resources?; (2) How does Internet adoption relate to population characteristics including age, income, and education?; and (3) How does broadband availability relate to adoption rates? To answer these questions, we use two datasets in this paper: (1) the American Community Survey (ACS), a household-level survey containing spatially aggregated information about broadband adoption and key population characteristics (e.g., income, education, occupation), and (2) FCC Form 477 fixed broadband data, a semi-annually collected dataset that indicates availability of ISPs at a census block level. We combine these datasets to answer the above questions. We find the following:

- Broadband adoption rates vary greatly across neighborhoods in Chicago: adoption rates range from 58% to 93% depending on neighborhood.
- The neighborhoods with the lowest adoption rates are concentrated on the South and West Sides of the city, in majority-Black areas that reflect Chicago's historical patterns of racial residential segregation.
- Adoption rates also correlate with Hispanic population concentration, low income, low educational attainment, and a higher proportion of elderly population.
- Nearly all census blocks (90%) have at least one high-speed broadband ISP present. The number of ISP options available varies greatly by census block, and 50.6% of census blocks have only one high-speed broadband ISP available (as defined by >100/20 Mbps).

Our findings quantify the extent of home Internet inequity in Chicago, highlighting the neighborhoods that would benefit the most from attention towards increasing connectivity rates. While our analysis stops short of establishing causal relationships, the high correlation between income and adoption rate suggests the importance of affordable Internet access either through subsidy programs (such as the United States federal government's Affordable Connectivity Program [12] or the City of Chicago's Chicago Connected program for students in Chicago Public Schools [10]) or measures to support deployment of community networks. The correlation of adoption with age highlights the importance of digital literacy programs such as digital navigators, as well as efforts to innovate on inclusive technologies, including in regards to privacy protection. Finally, the spatial disparities in ISP availability, including the number of ISP options and newer access technologies such as fiber and DOCSIS 3.1, highlight potential inequities in Internet infrastructure.

2 BACKGROUND AND RELATED WORK

In this section, we provide a brief background on the datasets we used in our analysis; we then provide an overview of related work.

2.1 Datasets

2.1.1 Census American Community Survey (ACS). This dataset is a nation-wide demographic survey conducted by the U.S. Census Bureau. Every year, the Census samples approximately 3.5 million addresses (roughly 1% of the United States population) and gathers population characteristics such as employment, income, and household characteristics. In 2013, the Census also included two questions around broadband adoption inquiring about access to Internet and mode of access The data is made public and is used by governments, communities, and private entities for many purposes (e.g., allocating funds). The Census shares spatially aggregated information from the ACS samples. For analysis in a smaller region, the census recommends using five-year aggregates; for larger geographies, yearly aggregates suffice. This is because of the sampled survey and aggregation across years ensures there are enough responses within a smaller geography. In addition, the Census also shares individual responses through Public Use Microdata Samples (PUMS), which are anonymized to preserve privacy. The PUMS data is available at a larger spatial granularity called Public Use Microdata Areas (PUMAs). In this paper, we use the five-year aggregate data, unless otherwise specified.

Limitation: The data combines information from last five years to obtain estimates and is thus not always reflective of the most current circumstances. Other limitations include potential errors in the estimates due to sampling and errors in survey response.

2.1.2 FCC Form 477 Data. The Federal Communication Commission (FCC) mandates that Internet Service Providers (ISPs) provide information about areas where they provide service. ISPs need to file their offerings at a census-block level; an ISP can include a census block in its offerings if it can provide Internet service to at least one household in the census block. Along with each census block, the ISPs must also file information about the maximum advertised download and upload speeds in the census block, the access technology (e.g., cable, fiber-to-the-home), and whether the service plan is for consumers or business. This data is one of the key datasets used to decide whether an area is unserved. We use the latest form 477 data to understand broadband availability in Chicago.

Limitation: Form 477 data may overstate broadband availability because: (1) if an ISP only covers a single household in a census block, the entire block is considered covered; (2) "availability" means that the ISP does not necessarily service the area currently but could provide service within an interval that is typical for that type of connection [14]. From a practical perspective, such service delays may act as a barrier to broadband adoption.

2.2 Related Work

Previous research has investigated the presence and extent of digital divide/inequality amongst various communities within the U.S. In [27], the authors utilize the crowdsourced speed test measurements from Measurement Lab [17] in California to identify the location and demographic factors that impact download speed. Their results show speed test performance positively correlates with household income and urban areas. Paul et al. conduct statistical analysis on publicly available datasets from another popular speed test vendor [26] (Ookla [25]). The objective of this work was to identify states where digital inequality in terms of internet performance exists between urban/rural and low/high-income areas across all states in the U.S. Their results once again confirm the presence of digital divide in the majority of the states in the dimensions of location and household income. A similar performance trend between communities using the same dataset was also captured in several previous studies [3, 5].

Previous work developed a new tool to collect internet availability information at the street address granularity from the databases of the ISPs [21]. Analysis of the collected data reveals minority communities (e.g. areas with low income and high poverty) suffer from a lack of Internet availability compared to their counterparts. The authors in [18] study factors that can potentially impact the adoption of the internet in a region. Their study reveals a lack of availability/purchasing power of high-quality internet, different internet usage types amongst communities, and perception towards high-quality internet to be critical contributors towards a lack of adoption of the internet in an area. Other work found that that a major reason behind digital inequity in the urban regions stems from households opting against purchasing high-quality of internet even when it is available [2] . This finding is further reinforced in the survey conducted by Liu et al. [19], who found in a study across 978 U.S. households that the surveyed population expressed less willingness to invest in Internet speeds exceeding 100 Mbps. Another study conducted in Detroit, Michigan finds while lower-income communities want to purchase high-quality of Internet, the higher associated cost proves to be a major barrier and creates digital divide [29]. An analysis of the urban region of San Antonio, Texas reveals the cost of deployment of new technologies by ISPs and geographical disparities primarily contribute to the digital divide between urban communities [9] .

Combining zip code level demographic information with its own data, Microsoft [4], estimated that adoption of high-speed Internet was lacking for 162.8 million Americans, a number far greater than the FCC's estimate. Galperin et al. identify the low-income minority population as a group likely to be disenfranchised from having access to residential fiber services that provide better Internet performance [16].

3 ADOPTION

In this section, we analyze the broadband adoption rates as reported by the Census ACS data. We consider adoption rates at both the census tract and neighborhood levels.

3.1 Method

We use the latest five-year data spanning 2016–2020 from the ACS survey to obtain broadband adoption rates. The survey asks residents the following two questions regarding Internet access:

- *At this house, apartment, or mobile home – do you or any member of this household have access to the Internet?*. The response can be either *no* or *yes*. For households with access, the survey also differentiates whether the access is through a paid subscription or otherwise.
- If the answer to above question is yes with an Internet subscription available, the survey also asks about the mode of Internet access. *Do you or any member of this household have access to Internet using a:* The options include cellular, broadband, satellite, dial-up Internet service, or others.

We consider households who responded yes to having a broadband connection at the household. Note the ACS broadband definition is not the same as the FCC's definition which uses specific speed thresholds. Rather, ACS specifies broadband Internet as high speed Interent (without any speed limits) and provides few examples of access technology which include cable, fiber optic, and even DSL service. We define adoption rate as the percentage of total households that responded yes to having Internet access through a broadband subscription.

To calculate adoption rates, we use the data in Table *B28002* containing spatially aggregated responses to the above survey questions. We consider the finest spatial granularity, i.e., census tract. The table contains estimate of number of households with broadband access along with its 90% confidence interval denoted as margin of error (MOE). To compare adoption rates across geographies, we calculate the percentage of households with broadband access by dividing the estimate with the total estimated households in the census tract. We also obtain margin of error for the derived percentage as follows:

$$MOE(\hat{P}) = \frac{1}{\hat{Y}}\sqrt{[MOE(\hat{X})]^2 - (\hat{P} \times [MOE(\hat{Y})])^2} \tag{1}$$

Here, $\hat{X}$ and $\hat{Y}$ are the estimated households with broadband access and total households, respectively. $\hat{P}$ is estimated percentage of households with broadband access and is simply $\frac{\hat{X}}{\hat{Y}}$. $MOE(\hat{X})$, $MOE(\hat{Y})$, and $MOE(\hat{P})$ denote the respective margin of errors. In case the expression under the square root is negative, we sum the two expressions under the square root instead of subtracting them, as recommended by the Census [8]. This leads to a more conservative estimation of margin of error.

As Chicago has distinct community areas, we also repeat the analysis at community-area level. We first map each census tract to the respective community area. If a census tract overlaps with multiple community areas, we associate it

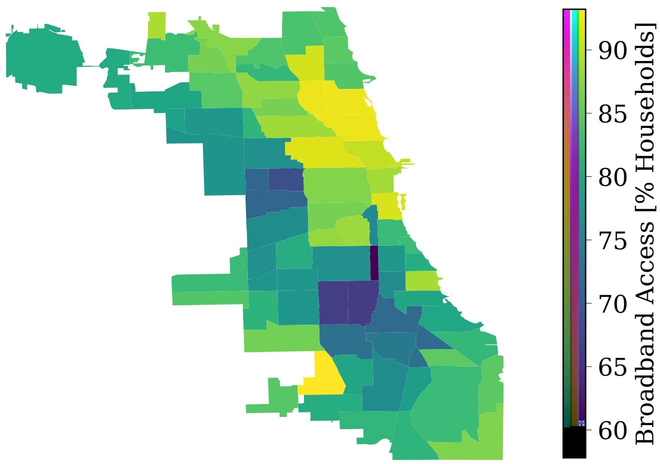


Fig. 1. *Internet Access across Community Areas in Chicago*

with the community with which it has the highest-area overlap. We then aggregate the census tract adoption rates within a community to obtain community-level adoption rates. We sum the tract-level estimates to obtain estimates of total households and households without Internet access. To obtain the margin of error, we use the ACS table containing the successive difference replication values [7]. This calculation provides a more accurate margin of error during aggregation.

3.2 Broadband adoption across community areas

We first explore the community-level broadband adoption rates. Figure 1 shows the fraction of households without Internet access across community areas in Chicago. We observe large disparities in Internet access across community areas. Communities with lowest adoption rates include Fuller Park (58%), Englewood (64%), West Englewood (64%), and East Garfield Park (67%). By comparison, the areas with the highest adoption rates, Beverly and Lake View report 93% and 92% of households with broadband access, respectively. Most of the areas with the lowest adoption rates are located in the South and West sides of Chicago, areas containing neighborhoods that are historically marginalized, consisting of immigrant and lower-income residents who settled away from the central business districts and wealthier, lakeside areas in the northern sections of Chicago [24].

We also analyze the margin of error in adoption rates across community areas as shown in Figure 2. The margin of error varies from 4.5% to 19.8% with a median of 8.1%. The margin of error is generally less than 10% of households for almost 90% of the community areas. We found the MOE to be high for three communities, i.e., West Elsdon, Pullman, and Jefferson Park. One reason is that the MOE approximation formula defined in Equation 1 could not be applied for these

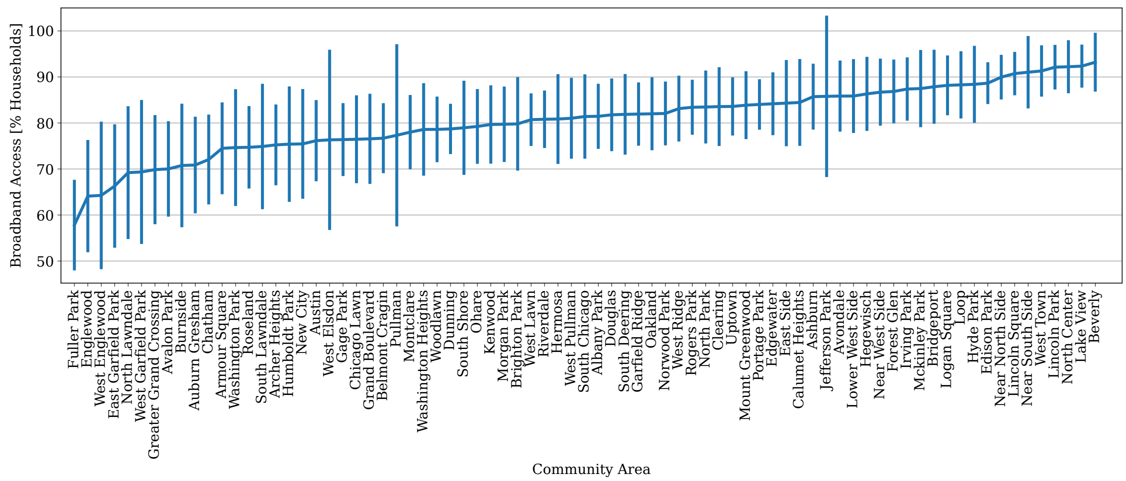


Fig. 2. *Adoption rates along with Margin of Error*

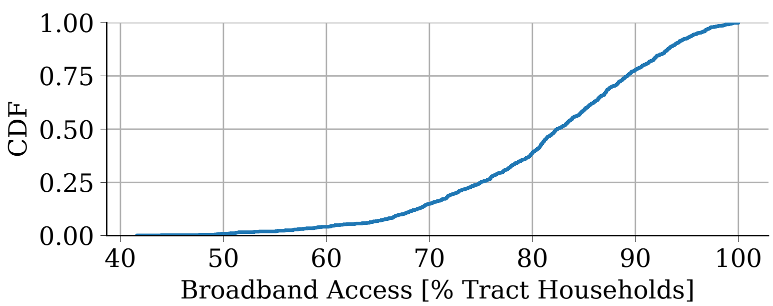


Fig. 3. *Households without Internet Access at tract level.*

neighborhoods as the expression under the square root was negative. We instead compute a more conservative MOE based on census recommendation which leads to higher MOE. Even considering the margin of errors, the adoption rates are significantly different between community with the highest and lowest adoption rates.

Takeaway: The ACS data provides evidence of stark Internet equity in Chicago. Although the underlying reasons of the divide can be different between urban and rural areas (e.g., affordability vs. connectivity), the data highlights that even urban areas require attention at the local, state, and federal levels—and efforts by communities and governments alike to bridge these gaps.

3.3 Broadband adoption at the census-tract level

Although community areas have a social meaning for both residents and local government administrators, there is merit to doing analysis at census-tract levels because census tracts are more fine-grained than community areas. Although a community may have a high adoption rate overall, there may be some smaller regions with lower adoption. Figure 3

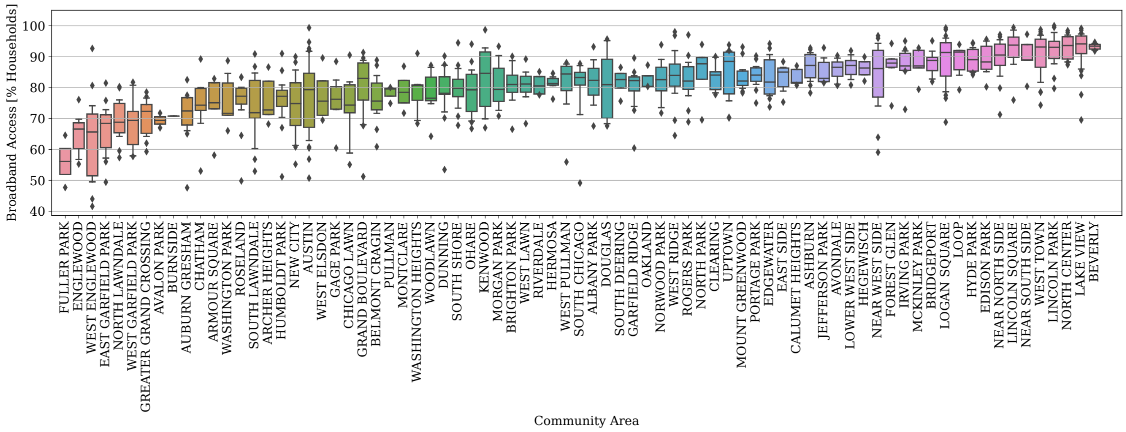


Fig. 4. *Distribution of adoption rates within community areas.*

	Hispanic	Black	White	Asian
Correlation with broadband adoption	-0.06	-0.49	0.58	0.26

Table 1. *Correlation of broadband adoption with Race/Ethnicity*

shows the cumulative distribution function (CDF) of the percentage of tract households with broadband access across tracts. The adoption rate varies from 42% to 100%; in the median tract, 82% of the households lack broadband access. The analysis shows clear a disparity in adoption rates across census tracts. Next, we consider whether tracts within a community show disparity in adoption rates at a census-tract level. We group tracts based on the community area and show a box plot of distribution of tract adoption rates. We find significant variance within communities. For example, the 10th and 90th percentile tract adoption rates in the *Near West Side* community are 75% and 95%, respectively. This finding indicates that targeted interventions may be required at sub-community area levels.

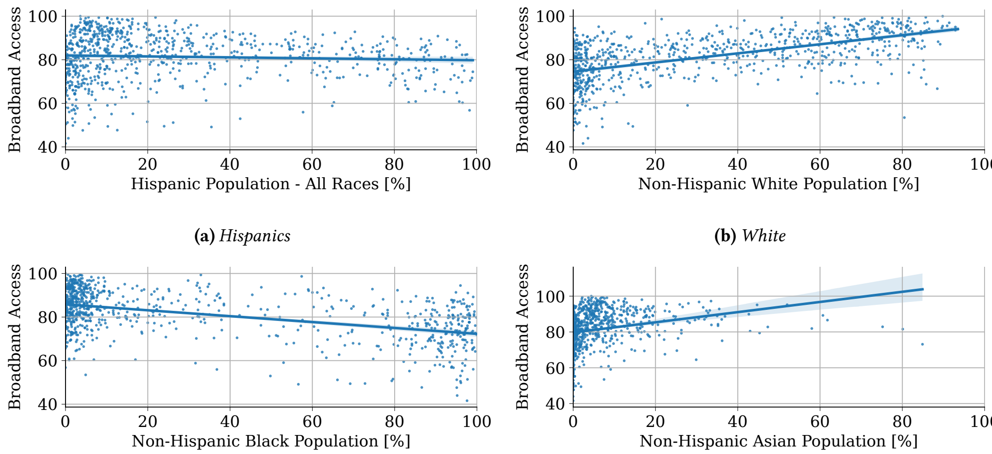
Takeaway: In addition to disparity at community-area level, there are disparities *within* some communities, indicating community areas are not homogeneous in terms of broadband adoption rates. Thus, more micro-level approaches (e.g., at block level) may be needed to address issues of low adoption within certain individual community areas.

4 CORRELATION WITH POPULATION CHARACTERISTICS

In this section, we study how various socioeconomic factors correlate with adoption rates. We first consider the relationship between adoption and race/ethnicity at the level of census tract. Next, we consider three major factors: income, education, and age. These three factors have been shown to correlate with Internet adoption in previous studies [13]. We examine whether these relationships also hold in Chicago.

4.1 Adoption Rates and Race/Ethnicity?

For this analysis, we use the Data Profile Tables from the ACS Census data. The Data Profile Tables or Data Profiles contain a variety of socio-economic and demographic information at a tract level. We select the following estimates at census tract level: (1). **Ethnicity**: percentage of Hispanics of all races (Table *DP*05_0071*PE*), (2) **Race:** percentage of



(a) *Hispanics*

(b) *White*

(c) *Blacks*

(d) *Asians*

Fig. 5. *Scatter plot of broadband adoption vs race/ethnicity constitution*

Non-Hispanic Blacks (Table $DP05\_0078PE$), Non-Hispanic Whites (Table $DP05\_0077PE$), and Non-Hispanic Asians (Table $DP05\_0080PE$), We do not include other races (e.g., Native Americans, Mixed race) as there is only a small proportion of people who fall into these categories in most tracts. We compute the Pearson correlation coefficient between the race/Hispanic ethnicity percentages and broadband adoption rates across census tracts (see Table 1). We find that the percentage of Black residents in a tract correlates negatively with broadband adoption rates, while the percentage of White and Asian residents has a positive (though weaker) correlation with adoption rates. The correlation between percent Hispanic residents and broadband adoption is negative but small.

We also show a scatterplot of tract racial composition and adoption rates along with a trend line obtained by fitting a linear regression (see Figure 5). Of particular interest is Figure 5c, showing the adoption rates and percentage of Black population in a census tract. This graph recalls the high levels of residential segregation between Black and non-Black populations in Chicago, and shows that broadband adoption rates are similarly divided. Most tracts have either few Black residents or a majority of Black residents. In the latter tracts, we find low adoption rates. In contrast, tracts with few or no Black residents have high adoption rates. This finding is corroborated by Figure 5b, which shows high adoption rates in tracts with a majority White population.

4.2 Adoption Rate and Population Characteristics

We next study the correlation between adoption rates and key population characteristics. We focus on three characteristics: income, education, and age. These three characteristics may have a causal effect on adoption. Income can affect the ability to get a broadband connection; education has an effect on both employability (and hence income) as well as digital literacy and hence the perceived utility of the Internet; age may also affect broadband adoption with older population less likely to adopt due to multiple reasons such as difficulty of using digital technology, privacy concerns, or perceived lack of utility. With the available datasets, demonstrating causality is challenging; thus, we restrict our analysis to correlation.

For this analysis, we again use the Data Profile Tables from the ACS Census data; we use the following tables:

Population Characteristic	Correlation Coefficient
Log median household income	0.72
Percentage of families below poverty level	-0.58
Percentage of population above 25 with Bachelor Degree or high	0.66
Percentage of population above 25 with a high school degree or higher	0.52
Percentage of population above 65	-0.38
Percentage of single-person householders above 65	-0.52

Table 2. *Correlation of population characteristics with broadband adoption*

- **Income**: We select two metrics for income. The median household income (Table DP03_0062E) and percentage of families below poverty level (Table DP03_0119PE). The latter metric normalizes the income by the number of people in the household. We further take the log of the median household income as existing work suggests using log income for modeling [11].
- **Education**: We consider two metrics for education, namely percentage of population above 25 with a high school degree or higher (Table DP02_0015PE) and percentage of population above 25 with a bachelors degree or higher Table DP02_0068PE).
- **Age**: We consider the percentage of older adults (above 65) in the population. We consider two metrics, percentage of population above 65 (DP05_0024PE) and percentage of single-person households with the householder age above 65 (Table DP02_0009E and DP02_0013E for males and females, respectively). The second metric can more strongly show the association between age and broadband adoption. For the second metric, we obtain a single number by adding the male and female householders.

We obtain the above metrics at the census-tract level and compute the Pearson's correlation coefficient with broadband adoption rates (see Table 2. Looking first at metrics of income, we find that broadband adoption rate is positively correlated (in fact most correlated) with median log income and negative correlation with percentage of families with income below the poverty level. This result is expected since low income may make it difficult to purchase broadband Internet access. The prices of popular ISPs like Comcast and AT&T do not vary based on geography within Chicago; as such, we can compare broadband affordability by comparing income across neighborhoods. High per-capita income tracts may generally find broadband to be more affordable and thus they also may have high broadband adoption rates.

We also find a high correlation between broadband adoption rates and education. Broadband adoption rates are more correlated at the tract level with percentage of people with a bachelors degree than with percentage of people with a high-school degree. Education is also highly correlated with income. As mentioned before, education can impact adoption through income as well as through households' perceived utility of Internet. Future work can consider isolating the impact of the latter by controlling for income.

Finally, we find a weak negative correlation (-0.17) between adoption rates and percentage of population above 65 in a tract. The negative correlation is stronger (-0.42) when we consider single person households with householder above age 65. This relationship suggests that the older population may have lower adoption rates due to low perceived utility of the Internet, may also be related to the difficulty of using technology. Increasing high-speed broadband adoption rates could, however, be critical for these households (e.g., with remote telehealth opportunities during and after the COVID-19 pandemic).

Takeaway: When examining bivariate correlations, we find that broadband adoption in Chicago is most correlated with income and education. In terms of policy, the association suggests the need to make broadband more affordable for the

Access Type	Technology	ISP	Advertised speeds [Mbps]	% Census Blocks Present
Wireless	Satellite	ViaSat	35/3	100
		HNS	25/3	99.71
		VSAT	2/1.3	99.71
	Terrestrial	T-Mobile	25/3	44.2
		Verizon	300/50	0.16
		Google Webpass	100/100, 200/200, 500/500, 1000/1000	0.4
		Everywhere Wireless	25/10,..,2000/2000	0.75
Wired	ADSL, ADSL2, ADSL2+, VDSL, SDSL, Fiber	AT&T	0.42-0.42, .., 1000/1000	89.59
	DOCSIS 3.1	Comcast	1000/35, 2000/2000	88.62
	DOCSIS 3.0	WOW	1000/50	20.23
	DOCSIS 3.1, 3.0, 2.0, 1.1, 1.0, Fiber	RCN	25/4, 500/20, 1000/20, 1000/1000	12.59

Table 3. *ISPs in Chicago by access technology.*

lower-income population (which is also more likely to comprised people of color) in Chicago. We also find a negative correlation between adoption and percentage of single-person households above 65 years of age. Community-based programs such as digital navigators, which aim to enhance digital literacy, may be useful for increasing the adoption rate, especially among the elderly.

5 AVAILABILITY

In this section, we analyze broadband availability in Chicago. We specifically consider variability of technology, speeds, and number of ISP options within Chicago. We use the latest FCC form 477 data from December 2020 which contains ISP-provided availability information at a census block level.

5.1 ISP Availability by Access Technology

We filter the form 477 data for census blocks within Chicago and characterize the ISPs based on the access technology. Table 3 shows the major ISPs, including their access technology, advertised speeds, and percentage of census blocks covered.

Satellite wireless: These include ISPs that use satellites (e.g., Low Earth Orbit Satellites) to provide Internet access. Consumers can obtain Internet access by installing a satellite receiver antenna. The satellite ISPs are characterized by low speeds and high last-mile latency compared to the wired ISPs. These satellites are mostly suited for rural or remote contexts where it is challenging or not profitable for wired ISPs to provide access. We find three satellite providers with residential offerings in Chicago. All three ISPs span nearly all of the census blocks. However, we do not include satellite providers in our analysis because of two reasons: (1) Internet speeds from these ISPs are typically slow. Two ISPs provide sub-broadband speeds (< 25/3 Mbps) and the other two provide speeds of 25/3 and 35/3 Mbps. (2) The plans are expensive compared to fixed broadband plans. For instance, the least expensive broadband plan from one of the ISPs is 99$/month.

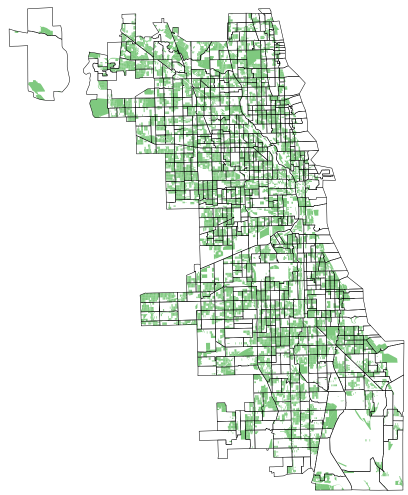
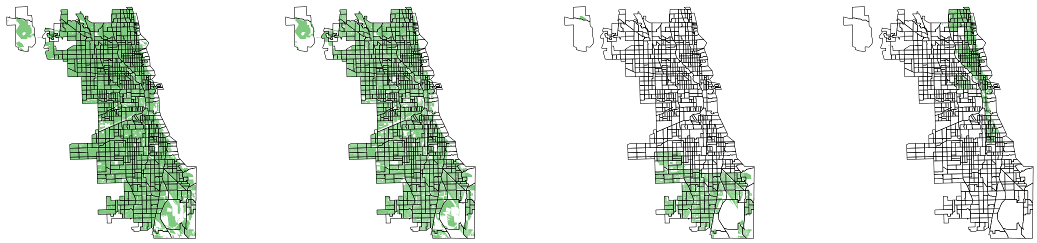


Fig. 6. *Spatial coverage of T-Mobile fixed wireless offerings.*

As a result, satellite networks are likely not feasible options for broadband users in Chicago which is mostly urban with less expensive, high-speed, and low-latency terrestrial connectivity options.

Terrestrial wireless: These ISPs provide access using a terrestrial wireless system. Typically, most of these ISPs have a last-mile wireless link with the upstream links being wired. For instance, ISPs that provide fixed broadband using cellular technology would be categorized as a terrestrial wireless ISP. We find 12 fixed terrestrial wireless providers with residential plans in least one census block within Chicago. Among these, 8 provide offerings in fewer than 30 census blocks with 6 serving only up to two census blocks. We exclude these providers from our analysis. We examine the speeds and coverage of the remaining four ISPs (see Table 3). Two providers, T-Mobile and Verizon, are cellular, and provide home Internet using 5G or LTE technology. T-Mobile is the largest terrestrial wireless provider, covering 20,498 census blocks. In terms of speed offerings, it reports only a single speed tier of 25/3 Mbps, which barely meets the FCC broadband standard. Verizon, on the other hand, reports speed offerings of up to 300/50 Mbps but covers only 0.16% of the census blocks. The other two providers are Everywhere Wireless and Google (doing business as Webpass) with presence in 0.4% and 0.75% census blocks. Both of these providers report up to gigabit symmetric speed offerings. This seems surprising given these are fixed wireless ISPs. However, based on the description online, these ISPs likely use fiber in most of their network with a single wireless hop in the last- mile. For instance, Webpass uses a rooftop antenna to receive wireless Internet at the building. It likely uses the Google Fiber infrastructure for upstream connection.

We next examine the spatial coverage of these ISPs. As shown in Figure 6, T-Mobile service seems to be evenly distributed across Chicago. In comparison, the other three ISPs have sparse coverage, with offerings mostly in the northern neighborhoods and business district areas of Chicago. This characteristic may result from some of the following factors: (1). these companies have fiber-based infrastructure in these regions, (2) these areas generally have high-occupancy buildings, with occupants having relatively higher income, thus providing better potential return on investment, especially for Google Webpass and Everywhere Wireless.



(a) *AT&T* (b) *Comcast* (c) *WOW* (d) *RCN*

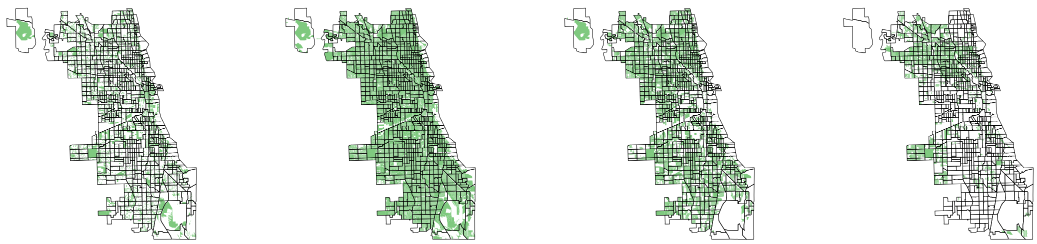
Fig. 7. *Spatial coverage of fixed wired ISPs. Green indicates availability*

Technology	% census blocks present	Download speed	Upload speed
ADSL2,ADSL2+	86.2%	0.77-25	0.38-3
ADSL	17.3%	0.77-6	0.26-0.51
SDSL	0.0%	0.42	0.42
VDSL	58.0%	18-100	1.5-20
Fiber	23.7%	1000	1000

Table 4. *AT&T: Advertised speeds and coverage [% of census blocks] by technology*

Wired: Twelve wired ISPs providing residential offerings in at least one census block in Chicago. Among them, eight ISPs are present in fewer than 25 blocks, with 5 ISPs serving only up to 2 census blocks. We focus on the remaining four ISPs which have a significant footprint in Chicago, also summarized in Table 3. Figure 7 shows the spatial coverage of these providers across Chicago. AT&T and Comcast are the largest wired providers with presence in more than 88% of census blocks in Chicago. The census blocks that are not covered are likely the blocks with zero residential population. In future, we plan to validate this using once the data from 2020 Census becomes public. The other two ISPs have a limited footprint. WOW provides offerings in far south side of Chicago while RCN has offerings in the Downtown and Northern lakeside areas of Chicago.

In terms of access technology, three ISPs— Comcast, RCN, and WOW—mostly use DOCSIS to provide Internet connectivity over hybrid-fiber-coaxial (HFC) networks. Each version of DOCSIS varies in channel configurations and throughput for upstream and downstream links. DOCSIS 3.1, the latest standard, can support up to 10 Gbps downstream and 1 Gbps upstream throughputs. Comcast uniformly supports DOCSIS 3.1, the latest DOCSIS standard, across all census blocks. This also reflects in the Comcast's speed offerings, as it uniformly reports maximum advertised speed of 1000/35 Mbps across all census blocks. In comparison, WOW supports an older cable standard, DOCSIS 3.0, across all census blocks. However, in terms of advertised speeds, WOW reports the same maximum advertised speed of 1000/50 Mbps across all census blocks. The advertised upload speeds are higher compared to Comcast, despite supporting an older cable standard. Finally, RCN reports different version of DOCSIS technologies in different census blocks. Among the 8,495 census blocks it serves by cable, 37% support DOCSIS 3.1, 60% support DOCSIS 3.0, and 3% support older version of DOCSIS (i.e., 1.0, 1.1 or 2.0). We also find difference in advertised speeds across the three standards, with the speeds being 1000/20 Mbps, 500/20 Mbps, and 25/4 Mbps for DOCSIS 3.1, 3.0, and 2.0 or older versions, respectively. RCN also provides



(a) *ADSL* **(b)** *ADSL 2, ADSL2+* **(c)** *VDSL* **(d)** *Fiber*

Fig. 8. *AT&T: Spatial coverage of different Access technologies*

(a) *DOCSIS 1.0, 1.1, or 2.0* **(b)** *DOCSIS 3.0* **(c)** *DOCSIS 3.1* **(d)** *Fiber*

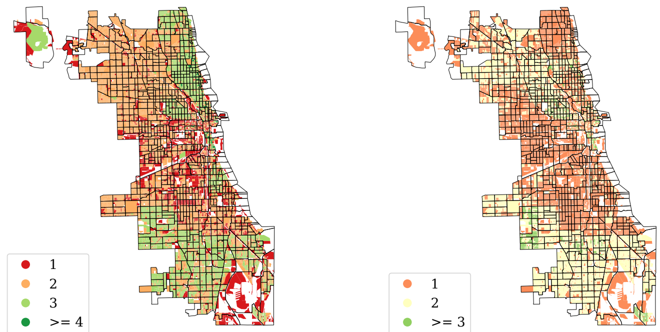
Fig. 9. *RCN: Spatial coverage of different Access technologies*

access using fiber in 1044 census blocks with maximum advertised speeds of 1000/1000 Mbps. Figure 9 shows the spatial map of RCN offerings coded by the access technology. Most Fiber offerings are centered around a single region, slightly north-west of the downtown Chicago.

The fourth major fixed wired ISP, i.e. AT&T, uses a mix of Digital Subscriber Line (DSL)-based and Fiber as the access technology. Among the 41532 census blocks served, it supports Asymmetric DSL (ADSL) 2 and ADSL2+ in 96.2% blocks, Very high speed DSL or VDSL in 64.7% blocks, Fiber to the home or fiber in 26.4% blocks, ADSL in 19.3% blocks, and Symmetric DSL in 0.02% blocks. Figure 8 shows the spatial distribution of the different access technologies. There is no clear pattern in the spatial distribution of DSL technology. The fiber, however, is mostly concentrated in the West and North western parts of Chicago. In terms of speed, the maximum advertised speed over Fiber is 1000/1000 Mbps across all census blocks. The speeds over the same DSL technology varies across census blocks. This is likely because DSL performance depends on the distance between the subscriber and Central Office (CO). Table 4 summarizes the different advertised download and upload speed pairs for different DSL technologies.

5.2 Number of ISPs in a Single Census Block

We next study the number of ISPs that are available in a census block. Note that having multiple ISPs in a census block does not necessarily imply more competition as each ISP may serve a disjoint set of addresses. It can be considered as a necessary but not sufficient condition to indicate competition. We consider two speed thresholds while counting the number of ISPs, (1). 25/3 Mbps, the speeds used by the FCC to define broadband, and (2) . 100/20 Mbps, the newly proposed minimum speeds for broadband [1]. Figure 10 shows the number of ISPs available within a census block based on different



(a) *Broadband (25/3 Mbps)* **(b)** *High-speed (100/20 Mbps) broadband*

Fig. 10. *Number of ISPs available across census block*

speed thresholds. We see disparity in the number of options available across different regions. While, the lakeside areas and the far south parts have 3 broadband options available (25.8% blocks), the remaining areas have only two options (59% blocks) available with some pockets (14.1% blocks) having only one broadband ISP option. For high-speed broadband options, 50.6% blocks have only one ISP option, 45.9% have two options, and the remaining 3.5% blocks having 3 or more options.

Are adoption rates correlated with number of ISPs? We now analyze if adoption rates are correlated with number of ISPs available in an area. We first calculate the number of ISPs with broadband offerings (> 25/3 Mbps) available in each census block. The ACS data, however, is available at census tract level. To match the two datasets, we compute the average of number of ISPs available across census blocks in a census tract. We then compute the pearson correlation coefficient between average number of ISPs and adoption rates across census tracts. We observe a weak positive correlation of 0.27 between availability and adoption. It is not clear however if there is a causal relationship. There could be other confounding factors such as legacy infrastructure and higher population density that may impact availability in an area.

Takeaway: AT&T and Comcast are available evenly across census blocks in Chicago. AT&T, however, varies in terms of access speeds due to their dependence on DSL technology in certain areas. Their fiber offerings are also available in selected regions. Among the terrestrial wireless ISPs, only T-Mobile has a city-wide presence. The remaining five ISPs (two wired and three wireless) have a more limited footprint. Four of these ISPs are concentrated in North Lakeside and Downtown areas of Chicago, with only one ISP providing sevice to the far south side of Chicago.

6 DISCUSSION AND FUTURE WORK

Causal factors for lack of broadband adoption: The ACS survey allows us to observe correlations between broadband adoption rates and population characteristics. These correlations provide some insights into factors affecting broadband adoption, but they do not tell us what is *causing* broadband adoption (or lack thereof). More controlled experiments and qualitative research may be useful for increasing our understanding of the different reasons for lack of adoption. We expect these reasons to be multiple and to vary by population group within the city of Chicago. Further research on causality could provide the basis for interventions to increase adoption.

Fine-grained availability analysis: Our analysis in this paper relies on broadband availability data from the FCC form 477 that may overstate availability for regions. Future work could thus look at availability at a more fine-grained level (e.g., at street address level) to study how availability varies within a census block. The FCC is planning to improve its form 477 data quality using Broadband Serviceable Location Fabric (Fabric) that provides ISPs to work with a standardized list of serviceable addresses [15]. It is not yet clear if such fine-grained availability data would be publicly available, especially at the level of street address. Another approach then could be to use tools such as the one proposed by Major et al. [21] that can obtain street-level availability data by querying the ISP websites.

Network performance analysis: This paper does not focus on broadband performance. Poor network performance can impede a user's ability to make best use of Internet connectivity, and poor performance may also discourage adoption. Understanding ISP performance is especially important in census blocks with only a single high-speed ISP (a significant proportion of census blocks), where incentives to maintain and upgrade infrastructure may be less. Unfortunately, crowdsourced performance datasets, such as Ookla and Measurement Lab's speed test datasets, are biased in a variety of ways, lacking data from under-connected communities [6, 22]. One possible workaround could be to measure performance with more extensive targeted sampling from neighborhoods of interest [20, 31].

7 CONCLUSION

In this paper, we analyzed Internet equity in Chicago across three dimensions: adoption, affordability, and availability. We find disparity in adoption rates across community areas in Chicago. The areas with lowest connectivity also exhibit low income, thus indicating that adoption may result from a lack of affordability, although future work could aim to firmly establish this causal relationship. In addition, we also observe low adoption in households with elderly populations or low education, possibly indicating issues related to perceived utility of broadband potentially impacting adoption. Finally, our broadband availability analysis using FCC form 477 data shows that most regions in Chicago have at least one broadband (and even high-speed broadband) option, yet different regions do exhibit variability in terms of the number of ISP options that are available.

ACKNOWLEDGMENTS

This work was funded in part by a `data.org` inclusive growth and recovery grant, as well as NSF Awards CNS-1704077, CNS-2028145, CNS-2223610, CNS- 2213821, CNS-2003257, and OAC-2126327. We are thankful to Devon Braunstein from the City of Chicago, Office of Mayor Lori Lightfoot for her continual engagement and feedback. We are also grateful to the Data Science Clinic students at the University of Chicago who have helped enable this research including Lena Diasti, Drew Keller, and Amy Maldonado.

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