Municipal and Cooperative Internet on Broadband Entry and Competition

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Abstract

The broadband market is unique for municipal (government-owned) and cooperative (member-owned) competitors. Their participation, however, raises conflict of interest concerns. Both municipalities and cooperatives are often owners of utility poles that are an essential input for broadband deployment. Internet service providers (ISPs) must lease pole attachment space. While most pole attachment rates are regulated, municipal and cooperative pole owners are exempt by Section 224 of the Telecommunications Act. This paper, therefore, studies the competitive effects of municipal and cooperative ISPs, and the effect of potential entry by municipal and cooperative electric utilities (non-ISPs), on broadband entry and quality. I add to the existing literature by building a dataset of municipal and cooperative non-ISP service areas, designing a method to clean the Federal Communications Commission's (FCC) broadband data, developing a novel geographic entry threat model, and analyzing municipalities and cooperatives in conjunction. I categorize markets into three types: rural, urban clusters (2,500 to 50,000 people), and urbanized areas (≥ 50,000 people). Looking at Illinois from June 2015 to June 2018, I find that the presence of a municipal ISP lowers the probability of market entry and service quality in urbanized areas. The presence of a cooperative ISP lowers the probability of market entry and service quality in rural areas and urban clusters. The presence of a municipal non-ISP has little to no effect on the probability of market entry or service quality. The presence of a cooperative non-ISP appears to increase the probability of market entry in rural and urbanized areas, but depress service quality in urbanized areas, although these effects could be attributed to poor data quality. These results have strong implications for forthcoming broadband legislation.

JEL Codes: L32; L41; L96

Keywords: Broadband deployment; Public enterprise; Anticompetitive practices

Introduction

City governments have long provided citizens with electricity, water, and telephone services through municipal utilities. In sparsely populated areas, member-owned firms, called "cooperatives", deliver these essential services. Although municipal and cooperative utilities are undoubtedly critical, their participation in the broadband market is potentially anticompetitive.

Ubiquitous yet unnoticed, utility poles underpin electricity and telephone services. Municipalities and cooperatives own and construct millions of poles across the United States. Broadband is no exception to pole attachment. Common broadband technologies from digital subscriber lines (DSL) to fiber optics all rely on pole support, especially for the "last mile" of service. Yet in many jurisdictions, private internet service providers (ISPs) are barred from erecting poles for practical and aesthetic reasons. Many private ISPs must therefore lease "attachment space" from pole owners.

Leasing pole attachment space is a longstanding practice since the advent of phone lines and cable television. The 1978 Pole Attachment Act, 47 U.S.C. Section 224, prohibits pole owners from charging exorbitant attachment rates from cable television providers by establishing the "Cable Rate Formula." But as wireless and wireline telecommunications developed in the 1990s, Congress amended Section 224 with the Telecommunications Act of 1996. The amended Section 224 extended the rate protections to telecommunications providers and similarly introduced the "Telecom Rate Formula," enforced by the Federal Communications Commission (FCC). There were, however, two categories of pole owners exempted from rate regulation: municipalities and cooperatives.

Policymakers reasoned that municipal and cooperative pole owners would not charge excessive rates because they desire telecommunications infrastructure in their jurisdictions. At the time, municipalities and cooperatives were not major competitors in the telecommunications industry. Reality has now changed with dozens of municipal and cooperative ISPs emerging in the last two decades. As of April 2021, recognizing this conflict of interest, 18 states outlaw and 5 states regulate municipal broadband (BroadbandNow, 2021). But in states where little pole rate regulations exist, municipal and cooperative ISPs have full control over their market's essential input, otherwise known as an "essential facility" in legal contexts.

In states where municipalities and cooperatives are allowed to compete in the broadband market, I identify two potential anticompetitive implications of municipality and cooperative pole ownership: one, they have the incentive to excessively extract from incumbent private ISPs, and two, if they are ISPs, they could easily discourage private sector entry. The first implication cannot be studied because pole rates are trade secrets. Much of this paper, therefore, focuses on the second implication. If either a municipal or a cooperative ISP can sufficiently deter entry by imposing unreasonable pole attachment rates, they may not only monopolize their service area, but also have little incentive to improve quality. In other industries, monopolists are pressured to innovate to deter entry and preserve profits; this pressure appears non-existent for municipal and cooperative ISPs.

Empirically, these issues are beginning to emerge. In a November 2020 Georgia Public Service Commission hearing on pole attachment rates, Dr. Michelle Connolly's expert testimony shows lower broadband penetration in areas where municipalities and cooperatives are pole owners. Municipalities and cooperatives also consistently charge higher rates than investor-owned (privately-owned) utility poles (Connolly, 2020).

A. Introduction to Municipal Broadband

Municipal ISPs are often extensions of municipal electric utilities (e.g., Lafayette, LA, Chattanooga, TN). Municipalities may also create a standalone ISP (e.g., Santa Monica, CA). Municipal broadband projects are generally financed by bonds and capacity leases to private ISPs (Lennett et al., 2014). The Institute for Local Self-Reliance's (ILSR) Community Broadband Map identifies 560 municipal ISPs.

Supporters of municipal broadband argue that public investment can introduce internet faster to unserved and underserved regions, provide better quality than incumbent private ISPs, and encourage broadband adoption. Whitacre and Gallardo (2020) demonstrate that in states with few or no restrictions on municipal broadband, fiber optic installation occurred faster and broadband availability is higher. Talbot et al. (2018) find that municipal broadband can encourage broadband adoption because of consistently lower prices than private ISPs.

On the other hand, most municipal broadband projects do not generate positive cashflow, resulting in heavy debt (Yoo and Pfenninger, 2017). Yoo and Pfenninger postulate that debt-laden municipal ISPs will eventually resort to charging more from its subscribers, who are less likely to have a second choice. Bolema (2019), a senior fellow at the Free State Foundation, posits that municipal networks may get unfair preferential treatment on regulatory approval. A 2016 report by the State Government Leadership Foundation, a conservative thinktank, argues that the entry of government firms will reduce private investment because they are not profit-maximizing (Ford, 2016). Ford further contends that subsidized entry is likely predatory in areas where private ISPs already exist because municipal ISPs can price under market. Lastly, empirical evidence shows that municipal broadband does not bring about the purported economic benefits of employment growth or increases in broadband subscription rates (Oh, 2019).

B. Introduction to Cooperative Broadband

In recent years, many electric cooperatives are deploying fiber optics and terrestrial fixed wireless for internal operations (e.g., reliable connectivity to power generation and transmission assets). Some cooperatives have begun to extend these internal broadband networks to their constituents. The National Rural Electric Cooperative Association (NRECA), the organization that represents the interests of cooperatives, reports high take-rates for cooperative broadband because of their strategy of measured deployment, choosing only to expand to areas with known demand (NRECA, 2020). State legislatures have started to ease restrictions on cooperative broadband to boost growth in rural economies (see FIBRE Act in Indiana).

There has also been pushback against cooperative broadband, albeit less than that of municipal broadband. Politically charged critics believe that cooperative providers are overbuilding private sector infrastructure or cross subsidizing their costly broadband business (Ford, 2019; Kavulla and Lacey, 2019). Cross-subsidization, if true, would impact low-income households the most. Schmit and Severson (2021) finds that new cooperative ISPs would have to increase their prices by 75% to 131% to be financially viable in the long-term.

C. Lack of Research on Municipal and Cooperative Broadband's Competitive Effects

Research on the competitive and quality effects of municipal ISPs is limited. One recent study suggests that the presence of municipal electric utilities is associated with lower upload and download speeds offered by private ISPs (Landgraf, 2020). Landgraf also shows that these lower speeds can be eliminated with restrictions on municipal broadband. Seamans (2012), however, demonstrates that private ISPs are quicker to upgrade when faced with municipal entry threat.

Similarly, there is limited empirical research on the competitive and quality effects of cooperative ISPs. A 2018 study by Purdue University shows that cooperative broadband has a net positive effect on rural communities in Indiana, although to achieve statewide rural coverage with cooperative ISPs, policy and financial assistance would be required (Grant, Tyner, and DeBoer, 2018).

There is, however, a larger body of research indirectly related. I focus on broadband entry and quality competition.

On the topic of entry threat, Karaer and Erhun (2015) show that incumbents may invest in higher quality to diminish profits for potential entrants. Incumbent investment is also closely linked with market size. In markets that are too small, incumbents may not invest at all when faced with a credible entry threat (Ellison and Ellison, 2011). More specific to broadband, entry conditions become progressively more difficult for the 4th ISP and beyond, and that entry costs for early entrants are lower than that of later entrants (Xiao and Orazem, 2011; Bresnahan and Reiss, 1991). ISPs also consider the effects on expected profits by anticipated entry when making entry decisions (Molnar and Savage, 2017). It is, therefore, crucial to determine the nature of entry threats posed by municipalities and cooperatives.

In broadband quality competition, research suggests that there is strong positive correlation between the number of wireline providers in a census tract with the highest broadband speed available in that tract (Wallsten and Mallahan, 2010). Reed and Watts (2018) demonstrate that six or more wireline providers increase download speeds. These findings comport with well-established industrial organization theory (Tirole, 1988) and is especially relevant to this study, as I determine whether municipal and cooperative ISPs and non-ISPs deliver the competitive pressure to induce better service quality.

I seek to answer two questions:

1. How does the presence of municipal and cooperative ISPs and non-ISPs affect entry decisions by private ISPs?
2. How does the presence of municipal and cooperative ISPs and non-ISPs impact broadband service quality?

To accomplish this, I analyze broadband deployment in the state of Illinois. As of April 2021, Illinois ranks 6th in state broadband access, has over 350 ISPs, and has an average downstream speed of 111.5 megabits per second (Mbps). BroadbandNow reports that over 94% of the Illinois population has access to wired internet with speeds greater than 25 Mbps (BroadbandNow, 2021). Over 300,000 Illinoisans do not have access to wired ISPs and 866,000 are served by only one ISP.

Illinois statutes restrict the Illinois Commerce Commission from regulating or influencing the "rates, quality of service, and availability of broadband service" (see Illinois Compiled Statutes 5/13-804). Illinois' mix of rural and urban regions, along with highly permissive broadband policies, makes it a good case to study.

Relative to previous national-level broadband studies, focusing on Illinois allows consideration of market conditions at the census block-level.

The paper is structured as follows: Section II describes municipal and cooperative ISPs and non-ISPs in Illinois; Section III details the dataset and data processing techniques; Section IV explains the theoretical framework; Section V outlines the empirical strategy; Section VI reports the results; Section VII discusses the results; Section VIII concludes.

II. Background on Municipal and Cooperative ISPs and Non-ISPs in Illinois

Illinois does not prohibit nor regulate any type of broadband services. Chapter 5, Section 220 of the Illinois Compiled Statutes explicitly states that the Illinois Commerce Commission "shall not regulate the rates, terms, conditions, quality of services, availability, classification of any service regarding (i) broadband services … (iii) information services."

A. Introduction to Illinois Municipal and Cooperative Utilities

Illinois municipal ISPs can be categorized as city networks, utility networks, or public-private networks. City networks are independent ISPs owned and operated by the local government. Utility networks are ISPs operated by a municipal utility. Public-private networks are municipality partnerships with a private ISP. Of the 12 Illinois municipal ISPs, 6 are city networks, 3 are utility networks, and 1 is a public-private network. 2 of the 12 Illinois municipal ISPs serve at the county-level, although it is unclear whether they cover the entire county. In addition, there are 40 Illinois cities or villages with municipal utilities that are not currently ISPs.

All Illinois cooperative ISPs are extensions of electric cooperatives. Most started as internal network upgrades. Jo-Carroll Energy (JCE), based in northwest Illinois, initially deployed fiber optics to reliably connect its industrial control systems with low latency. Using this backbone, JCE launched its residential broadband division in 2008, rolling out fiber only to neighborhoods with surveyed high demand to minimize investment risk. Prairie Power Incorporated (PPI) deployed fiber optics for power transmission as well. Of the 34 Illinois electric cooperatives, 14 are also ISPs.

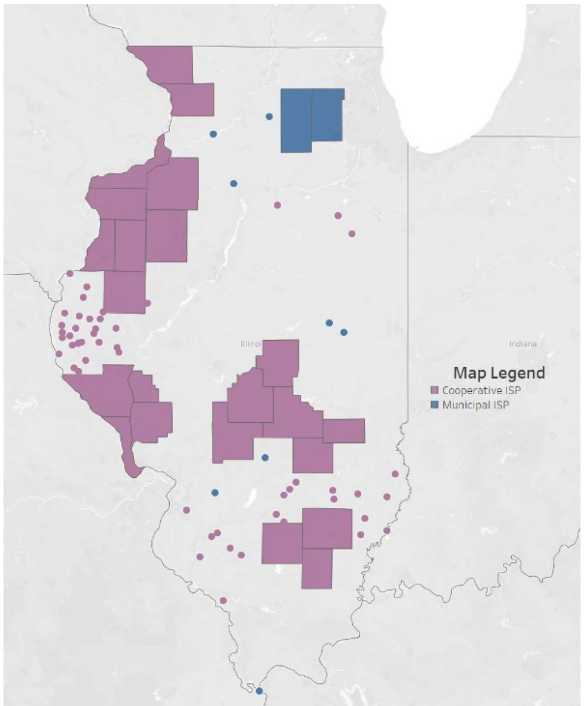

Figure 1A: Map of Illinois Municipal and Cooperative ISPs (Blue: Municipal; Purple: Cooperative)

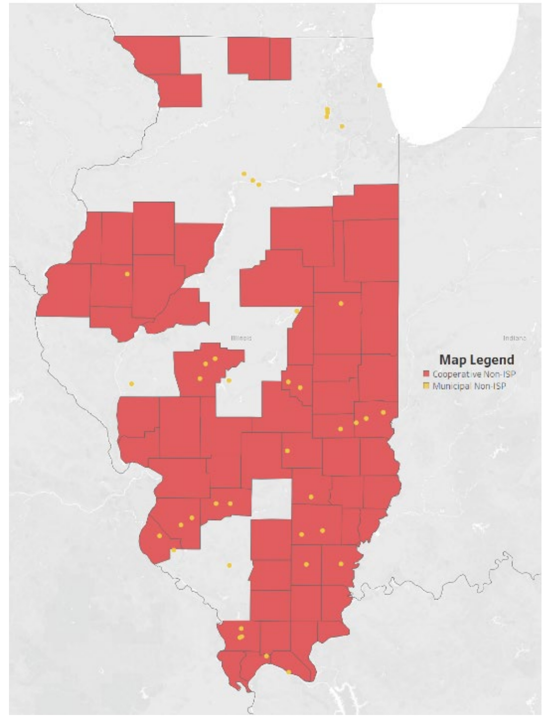

Figure 1B: Map of Illinois Municipal and Cooperative Non-ISPs (Yellow: Municipal; Red: Cooperative)

Note on Figures 1A and 1B: Dots are cities or villages. Filled-in territories are counties. There is likely overestimation in coverage due to lack of data granularity.

This paper categorizes municipal and cooperative providers into 4 types: municipal ISP, municipal non-ISP, cooperative ISP, and cooperative non-ISP. This breakdown defines “treatment areas” by coding dummy variables for census blocks. Census blocks are the smallest geographic classification by the U.S. Census Bureau, usually not exceeding one square mile.

B. Illinois Municipal and Cooperative Broadband Technologies

The following tabulates the number of Illinois census blocks served by either a municipal or a cooperative ISP and their respective technology:

Table 1A: Number of Census Blocks Served by Illinois Municipal ISPs by Technology

Technology Type (Theoretical Max Download Speed of Technology, Megabits Per Second, Higher is Better)	Jun. 2015	Dec. 2015	Jun. 2016	Dec. 2016	Jun. 2017	Dec. 2017	Jun. 2018
AxDSL (12 Mbps)	497	521	529	531	532	303	303
ADSL2, 2+ (24 Mbps)	0	0	0	0	0	228	228
Fiber (1000 Mbps)	426	443	450	538	533	543	542
Teres. Fixed Wireless (500 Mbps)	0	0	0	199	199	210	211

Table 1B: Number of Census Blocks Served by Illinois Cooperative ISPs by Technology

Technology Type (Theoretical Max Download Speed of Technology, Megabits Per Second, Higher is Better)	Jun. 2015	Dec. 2015	Jun. 2016	Dec. 2016	Jun. 2017	Dec. 2017	Jun. 2018
AxDSL (12 Mbps)	2,552	2,551	1,729	1,178	780	780	766
ADSL2, 2+ (24 Mbps)	6,666	6,803	6,737	6,471	6,308	4,782	4,272
VDSL (300 Mbps)	462	462	462	462	462	462	316
Cable Modem DOCSIS < 3 (Not Standardized)	363	363	363	355	349	354	185
Fiber (1000 Mbps)	3,819	4,295	4,535	5,843	7,697	8,972	11,151
Teres. Fixed Wireless (500 Mbps)	22,857	19,659	17,743	43,463	27,625	27,383	26,980

Illinois municipal broadband services range from low speed Asymmetric xDigital Subscriber Line (AxDSL) to fiber. The above table, unfortunately, is limited and underrepresented, because not all Illinois municipal ISPs filed with the FCC. Of the twelve Illinois municipal ISPs, only six are listed in the FCC's publicly available data. Municipal entry with obsolete ADSL2 and ADSL2+ technology in December 2017 (Henry County Communications, Inc.) is a cause for concern and indicates a possibility that municipal ISPs are unwilling to invest in newer technologies because they can ‘artificially’ reduce the entry threat they face through preferential treatment and excessive pole rates on competitors.

Illinois cooperative ISPs use all DSL technologies, fiber, and terrestrial fixed wireless. Terrestrial fixed wireless is favored for its reach into sparsely populated areas and difficult terrain. Illinois cooperative ISPs are generally phasing out older technology. All Illinois cooperative ISPs have been consistently reporting to the FCC.

C. Entry Behavior by Municipal and Cooperative ISPs: First or Last?

To verify supporting arguments for municipal and cooperative broadband, the following table tabulates the rank of entry in Illinois, by either a municipal ISP or a cooperative ISP, from June 2015 to June 2018:

Table 2: Number of Census Block Entry by Municipal and Cooperative ISPs in Illinois by N^{th} Firm to Enter, from June 2015 to June 2018

N^{th} Firm to Enter	Number of Census Blocks Entered by a Municipal ISP	Number of Census Blocks Entered by a Cooperative ISP
1^{st}	444	2,630
2^{nd}	247	11,122
3^{rd}	243	9,492
4^{th}	95	5,916
5^{th}	19	817
6^{th}	2	10
Total	1,050	29,987

The results are concerning. Municipal ISPs were first to enter less than 43% of the time. Cooperative ISPs fall even lower, at less than 8.8%. Recall Xiao and Orazem's (2011) finding that the 4th entrant onward makes little difference in the broadband market's competitive conduct. Supporters' claims that municipal or cooperative broadband can improve the competitive environment should be questioned.

Entry costs also tend to scale by rank of entry, because successive entrants must aggressively advertise to capture market share from incumbents, compounded by lower price-setting ability. Rather than entering where private ISPs are unwilling, municipal ISP entry is more common in census blocks where incumbent providers exist. The net social gain from non-first municipal ISP entry should be more closely examined.

D. Demographic Information in Areas Served by Illinois Municipal and Cooperative Utilities

Using the U.S. Census Bureau's definitions, I also define 3 types of markets: Rural, 'Urban Clusters' (UCs), composed "of at least 2,500 and less than 50,000 people," and 'Urbanized Areas' (UAs), composed "of 50,000 or more people."

Table 3A: Number of Rural, Urban Cluster, and Urbanized Area Census Blocks Served by Municipal ISPs in Illinois

Market Type	Jun. 2015	Dec. 2015	Jun. 2016	Dec. 2016	Jun. 2017	Dec. 2017	Jun. 2018
Urbanized Area	14,517	14,552	14,808	14,811	15,027	14,828	14,148
Urban Cluster	2,198	2,198	2,199	2,199	2,210	2,210	2,177
Rural	9,375	9,460	9,570	9,579	9,713	9,698	8,853
Total	26,090	26,210	26,577	26,589	26,950	26,736	25,178

Table 3B: Number of Rural, Urban Cluster, and Urbanized Area Census Blocks Served by Cooperative ISPs in Illinois

Market Type	**Jun. 2015**	**Dec. 2015**	**Jun. 2016**	**Dec. 2016**	**Jun. 2017**	**Dec. 2017**	**Jun. 2018**
Urbanized Area	15	32	32	3,326	517	562	566
Urban Cluster	5,517	5,214	4,805	9,376	7,709	7,805	8,156
Rural	23,732	21,778	20,919	38,016	29,887	30,189	30,683
Total	29,264	27,024	25,756	50,718	38,103	38,556	39,405

Illinois municipal ISPs served 26,090 census blocks (≈6.0% of total) in June 2015 and 25,178 census blocks (≈5.8% of total) by June 2018. The number of urbanized area census blocks served by municipal ISPs is consistently the largest category, calling into question whether municipal ISPs are truly only serving areas where private ISPs avoid.

Illinois cooperative ISPs served 29,264 census blocks (≈6.8% of total) in June 2015 and 39,405 census blocks (≈9.1% of total) by June 2018. Cooperative ISPs are mostly in rural census blocks. The uptick in December 2016 can be traced to the sudden increase in terrestrial fixed wireless reports in December 2016 in Table 1B. Areas served by cooperative ISPs do not stray from expectation.

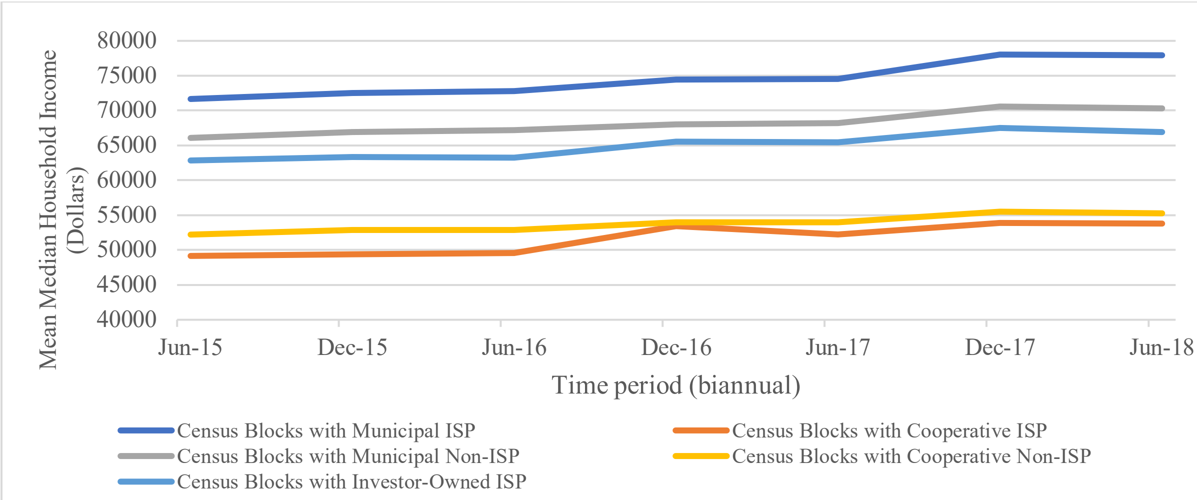

Figure 2: Graph of Mean Median Household Income in Census Blocks by Types of ISPs

Table 4: Mean Median Household Income in June 2018 in Illinois, Disaggregated by Market and ISP Type

	Rural		**Urban Cluster**		**Urbanized Area**	
	Municipal ISP	**Cooperative ISP**	**Municipal ISP**	**Cooperative ISP**	**Municipal ISP**	**Cooperative ISP**
Mean Median Household Income in June 2018	$73,173.57 (55th percentile)	$56,160.91 (44th percentile)	$60,047.44 (47th percentile)	$43,638.36 (33rd percentile)	$83,729.64 (61st percentile)	$67,418.85 (52nd percentile)
Number of Blocks in June 2018	8,853	30,683	2,177	8,156	14,148	566

In comparison, the mean median household income in census blocks served by municipal ISPs is highest in all time periods (Figure 2). In June 2018, except in urban clusters, mean median household income in census blocks served by municipal ISPs is above Illinois' 50th percentile for 2018 (Table 4). While these areas are not high income, they do not appear to require the purported financial relief by municipal ISPs. Cooperative ISPs appear to serve relatively low-income areas, consistent with expectation.

III. Data

In June and December annually, the FCC collects Fixed Broadband Deployment Data through its Form 477. The Form 477 records disaggregated broadband speeds, technology classifications, and internet service providers at the census block-level. This paper examines seven time periods, from June 2015 to June 2018, inclusive. I exclude earlier data because of major adjustments to the Form's format in 2014. I also exclude satellite ISPs because satellite broadband data is provided to the FCC only at the state-level (Flamm and Varas, 2019). Satellite ISPs are also not subject to the same strategic decision-making or constraints as traditional wireline providers.

I do not include the FCC's Mobile Deployment Data, because it is collected using shapefiles that do not fit neatly in census blocks. While mobile internet may have a tangible impact on local service quality, municipal and cooperative ISPs rarely provide mobile internet, so the data would complicate the analysis.

The Form 477 does not indicate whether an ISP is a municipality or a cooperative. Using data from BroadbandNow, Community Network's 'Community Network Map', and researching each holding company on Bloomberg's Company Profiles, I build an initial list of Illinois municipal and cooperative ISPs. I then cross-verify ISP names with the Form 477. For municipal ISPs not in the Form 477, I visit each of their websites and gather service area data using outage maps or readily provided service locations. This method is imperfect. Outage maps and service locations are not nearly as granular as the Form 477. The highest resolution of outage maps is zip codes. It is therefore likely that the number of census blocks with municipal ISP presence is overestimated. I minimize this overestimation by using the U.S. Department of Housing and

Urban Development's (HUD) zip code to census tract dataset, and interaction with census block population to eliminate uninhabited areas.

I create a list of municipal utilities that are not currently ISPs (non-ISPs) from the Illinois Municipal Electric Agency, Illinois Municipal Utilities Association, and the Illinois Public Energy Agency websites. I then visit each municipal utilities' website to assemble their service areas using the HUD dataset and the population interaction procedure. I create a list of cooperative electric utilities that are not currently ISPs from the Association of Illinois Electric Cooperatives website and repeat the service area gathering process.

This effort is the first complete and granular data collection of municipal and cooperative ISP and non-ISP service areas in broadband economics research. I include this data using census block-level indicator variables.

I use demographic data collected by the American Community Survey (ACS), collected at the census block group level annually. I use the ACS Five Year estimates; for example, the estimate for 2015 would be the averaged estimates from 2011 to 2015. The ACS provides the median household income and education variables. I collect census block population and household estimates from the FCC's Staff Block Estimates.

I create several market structure variables using Form 477 raw data. The 'number of entrants' variable counts the number of unique firms by their FCC Registration Number (FRN) that were not in the census block in the previous time period. Time period 1 (June 2015) serves as the initial state. The 'number of exits' variable counts the number of unique firms that were in the census block in the previous time period but not in the present time period. These statistics are not based on aggregate firm numbers in a census block because a firm entering and another exiting in the same period would result in a net change of zero. My approach also quantifies the number of incumbent firms. A firm is considered incumbent if they were present in the census block in the previous period. I also create the natural log of a census block's maximum download speed for each time period to proxy for service quality. Log block maximum speed is the dependent variable for this paper's second stage of analysis.

A. Form 477 Data Cleaning

The manual filing of the Form 477 inevitably leads to data entry errors. The FCC acknowledges this by allowing Form 477 corrections months and years after initial submission dates. Despite the correction process, there are still obvious errors and anomalies. These errors occur most often in the "maximum advertised download speed" (*maxaddown*, henceforth "download speed") variable. I identify 3 categories of errors: broadband speed oscillations, missing entries, and speeds exceeding technology specifications. A Form 477 study done in 2018 found similar data oddities (Gadiraju et al., 2018), although they were ignored and nothing was done to remedy them. This paper makes the literature's first attempt to rectify some of these errors. I make the following assumptions:

1. **Broadband speed oscillations:** Holding census block, firm, and technology constant, if the download speed in the $t–1$ and $t+1$ observations of the target observation are equal, then it is impossible for the target observation's download speed to be higher or lower than the $t–1$ or $t+1$ speed.
2. **Missing entries:** If a census block, firm, and technology combination appears at time $t–1$ and $t+1$, but not at t, then it is a missing entry. Providers cannot reasonably uninstall and reinstall the *same* broadband infrastructure in under 12 months.

3. **Speeds exceeding technology specifications:** If an observation's download speed exceeds the maximum speed for that technology's International Telecommunication Union specification, then the observation is erroneous (see Appendix A2).

I recognize that there are other Form 477 errors, such as overestimating broadband availability in a census block (Ford, 2019; Taglang, 2020; Busby and Tanberk, 2020). But because this study focuses on broadband competition rather than broadband adoption, correcting for availability is less necessary.

A. Broadband Speed Oscillations

I find four types of 'oscillations': upward spike, downward spike, persistent upward spike, and permanent decrease (see error frequency in Appendix A3). These cases can be reasonably assumed to be errors, because for a census block, firm, and technology combination to be classified as an oscillation, observations immediately prior and after must be identical.

1. **Upward Spike:** An "upward spike" is characterized by an increase in download speed in *t+1*, followed immediately by a decrease in *t+2*, back to the speed at *t.*

	hoconum	hocofinal	blockcode	techcode	maxaddown	maxadup	timeindex
37	130077	AT&T Inc.	170010001001048	10	.768	.128	1
38	130077	AT&T Inc.	170010001001048	10	.768	.128	2
39	130077	AT&T Inc.	170010001001048	10	.768	.128	3
40	130077	AT&T Inc.	170010001001048	10	6	.512	4
41	130077	AT&T Inc.	170010001001048	10	.768	.128	5
42	130077	AT&T Inc.	170010001001048	10	.768	.128	6

Figure 3A: Example of "Upward Spike"

2. **Downward Spike:** A "downward" spike is characterized by a decrease in download speed in *t+1*, followed immediately by an increase in *t+2,* back to the speed at *t.*

hoconum	hocofinal	stateabbr	blockcode_str~g	techcode	maxaddown	maxadup	timeindex
130077	AT&T Inc.	IL	170010004004005	10	6	.512	1
130077	AT&T Inc.	IL	170010004004005	10	6	.512	2
130077	AT&T Inc.	IL	170010004004005	10	3	.384	3
130077	AT&T Inc.	IL	170010004004005	10	6	.512	4
130077	AT&T Inc.	IL	170010004004005	10	6	.512	5

Figure 3B: Example of "Downward Spike"

3. **Persistent Upward Spike:** A "persistent upward spike" is characterized by a prolonged, 2 or 3 time periods increase in download speed, followed by a decrease to the original speed.

	hoconum	hocofinal	blockcode	techcode	maxaddown	maxadup	timeindex
55	130012	Adams Telephone Co-Operative	170010001002021	70	4	4	1
56	130012	Adams Telephone Co-Operative	170010001002021	70	8	3	2
57	130012	Adams Telephone Co-Operative	170010001002021	70	8	3	3
58	130012	Adams Telephone Co-Operative	170010001002021	70	8	3	4
59	130012	Adams Telephone Co-Operative	170010001002021	70	4	2	5
60	130012	Adams Telephone Co-Operative	170010001002021	70	4	4	6
61	130012	Adams Telephone Co-Operative	170010001002021	70	4	4	7

Figure 3C: Example of a "Persistent Upward Spike"

4. **Permanent Decrease:** A "permanent decrease" is characterized by a prolonged (4 time periods) decrease in the maximum advertised download speed. An example is provided below.

	hoconum	hocofinal	stateabbr	blockcode_str~g	techcode	maxaddown	maxadup	timeindex
340	130077	AT&T Inc.	IL	170010002011033	10	3	.384	1
341	130077	AT&T Inc.	IL	170010002011033	10	3	.384	2
342	130077	AT&T Inc.	IL	170010002011033	10	.768	.128	3
343	130077	AT&T Inc.	IL	170010002011033	10	.768	.128	4
344	130077	AT&T Inc.	IL	170010002011033	10	.768	.128	5
345	130077	AT&T Inc.	IL	170010002011033	10	.768	.128	6

Figure 3D: Example of a "Permanent Decrease"

These errors were carefully examined. For ‘permanent decreases,’ it is possible that an ISP revised its download speed downward and originally reported incorrect values. Because my panel is relatively short, ‘permanent decreases’ cannot be verified. Any census block, firm, and technology combination with a potential error of four time periods (over half of the total time periods) are ignored in regressions. For combinations with potential errors of three time periods or less (i.e. upward spike, downward spike, persistent upward spike), I rectify them with leading and ending download speed values (given that they are equal) in a new variable called *maxaddown_carryforward.*

Some of these errors may be due to relatively frequent infrastructure upgrades (see Appendix B for transition matrices of the number of technologies that a single ISP may have in a block). Anomalies may also arise from legacy observations. Comcast undertook a major cable upgrade in Illinois from around June 2016 to December 2016, going from DOCSIS3.0 to DOCSIS3.1, and likely misreported the number of blocks offering DOCSIS3.1 in the June 2016 Form 477 collection.

B. Missing Entries

Missing entries are gaps in reporting by a census block, firm, and technology combination. Gaps are demonstrated by observations both prior and after. But if a census block, firm, and technology combination disappears in time period 7 while having a consecutive run prior, then it is considered a market exit rather than a gap. Because imputing gaps is a rather drastic maneuver, I make a distinction between gaps of one period and gaps of two periods. Imputing gaps of one period assumes that ISPs cannot uninstall and reinstall the *same* broadband infrastructure in under 12 months. Imputing gaps of two periods assumes that ISPs cannot uninstall and reinstall the *same* broadband infrastructure in under 18 months. Examples of these gaps are shown below:

	hocofinal	stateabbr	blockcode	techcode	timeindex
1	AT&T Inc.	IL	1.703e+14	11	1
2	AT&T Inc.	IL	1.703e+14	11	2
3	AT&T Inc.	IL	1.703e+14	11	4
4	AT&T Inc.	IL	1.703e+14	11	5
5	AT&T Inc.	IL	1.703e+14	11	6
6	AT&T Inc.	IL	1.703e+14	11	7

Figure 4A: Gap of One Time Period

	hocofinal	stateabbr	blockcode	techcode	timeindex
7437795	AT&T Inc.	IL	1.720e+14	11	1
7437796	AT&T Inc.	IL	1.720e+14	11	4
7437797	AT&T Inc.	IL	1.720e+14	11	5
7437798	AT&T Inc.	IL	1.720e+14	11	6

Figure 4B: Gap of Two Time Periods

Missing entries are likely caused by the Form 477 requirement of 'having at least one subscriber'. But even if a census block, firm, technology combination did not have a subscriber, they are viable competition. Any gap over two periods is considered a genuine exit and re-entry. A table detailing the frequency and types of gaps is in Appendix A4.

C. Broadband Speeds Exceeding Technological Specification

ISPs sometimes report download speeds that far exceed a technology's specification. Both large ISPs (e.g., AT&T, Spectrum) and small ISPs make this error, suggesting fundamental problems with the Form 477. It is not uncommon to see observations of Asymmetric xDSL surpass 20 Mbps, far over its maximum International Telecommunication Union specification (G.992.1) of 12 Mbps.

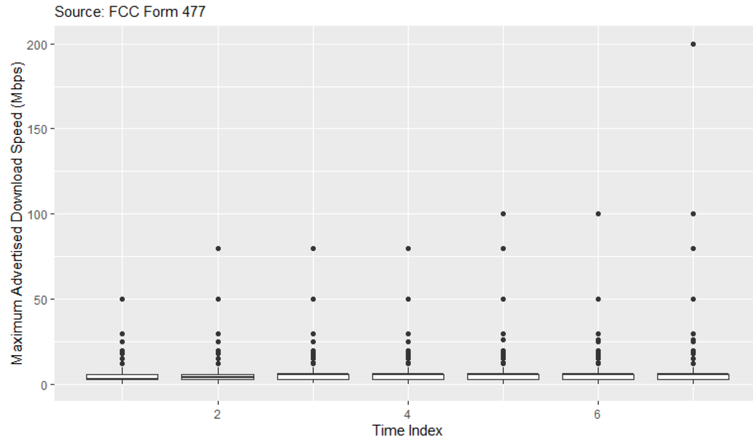

Figure 5A: Boxplot of Asymmetric xDSL Speed (June 2015 – June 2018)

Most maximum speed errors are likely caused by confusion over types of DSL. VDSL technology can support speeds up to 300 Mbps (see Figure 5B), whereas Asymmetric xDSL, even after upgrades, may only support up to 12 Mbps. Figure 5A shows that the vast majority of the Asymmetric xDSL observations are in the ≤ 12 Mbps range, verifying the technical specification. The boxplots for ADSL2, ADSL2+ (max speed of 24 Mbps) and VDSL (max speed of 300 Mbps) are included below for reference:

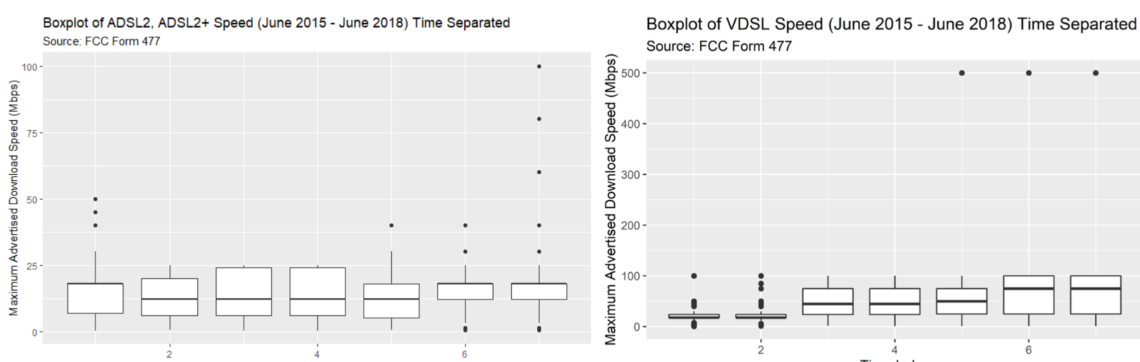

Figure 5B: Boxplots of ADSL2, ADSL2+ and VDSL (June 2015 – June 2018)

The number of observations reporting over technology specification is in Appendix A5. The technical standard for each Form 477 technology is in Appendix A2. I sought the "highest known" download speed for each technology to avoid disqualifying accurate observations. Census block, firm, and technology combinations flagged with this error are excluded from regressions.

B. Differences Between Cleaned and Uncleaned Datasets

I find statistically significant differences after data cleaning. In all three datasets (uncleaned, 1 time period imputed, and 2 time periods imputed), I find that the *maxaddown_carryforward* variable is, on average, lower than the original *maxaddown*. There are relatively few cases where *maxaddown* was adjusted upwards (see Appendix A3). Most adjustments are downward, such as excluding census block, firm, technology combinations with unrealistically high speeds. The average decrease is less than 1 Mbps.

Table 5: Summary Statistics for Differences Between Original *maxaddown* and *maxaddown_carryforward* in Different Datasets

	Uncleaned data	**1 time period imputed**	**2 time periods imputed**
Mean Difference (Mbps)	-0.842	-0.839	-0.839
95% Confidence Interval	(-0.848, -0.837)	(-0.844, -0.833)	(-0.844, -0.833)
Observations	6,802,809	6,846,163	6,855,176

C. Construction of the Geographic Entry Threat Model

Wilson, Xiao, and Orazem (2020) argue that when an ISP faces entry threats, they will lower expectations of future profit. They test their hypothesis by superimposing a circle on the centroid of zip code tabulation areas (ZCTAs) to identify entry threats. I improve on this method by developing a much more granular and precise geographic entry threat model. I first compute an adjacency matrix at the census block-level that contains adjacent census block pairs and the length of their shared border. I then overcome major computational difficulties when analyzing between-firm relationships (whether a firm is a threat or adjacent to itself) by innovating a scalable matching algorithm. For context, in Illinois, there are 1,384 ZCTAs, compared to 451,154 census blocks. This method fully exploits the Form 477's detail and is the first of its kind in broadband competition research.

I hypothesize that a lower expectation of future profit due to geographically adjacent threats will disincentivize technology or quality upgrades, thus lowering service quality. I define 'adjacent threats' as firms that serve census blocks that are first-order neighbors of census block *i* but are not in census block *i*.

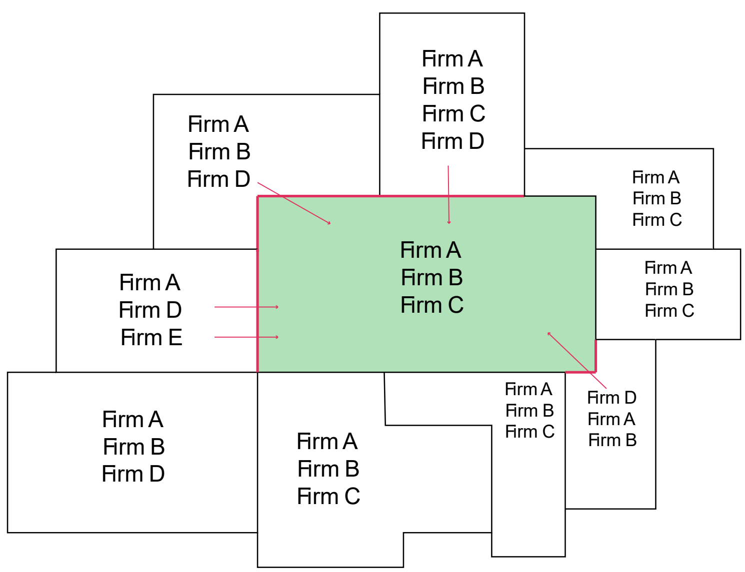

Figure 6: Graphic for Adjacent Threat

Suppose census block i, colored green, has 3 ISPs: A, B, and C. Firms D and E are not currently in census block *i,* but are operating in directly adjacent blocks (first order neighbors). There are many adjacent blocks that contain the exact same combination of firms as census block *i,* so these blocks are not considered threats. Firm D's and E's close proximity makes their expansion into census block *i* easier and more likely (highlighted by the arrows). The 'proportion of perimeter threatened' is the length of block i*'s* perimeter bordered by firms not in block *i* divided by block i*'s* total perimeter. The perimeter of census block *i* that is "threatened" is colored in red. Equation 1 accounts for differences in perceived threat:

Equation 1: 'Adjacent Threat Index' Composition

$$\text{Adjacent Threat Index}_{it} = \text{Proportion of Perimeter Threatened}_{it} \cdot \#\text{ Unique Adjacent Firms Not in Block } i_{it}$$

where *i* indexes census blocks in Illinois and *t* represents the time period. The high turnover of ISPs necessitates a recalculation of the index for each time period (Connolly and Prieger, 2013). For Figure 6, Adjacent Threat Index = 0.5 * 2 = 1, as approximately 50% of census block i*'s* perimeter is 'threatened' by two unique adjacent firms that are not in block *i.* If a 'threat' is adjacent by a node (that is, a corner), then it is not factored into the index, as that firm would presumably have to expand to a block directly adjacent first before entering census block *i*.

Although this geographic entry threat model is a significant improvement on previous efforts, it is still limited. It does not account for differences in adjacent firms and assumes that they are homogenous. Larger, national firms would pose a much greater adjacent threat because they are well-resourced and are often the most innovative. My model also diffuses the effect of one adjacent firm to the entire threatened perimeter. Future analyses with more computing power may be able to overcome these limitations.

IV. Theoretical Framework

I base this study's theoretical framework on Ericson and Pakes (1995) (henceforth EP) theory of dynamic interactions in oligopolistic industries. Players (firms) are heterogenous: they are either an incumbent firm or a potential entrant. Entry, exit, or stay decisions are made at the start of each time period. The EP framework relies on Markov perfect equilibrium (Maskin and Tirole, 1987), where next steps by competitors are conditioned only on the current 'state', thereby excluding possibilities of collusion or cooperation. The data fits well with these assumptions.

A. Census Block Entry

Potential entrants base their decisions on the net present value of entering at present time. I do not account for the option of delaying entry, although entry delay exists in the broadband market (Wilson, Xiao and Orazem, 2020). The expected profit function for a potential entrant is given below:

Equation 2: Profit Function for a Potential Entrant

$$\begin{aligned}\mathbb{E}(\Pi^e_{bt}) = \alpha_{0t} \\ &+ \alpha_{1t}\text{MuniISPinBlock}_{bt} + \alpha_{2t}\text{CoopISPinBlock}_{bt} \\ &+ \alpha_{3t}\text{MuniNonISPinBlock}_{bt} + \alpha_{4t}\text{CoopNonISPinBlock}_{bt} \\ &+ \sum_{i=5}^{n} \alpha_{it} X_{ibt} \\ &+ \nu^e_{bt}\end{aligned}$$

At time *t*, for block *b,* potential entrant *e* is assumed to have reliable information on the presence of municipal ISPs and non-ISPs, or cooperative ISPs and non-ISPs, market structure information and demand (i.e., number of incumbent firms, quality of service, population; $\sum_{i=5}^{n} \alpha_{it} X_{ibt}$), and a stochastic error term for unobservable internal factors (υ_{bt}^{e}). Equation 2 is somewhat idealized because it assumes that potential entrants have more timely information than the researcher, such that they decide entry "in the moment". A potential entrant will enter if and only if $E(\Pi^{e}_{bt}) \geq 0$.

Equation 2 does not take into consideration 'adjacent threat'. For potential entrants that are not currently adjacent to block *b*, I assume that its information is limited to the "current state of the field", where it cannot reliably predict future behaviors of incumbents. Non-adjacent potential entrants are also less likely to know the exact geographic borders of their deployment. Adjacent potential entrants are likely to have better information on the local competitive landscape and can better predict actions by nearby incumbents. It may, however, be too generous to factor this knowledge in, as it would assume that potential entrants are extremely forward-looking, when in reality, "potential entrants are short lived" (Dorazelski and Pakes, 2007). The core difference between these two types of potential entrants likely lies in setup costs, where potential entrants already adjacent are heavily favored. But it is not possible to determine types of potential entrants from the researcher's perspective.

This entry model does not delineate between technologies, so differences in entry technology is likely captured by the stochastic error term. A potential entrant may enter with such superior technology that it can capture most, if not all, of incumbent market share. The additional market share may be enough to offset extra costs imposed by the presence of municipal or cooperative ISPs or non-ISPs.

B. Broadband Speed/Technology Upgrades

In each time period, incumbent firms must decide whether to remain or to exit (Doraszelski and Pakes, 2007). If an incumbent remains, then they must decide how much to invest. For broadband, 'investment' means deploying superior technologies. The profit function for an incumbent ISP is as follows:

Equation 3: Profit Function for an Incumbent ISP

$$\begin{aligned}\mathbb{E}(\Pi^i_{bt}) = {} & \alpha_{0t} \\ & + \alpha_{1t}\,(\text{UniqueAdjFirms}_{bt} \cdot \text{ThreatenedPerimeter}_{bt}) \\ & + \alpha_{2t}\text{MuniISPinBlock}_{bt} + \alpha_{3t}\text{CoopISPinBlock}_{bt} \\ & + \alpha_{4t}\text{MuniNonISPinBlock}_{bt} + \alpha_{5t}\text{CoopNonISPinBlock}_{bt} \\ & + \sum_{i=6}^{n} \alpha_{it} X_{ibt} \\ & + \nu^i_{bt}\end{aligned}$$

At time *t*, in block *b,* incumbent *i*'s expected future profit is determined by block *b's* adjacent threat, the presence of municipal or cooperative ISPs, the presence of municipal or cooperative non-ISPs, a vector of market structure and demand variables ($\sum_{i=6}^{n} \alpha_{it} X_{ibt}$), and stochastic error term that accounts for unobserved internal factors of incumbent i (υ^i_{bt}).

An incumbent will remain in a block if and only if $E(\Pi^i_{bt}) \geq 0$. An incumbent will only invest in superior technologies or increased penetration if it believes that it can gain market share over other incumbents, increase prices, or deter future entrants by doing so (Xiao and Orazem, 2011). Greater adjacent threat (and therefore higher entry probability) means that more must be expended to retain or secure market share. Intrinsic characteristics of the broadband market may make this investment more worthwhile because of broadband deployment's high fixed costs and time commitment, allowing incumbents to guarantee some monopolization at higher levels of service in the short term (Schumpeter, 1943).

The EP framework also states that higher investment at present does not guarantee a better future payoff, but it does ensure a more favorable distribution of future payoffs. I hypothesize that the presence of municipal ISPs or non-ISPs, or cooperative ISPs or non-ISPs, can significantly alter this distribution of future payoffs. It is plausible that even when a private sector ISP is willing to innovate for short-term profits, other factors associated with the presence of municipal or cooperative ISPs or non-ISPs (i.e., risk of future increase in pole attachment rates) may offset these profit calculations sufficiently to pre-empt investment.

V. Empirical Strategy

A. Conditional Fixed Effects Logit Model

I use a conditional fixed effects logit model to determine the impact of municipal and cooperative ISPs' and non-ISPs' impact on market entry. The dependent variable is a binary variable for census block entry. There is no publicly available data for census block broadband penetration, so entry is assumed to mean 100% block coverage, though this is rarely the case. I make use of lagged independent variables with the assumptions that firms are forward-looking in the short term and that entry decisions are dynamic (see Section IV). I ignore potential complications of Nickell bias because *T* is relatively low (Nickell, 1981). The model is as follows:

Equation 4: Conditional Fixed Effects Logit Model

$$\begin{aligned}
\ln \frac{L_i}{1-L_i} = {} & \beta_0 \\
& + \beta_1(\text{Number of Incumbents}_{it-1}) \\
& + \beta_2(\text{Adjacent Threat Index}_{it-1}) \\
& + \beta_3(\text{Municipal ISP Presence}_{it-1}) + \beta_4(\text{Cooperative ISP Presence}_{it-1}) \\
& + \beta_5(\text{Municipal Non-ISP Presence}_{it-1}) + \beta_6(\text{Cooperative Non-ISP Presence}_{it-1}) \\
& + \beta_7(\text{Block Housing Density}_{it-1}) + \beta_8(\text{Median Household Income}_{it-1}) \\
& + \alpha_i + \delta_t + \varepsilon_{it}
\end{aligned}$$

where census blocks in Illinois are indexed by *i*, *t* denotes the time period, α_i represents census block fixed effects, and δ_t symbolizes time fixed effects. L_i is the likelihood of any ISP entering census block *i* in the present time period. I include time fixed effects to partially address omitted variable bias, particularly capturing the evolution of broadband technologies, regulation changes, and macroeconomic trends. Census block fixed effects consider local geographic features and likely many unobserved factors that impact market entry. All explanatory variables are lagged one time period (6 months). This logit model does not consider the infrequent scenarios of city limit constraints for municipal ISPs and consortiums formed by cooperative ISPs.

B. Fixed Effects Model

I determine impacts on service quality by municipal and cooperative ISPs and non-ISPs using a fixed effects model, with dependent variable log block maximum speed. A Hausman test confirms this choice. The fixed effects model eliminates some unobserved heterogeneity, such as differences in firm size, and some variation caused by confounding factors (Wooldridge, 2010). The model is as follows:

Equation 5: Fixed Effects Model

$$
\begin{aligned}
\ln(\text{Block Maximum Speed}_{it}) = \beta_0 \\
&+ \beta_1(\text{Number of Incumbents}_{it}) + \beta_2(\text{Number of Entrants}_{it}) + \beta_3(\text{Number of Exits}_{it}) \\
&+ \beta_4(\text{Adjacent Threat Index}_{it}) \\
&+ \beta_5(\text{Municipal ISP Presence}_{it}) + \beta_6(\text{Cooperative ISP Presence}_{it}) \\
&+ \beta_7(\text{Municipal Non-ISP Presence}_{it}) + \beta_8(\text{Cooperative Non-ISP Presence}_{it}) \\
&+ \beta_9(\text{Block Housing Density}_{it}) + \beta_{10}(\text{Median Household Income}_{it}) \\
&+ \alpha_i + \delta_t + \varepsilon_{it}
\end{aligned}
$$

The logical arrangement of this fixed effects specification is very similar to that of the conditional fixed effects logit model, except the variables are not lagged. α_i controls for census block fixed effects, δ_t captures time fixed effects, and ε_{it} is the idiosyncratic heteroskedasticity-robust error. I take the natural logarithm of the census block maximum speed to counteract skewness from high download speeds (i.e., fiber or DOCSIS 3.1 with 1000 Mbps).

The regressors are separated into four categories. Number of incumbents, number of entrants, and number of exits are market structure variables. Adjacent threat index, explained in

Section III, captures the effect of entry threat by firms in adjacent census blocks not already in block *i*. Indicator variables for the presence of municipal and cooperative ISPs and non-ISPs are the main interest. Housing density and the natural log of median household income characterize a census block's broadband demand.

The location and placement of municipal and cooperative ISPs is considered mostly exogenous, although unobserved factors (like self-dealing) may violate this assumption.

I am, however, cognizant of potential endogeneity, particularly in the market structure and adjacent threat variables. Reverse causality may arise where the number of entrants is lower because of high block maximum speed. The adjacent threat index may suffer from reverse causality as well because regions with lower block maximum speeds may invite more adjacent competitors. Some market attractiveness variables, like block housing density, can also be endogenous, especially as people migrate to areas with better broadband (Kim and Orazem, 2016). I did not find a strong and valid instrument for 2 stage least squares. I loosen the fixed effect exogeneity assumption to accommodate these issues.

VI. Results

A. Impacts by Municipal and Cooperative ISPs and Non-ISPs on Broadband Market Entry

The conditional fixed effects logit regression shows that the presence of a municipal or a cooperative ISP heavily depresses the probability of entry, while the presence of a municipal non-ISP appears to have little effect, and the presence of a cooperative non-ISP seems to promote entry. ‘OR’ stands for odds ratio for easier interpretation. The full logit model for the 1 time period imputed dataset is below; logit models on uncleaned and 2 time periods imputed data are in Appendix C1-1.

Table 6: Conditional Fixed Effect Logit Regression Odd Ratio Estimates for the Presence of Municipal or Cooperative ISPs on the Probability of Census Block Entry

	1 time period imputed dataset	
	Dependent variable: *Census block entry*	
VARIABLES	Odds ratio	*“Odds of block entry with one unit increase in variable”*
Number of incumbents in previous time period	1.611***	61.1% higher
Adjacent Threat Index in previous time period	3.354***	335.4% higher
Presence of municipal ISPs in the previous time period	0.191***	80.9% lower
Presence of cooperative ISPs in the previous time period	0.126***	87.4% lower
Presence of municipal non-ISPs in the previous time period	0.829	Not significant
Presence of cooperative non-ISPs in the previous time period	2.207***	120.7% higher
Block housing density in previous time period	1.000***	Significant but small effect
Log of block group median household income in previous time period	1.017***	1% increase in median household income equates to 1.7% increased probability of entry
Time fixed effects	YES	

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

I also execute a rural versus urban clusters versus urbanized areas comparison (Table 5). In all three datasets, the presence of a municipal ISP lowers the probability of entry significantly in rural and urbanized area census blocks, but not in urban clusters blocks (although this may be because of low within-group variation). The presence of a cooperative ISP suppresses probability of block entry in all markets. The presence of a municipal non-ISP appears to have little to no effect, while the presence of a cooperative non-ISP increases the probability of block entry in rural and urbanized area census blocks. This increase in probability, however, is likely due to the low resolution of cooperative non-ISP data, where it is capturing the intrinsic high rate of entry in the broadband market itself. For conciseness, I only include the full regression result of the 1 time period imputed dataset is below. Results from uncleaned and 2 time periods imputed data can be found in Appendix C1-2 and C1-4, respectively.

Table 7: Conditional Fixed Effects Logit Regression Estimates for the Presence of Municipal or Cooperative ISPs on the Probability of Census Block Entry, Disaggregated by Rural and Urban Census Blocks

	1 time period imputed					
	Dependent variable: *Census block entry*					
	Rural (< 2,500 people)		Urban Clusters (2,500 to 50,000 people)		Urbanized Area (> 50,000 people)	
	Odds Ratio	*"Odds of block entry in present time"*	Odds Ratio	*"Odds of block entry in present time"*	Odds Ratio	*"Odds of block entry in present time"*
Number of incumbents in previous time period	1.122***	12.2% higher	1.719***	71.9% higher	0.994***	0.6% lower
Adjacent Threat Index in previous time period	2.573	157.3% higher	10.185***	918.5% higher	4.269***	326.9% higher
Presence of municipal ISPs in the previous time period (*n = 25,178 blocks by June '18*)	0.173*** (*n = 8,853 blocks by June '18*)	82.7% lower	0.700 (*n = 2,177 blocks by June '18*)	Not statistically significant	0.192*** (*n = 14,148 blocks by June '18*)	80.8% lower
Presence of cooperative ISPs in the previous time period *(n = 39,405 blocks by June '18)*	0.192*** (*n = 30,683 blocks by June '18*)	80.8% lower	0.110*** (*n = 8,156 blocks by June '18*)	89.0% lower	0.105*** (*n = 566 blocks by June '18*)	89.5% lower
Presence of municipal non-ISPs in the previous time period	0.618	Not statistically significant	1.100	Not statistically significant	1.466	Not statistically significant
Presence of cooperative non-ISPs in the previous time period	2.289***	128.9% higher	0.928	Not statistically significant	13.696***	1269.6% higher
Block housing density in previous time period	1.000***	Significant but small	1.000***	Significant but small	1.000***	Significant but small
Log of block group median household income in previous time period	0.507***	1% increase in median household income equates to 49.3% decreased probability of entry	1.066***	1% increase in median household income equates to 6.6% increased probability of entry	1.181***	1% increase in median household income equates to 18.1% increased probability of entry
Time fixed effects	YES		YES		YES	

*** p<0.01, ** p<0.05, * p<0.1

B. Impacts by Municipal and Cooperative ISPs and Non-ISPs on Broadband Service Quality

In all datasets, I find that the presence of a municipal ISP (except in the uncleaned dataset) or non-ISP, or a cooperative ISP or non-ISP, depresses a census block's maximum speed, although the magnitude of decrease is small:

Table 8: Fixed Effects Regression Coefficients for Presence of Municipal and Cooperative ISPs and non-ISPs on Log Block Maximum Speed (Abridged; See Full Regression in Appendix C2-1)

	Dependent variable: *Log block maximum speed*		
	Uncleaned data	1 time period imputed	2 time periods imputed
Presence of municipal ISPs (Block)	-0.0386	-0.0624**	-0.222***
	(0.0314)	(0.0307)	(0.0244)
Presence of cooperative ISPs (Block)	-0.342***	-0.286***	-0.282***
	(0.00404)	(0.00397)	(0.00395)
Presence of municipal non-ISPs (Block)	-0.164***	-0.171***	-0.105***
	(0.0392)	(0.0384)	(0.0375)
Presence of cooperative non-ISPs (Block)	-0.259***	-0.241***	-0.213***
	(0.0289)	(0.0283)	(0.0281)

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

I break down the service quality analysis by rural versus urban clusters versus urbanized areas comparison as well. The presence of a municipal ISP consistently lowers block maximum speed in urbanized areas. The presence of a cooperative ISP consistently lowers block maximum speed in rural areas and urban clusters, with a minor decrease in urbanized areas in the imputed datasets. The presence of a municipal non-ISP lowers block maximum speed markedly in urbanized areas, but not in others. The presence of a cooperative non-ISP lowers block maximum speed in urbanized areas, with minor negative effects in urban clusters. The full fixed effects regression result of the 1 time period imputed dataset is below. Results from uncleaned and 2 time periods imputed data can be found in Appendix C2-2 and C2-4, respectively.

Table 9: Fixed Effects Model Regression Coefficients for Presence of Municipal and Cooperative ISPs and non-ISPs on Log Block Maximum Speed, Disaggregated by Rural, Urban Clusters, and Urbanized Area Census Blocks

	1 time period imputed		
	Dependent variable: *Log block maximum speed*		
	Rural (< 2,500 people)	Urban Clusters (2,500 to 50,000 people)	Urbanized Area (> 50,000 people)
Number of Entrants (Block)	0.493***	0.522***	0.306***
	(0.00231)	(0.00374)	(0.00181)
Number of Exits (Block)	-0.0215***	-0.0884***	0.0837***
	(0.00217)	(0.00336)	(0.00176)
Number of Incumbents (Block)	0.469***	0.553***	0.436***
	(0.00230)	(0.00370)	(0.00179)
Adjacent Threat Index (Block)	-0.253***	-0.303***	-0.413***
	(0.00372)	(0.00865)	(0.00357)
Presence of Municipal ISPs (Block)	-0.00550	0.0660	-0.170***
	(0.0498)	(0.166)	(0.0361)
Presence of Cooperative ISPs (Block)	-0.0139***	-0.300***	0.0327***
	(0.00517)	(0.00823)	(0.0104)
Presence of Municipal Non-ISPs (Block)	-0.0329	-0.130	-0.380***
	(0.0628)	(0.144)	(0.0461)
Presence of Cooperative Non-ISPs (Block)	-0.0402	-0.168*	-0.195***
	(0.0387)	(0.0874)	(0.0539)
Housing Density (Block)	-6.07e-05*	-0.000249***	-6.73e-05***
	(3.35e-05)	(5.82e-05)	(8.51e-06)
Median Household Income (Block Group)	5.27e-07***	2.79e-06***	7.43e-07***
	(1.78e-07)	(2.72e-07)	(8.74e-08)
Time fixed effect	YES	YES	YES

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

Table 9 shows that most of the negative effect in Table 8 are driven by the presence of municipal and cooperative ISPs and non-ISPs in urban clusters and urbanized areas, with very little to no effect in rural regions.

C. Others

High levels of adjacent threat greatly increase the odds of block entry in a subsequent time period, as expected. I also find that service quality is negatively correlated with the degree of entry threat, matching the conclusion drawn by Wilson, Xiao, and Orazem (2020).

VII. Discussion

A. Effects on Probability of Market Entry by Municipal and Cooperative ISPs

I find that the presence of a municipal ISP decreases the probability of market entry in rural and urbanized areas, after controlling for market structure. In rural areas, there are generally less than two incumbent firms, so an incumbent municipal ISP decreasing the probability of market entry is no different than an investor-owned ISP saturating its market. In urbanized areas, however, there is much higher market demand given much greater household density. Municipal ISPs decreasing probability of entry in urbanized areas potentially means that they are leveraging their ownership of utility poles to deter entry and preserve market share. Table 4 in Section II shows that municipal ISP service areas are no less desirable with respect to median household income. Private ISPs would certainly have greater economies of scale. Taxpayer dollars for urbanized area municipal ISPs may be better spent elsewhere.

The presence of a cooperative ISP decreases the probability of entry in all three types of markets (Table 7). In rural areas, the cause for lower probability of entry is likely also because of market saturation. In urbanized areas, the result should be cautiously interpreted because of low observations (n = 556 in June 2018). The lower probability of entry in urban clusters, however, does not suffer from the above issues. After controlling for block housing density and median household income, I find that the presence of a cooperative ISP is associated with 89.0% lower odds of entry in urban clusters (Table 7). This result suggests potential anticompetitive pole ownership behavior.

B. Effects on Probability of Market Entry by Municipal and Cooperative Non-ISPs

The presence of a municipal non-ISP is not associated with lower probabilities of entry. Municipal non-ISPs may genuinely desire for private ISPs to serve their jurisdiction. Municipal projects also take considerable time and effort to be approved. Private ISPs, particularly sizeable ones, may believe that they can successfully "intervene" in planning stages, thereby reducing the perceived entry threat.

The presence of a cooperative non-ISP, on the other hand, is associated with a significant increase in the probability of entry. This effect is likely not due to factors intrinsic to cooperative non-ISPs, but rather how the dataset is constructed. Recall that all cooperative non-ISPs only have service area data at the county level (Figure 1B). Given that cooperative non-ISPs serve 62 out of 102 counties in Illinois, this large positive effect on entry is likely only capturing the broadband market's high firm turnover.

C. Effects on Broadband Service Quality by Municipal and Cooperative ISPs

I find that the presence of a municipal ISP is associated with lower block maximum speeds in urbanized areas only. The presence of a cooperative ISP is associated with lower block maximum speed in rural and urban clusters, although the effect's magnitude in rural areas is very small. These negative effects can be traced back to the utility pole rate discussion and the theoretical framework. If municipal and cooperative ISPs can sufficiently deter entry via excessive pole rates, then their perception of entry threats is reduced, thereby increasing expected profits (Equation 3). Sustained and protected positive profits may significantly disincentivize investments in service quality upgrades.

D. Effects on Broadband Service Quality by Municipal and Cooperative Non-ISPs

The presence of a municipal or a cooperative non-ISP is associated with lower block maximum speeds in urbanized areas only. While municipal and cooperative non-ISPs do not reduce the probability of entry, they may have a large enough impact on the expected profit calculations of incumbent private ISPs to slow down, but not necessarily eliminate, investment on infrastructure upgrades. This result, unfortunately, can only be suggestive, because of poor data resolution for municipal and cooperative non-ISPs.

E. In Conjunction

The most powerful results of this analysis come from linking the conclusions for probability of entry with that of service quality. The presence of a municipal ISP is associated with lower probability of entry and service quality in urbanized areas. Regulations barring municipalities from serving urban clusters and urbanized areas may be prudent. At the same time, municipal broadband for rural areas can (and maybe should) be considered to close the digital divide.

The presence of a cooperative ISP is associated with lower probability of entry and service quality in rural areas and urban clusters. Similarly, it may be sensible policy to prevent cooperative ISPs from operating in urban clusters and urbanized areas. The lower service quality, however, is small enough in magnitude that it should be relegated to a secondary concern. Programs supporting cooperative broadband in rural areas can be beneficial.

F. Errors and Limitations

There are some noteworthy limitations to this paper's analysis. I only use the U.S. Census Bureau's designation for rural, urban clusters, and urbanized areas, instead of conducting a more rigorous matching analysis. Blocks within rural, urban clusters, and urbanized areas are not homogenous and vary considerably. Block entry is also not homogenous; differences in entry technology and firm size are obvious examples. Noise is introduced by low data resolutions.

The data cleaning techniques do not cover all errors. There were several suspicious speed oscillations that did not conform to the data cleaning assumptions.

Imputation of 2 time periods may be overly aggressive and its results less valid. The process undoubtedly overestimates the number of entries and incumbents and underestimates the number of exits. Future research can improve on these shortcomings and limitations.

VIII. Conclusion

Against the backdrop of renewed policy debates over the legality of municipal and cooperative broadband, this paper sheds light on the competitive effects of municipal and cooperative ISPs and non-ISPs in Illinois. I create brand-new datasets of municipal and cooperative service areas, develop a novel geographic entry threat model, and conduct extensive data cleaning. Techniques laid out in this paper can aid future broadband competition research.

Conditional fixed effects logit regressions demonstrate that the presence of a municipal ISP deters entry in rural and urbanized area census blocks, and the presence of a cooperative ISP dissuades market entry in all market types. Municipal and cooperative non-ISPs appear to influence market entry little, although this may be attributed to poor data.

Fixed effects regressions show that the presence of a municipal ISP exerts a statistically significant negative effect on service quality in urbanized areas. The presence of a cooperative ISP is associated with lower service quality in rural areas and urban clusters. The presence of municipal or cooperative non-ISPs depresses service quality in urbanized areas, likely for their perceived threat of future entry.

An uncomfortable truth unravels as lower market entry probabilities are coupled with decreases broadband service quality. Legislators may be wise to prohibit municipal and cooperative broadband in urban clusters and urbanized areas. But in rural area, encouraging municipal or cooperative broadband can be essential to address the urban-rural digital divide.

It bears mentioning that these results may not generalize due to the sheer number of factors considered. A relatively easy next step would be to employ the same analysis on other states with municipal and cooperative ISPs. Genetic matching should be used to identify similar census blocks for a more robust treatment-based analysis. Differentiating between technologies in market entry would be more accurate. Thoroughly investigating the economic consequences of digital divide solutions now benefits Americans sooner and avoids painful decisions in the future.

Appendix A: Dataset Explanations

Table A1: Encoded Time Periods

Time Period #	Corresponding Time of Release
1	June 2015
2	December 2015
3	June 2016
4	December 2016
5	June 2017
6	December 2017
7	June 2018

Table A2: Theoretical Maximum Speeds for Technologies in the Form 477

Technology Label	Max Speed (downstream)	Source
Asymmetric xDSL	12 Mbps (over POTS)	ITU G.992.1
ADSL2 & ADSL2+	24 Mbps	ITU G.992.3 / ITU G.992.5
VDSL & VDSL2	300 Mbps	ITU G.993.1 / ITU G.993.2
Symmetric xDSL	N/A (Proprietary technology)	N/A
Other Copper Wireline	N/A	N/A
Cable Modem (non-DOCSIS)	N/A (Not standardized)	N/A
Cable DOCSIS 1, 1.1, 2.0	40 Mbps	Cable Labs
Cable DOCSIS 3.0	1 Gbps	Cable Labs
Cable DOCSIS 3.1	10 Gbps	Cable Labs
Fiber	1 Gbps +	Multiple sources
Terrestrial Fixed Wireless	500 Mbps (business-grade)	BroadbandNow

Table A3: Tabulation of Dataset Anomalies and Errors

	Number of unique census blocks (in all time periods)	Number of unique firms	Number of census block, firm, technology combinations (in all time periods
Upward spike	1,281	12	1,284
Downward spike	765	11	772
Persistent upward spike	28,118	24	28,455
Permanent decrease	38,109	23	38,667

Table A4: Tabulation of Missing Entries

	Number of census block, firm, technology combinations (in all time periods)
Gap of 1 time period	36,514
Gaps of 2 time periods	12,364
Gaps of 3 time periods	24,276
Gaps of 4 time periods	388
Gaps of 5 time periods	65

Table A5: Tabulation of Observations Over Theoretical Maximum Download Speed

	Number of observations over maximum theoretical speed	Number of census block, firm, technology combinations (in all time periods
Tech Code 10 (Asymmetric xDSL)	37,701	6,469
Tech Code 11 (ADSL2, ADSL2+)	55,626	40,279
Tech Code 12 (VDSL)	6	4
Tech Code 41	1,328	1,328
Tech Code 70 (Terrestrial Fixed Wireless)	523	522

Appendix B: Broadband Technology Transition Matrices

- The discrepancies between the totals (e.g. Table 1 – "Total of Time Index 2: 2,148,879 (1 technology)" → Table 2 – "Total of Time Index 2: 2,144,352 (1 technology)") is due to firms entering and exiting. The matrices only account for those who have data across any two time indexes that are examined.
- Each cell starts with the frequency, then the probability of that type of scenario (in percent).
- This matrix is "net", so it does not account for a firm having the same number of technologies in a block but swapped one of them out. Positive net change in # of technologies is highlighted in green and negative net change is highlighted in red.

Table B1: Time Index 1 → Time Index 2 (June 2015 – December 2015)

		# of technologies held by a firm in a block **(Time Index 2)**			
		1	2	3	Total of Time Index 1
# of technologies held by a firm in a block **(Time Index 1)**	1	2,136,267	16,408	6,763	2,159,438
	(probability)	(98.93%)	(0.76%)	(0.31%)	
	2	12,389	64,801	3,523	80,713
	(probability)	(15.35%)	(80.29%)	(4.36%)	
	3	223	80,969	1,498	82,690

Table B2: Time Index 2 → Time Index 3 (December 2015 – June 2016)

		# of technologies held by a firm in a block **(Time Index 3)**			
		1	2	3	Total of Time Index 2
# of technologies held by a firm in a block **(Time Index 2)**	1	2,136,894	7,266	192	2,144,352
	(probability)	(99.65%)	(0.34%)	(0.01%)	
	2	3,265	180,367	2,330	185,962
	(probability)	(1.76%)	(96.99%)	(1.25%)	

Table B3: Time Index 3 → Time Index 4 (June 2016 – December 2016)

		# of technologies held by a firm in a block **(Time Index 4)**				
		1	2	3	4	Total of Time Index 3
# of technologies held by a firm in a block **(Time Index 3)**	1	2,099,598	1,899	45	1	2,101,543
	(probability)	(99.91%)	(0.09%)	(0.00%)	(0.00%)	
	2	1,911	200,072	1,401	14	203,398
	(probability)	(0.94%)	(98.36%)	(0.69%)	(0.01%)	
	3	19	415	21,277	42	21,753

Table B4: Time Index 4 → Time Index 5 (December 2016 – June 2017)

		# of technologies held by a firm in a block **(Time Index 5)**					
		1	2	3	4	5	Total of Time Index 4
# of technologies held by a firm in a block **(Time Index 4)**	1	2,122,612	15,422	773	132	0	2,138,939
	(probability)	(99.24%)	(0.72%)	(0.04%)	(0.01%)	(0.00%)	
	2	1,871	108,058	88,557	4,906	1	203,393
	(probability)	(0.92%)	(53.13%)	(43.54%)	(2.41%)	(0.00%)	
	3	25	1,908	20,761	71	0	22,765
	(probability)	(0.11%)	(8.38%)	(91.20%)	(0.31%)	(0.00%)	

Table B5: Time Index 5 → Time Index 6 (June 2017 – December 2017)

		# of technologies held by a firm in a block **(Time Index 6)**					
		1	2	3	4	5	Total of Time Index 5
# of technologies held by a firm in a block **(Time Index 5)**	1	1,971,750	3,426	36	1	0	1,975,213
	(probability)	(99.82%)	(0.17%)	(0.00%)	(0.00%)	(0.00%)	
	2	4,206	118,506	3,199	39	0	125,950
	(probability)	(3.34%)	(94.09%)	(2.54%)	(0.03%)	(0.00%)	
	3	19	418	107,507	2,278	0	110,222
	(probability)	(0.02%)	(0.38%)	(97.54%)	(2.07%)	(0.00%)	
	4	19	8	74	5,068	1	5,152

Table B6: Time Index 6 → Time Index 7 (December 2017 – June 2018)

		# of technologies held by a firm in a block **(Time Index 7)**				
		1	2	3	4	Total of Time Index 6
# of technologies held by a firm in a block **(Time Index 6)**	1	1,992,911	1,033	38	0	1,993,982
	(probability)	(99.95%)	(0.05%)	(0.00%)	(0.00%)	
	2	1,368	55,430	1,281	6	58,085
	(probability)	(2.36%)	(95.43%)	(2.21%)	(0.01%)	
	3	55	959	22,181	65	23,260
	(probability)	(0.24%)	(4.12%)	(95.36%)	(0.28%)	

Appendix C: Regressions

Table C1-1: Baseline Conditional Fixed Effects Logit Regression on Census Block Entry

	Dependent Variable: *Block Entry*					
VARIABLES	Uncleaned Data		1 time period imputed		2 time periods imputed	
	Coefficients	Odds Ratios	Coefficients	Odds Ratios	Coefficients	Odds Ratios
Number of Incumbents (Lag 1)	0.365***	1.440	0.477***	1.611	0.500***	1.649
	(0.00431)		(0.00449)		(0.00454)	
Adjacent Threat Index (Lag 1)	1.117***	3.055	1.210***	3.354	1.210***	3.354
	(0.0132)		(0.0141)		(0.0142)	
Municipal ISP Presence (Lag 1)	**-1.250*****	**0.287**	**-1.655*****	**0.191**	**-2.024*****	**0.132**
	(0.132)		**(0.135)**		**(0.109)**	
Cooperative ISP Presence (Lag 1)	**-1.869*****	**0.154**	**-2.073*****	**0.126**	**-2.083*****	**0.125**
	(0.0154)		**(0.0158)**		**(0.0158)**	
Municipal Non-ISP Presence (Lag 1)	**-0.406****	**0.666**	-0.187	0.829	0.0340	1.035
	(0.189)		(0.195)		(0.193)	
Cooperative Non-ISP Presence (Lag 1)	**0.567*****	**1.764**	**0.792*****	**2.207**	**0.924*****	**2.520**
	(0.169)		**(0.181)**		**(0.183)**	
Block Housing Density (Lag 1)	-0.000222***	1.000	-0.000246***	1.000	-0.000229***	1.000
	(5.58e-05)		(5.71e-05)		(5.70e-05)	
Median Household Income (Block Group) (Lag 1)	2.51e-06***	1.000	2.20e-06***	1.000	2.35e-06***	1.000
	(3.51e-07)		(3.57e-07)		(3.57e-07)	
Time Fixed Effects						
Time Index 4 (December 2016)	0.676***	1.966	0.762***	2.144	0.792***	2.209
	(0.00642)		(0.00674)		(0.00679)	
Time Index 5 (June 2017)	-0.847***	0.429	-0.789***	0.454	-0.786***	0.456
	(0.00910)		(0.00972)		(0.00987)	
Time Index 6 (December 2017)	1.812***	6.124	1.852***	6.370	1.869***	6.483
	(0.00641)		(0.00671)		(0.00677)	
Time Index 7 (June 2018)	2.355***	10.536	2.562***	12.959	2.589***	13.323
	(0.00689)		(0.00719)		(0.00726)	
Census Block Fixed Effect	YES		YES		YES	
Observations	1,523,811		1,499,529		1,495,369	
Number of Census Blocks	313,013		307,624		306,717	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C1-2: Conditional Fixed Effects Logit Regression Disaggregated by Rural, Urban Cluster, and Urbanized Area Census Blocks **(Uncleaned Data)**

	Dependent Variable: *Block Entry*					
VARIABLES	Rural	Rural	Urban Cluster	Urban Cluster	Urbanized Area	Urbanized Area
	Coefficients	Odds Ratios	Coefficients	Odds Ratios	Coefficients	Odds Ratios
Number of Incumbents (Lag 1)	0.0507***	1.052	0.302***	1.353	-0.170***	0.844
	(0.00784)		(0.0121)		(0.00780)	
Adjacent Threat Index (Lag 1)	1.004***	2.730	1.778***	5.918	1.492***	4.445
	(0.0194)		(0.0438)		(0.0229)	
Municipal ISP Presence (Lag 1)	**-0.977*****	**0.376**	-0.603	0.547	**-1.510*****	**0.221**
	(0.222)		(0.868)		**(0.206)**	
Cooperative ISP Presence (Lag 1)	**-1.534*****	**0.216**	**-1.996*****	**0.136**	**-2.121*****	**0.120**
	(0.0209)		**(0.0403)**		**(0.0749)**	
Municipal Non-ISP Presence (Lag 1)	**-0.863****	**0.422**	-0.676	0.509	0.416	1.516
	(0.356)		(0.798)		(0.268)	
Cooperative Non-ISP Presence (Lag 1)	**0.540****	**1.716**	-0.00396	0.996	**2.591*****	**13.340**
	(0.231)		(0.492)		**(0.521)**	
Block Housing Density (Lag 1)	-0.000304**	1.000	-0.000672**	1.000	-0.000311***	1.000
	(0.000151)		(0.000281)		(6.80e-05)	
Median Household Income (Block Group) (Lag 1)	-9.44e-06***	1.000	-4.50e-06***	1.000	3.51e-06***	1.000
	(8.00e-07)		(1.23e-06)		(5.36e-07)	
Time Fixed Effects						
Time Index 4 (December 2016)	1.582***	4.866	2.339***	10.373	-0.268***	0.765
	(0.0123)		(0.0235)		(0.00917)	
Time Index 5 (June 2017)	0.0698***	1.072	0.232***	1.261	-1.632***	0.196
	(0.0154)		(0.0294)		(0.0136)	
Time Index 6 (December 2017)	3.215***	24.913	3.738***	42.007	0.783***	2.188
	(0.0134)		(0.0247)		(0.00837)	
Time Index 7 (June 2018)	1.353***	3.868	2.499***	12.175	3.010***	20.291
	(0.0141)		(0.0258)		(0.0100)	
Census Block Fixed Effect	YES		YES		YES	
Observations	464,795		196,268		862,748	
Number of Census Blocks	96,134		39,821		177,058	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C1-3: Conditional Fixed Effects Logit Regression Disaggregated by Rural, Urban Cluster, and Urbanized Area Census Blocks **(1 Time Period Imputed)**

	Dependent Variable: *Block Entry*					
VARIABLES	Rural	Rural	Urban Cluster	Urban Cluster	Urbanized Area	Urbanized Area
	Coefficients	Odds Ratios	Coefficients	Odds Ratios	Coefficients	Odds Ratios
Number of Incumbents (Lag 1)	0.116***	1.123	0.541***	1.717	-0.00572	0.994
	(0.00783)		(0.0126)		(0.00807)	
Adjacent Threat Index (Lag 1)	0.947***	2.577	2.321***	10.190	1.452***	4.271
	(0.0204)		(0.0507)		(0.0238)	
Municipal ISP Presence (Lag 1)	**-1.727*** **	**0.178**	-0.349	0.705	**-1.652*** **	**0.192**
	(0.220)		(0.876)		**(0.208)**	
Cooperative ISP Presence (Lag 1)	**-1.648*** **	**0.192**	**-2.205*** **	**0.110**	**-2.250*** **	**0.105**
	(0.0210)		**(0.0417)**		**(0.0791)**	
Municipal Non-ISP Presence (Lag 1)	-0.482	0.618	0.100	1.105	0.381	1.463
	(0.362)		(0.846)		(0.270)	
Cooperative Non-ISP Presence (Lag 1)	**0.828*** **	**2.289**	-0.0770	0.926	**2.623*** **	**13.777**
	(0.242)		(0.490)		**(0.520)**	
Block Housing Density (Lag 1)	-0.000572***	1.000	-0.000917***	1.000	-0.000323***	1.000
	(0.000159)		(0.000284)		(6.91e-05)	
Median Household Income (Block Group) (Lag 1)	-1.12e-05***	1.000	-1.31e-06	1.000	3.44e-06***	1.000
	(8.02e-07)		(1.17e-06)		(5.51e-07)	
Time Fixed Effects						
Time Index 4 (December 2016)	1.651***	5.214	2.680***	14.580	-0.173***	0.841
	(0.0131)		(0.0271)		(0.00945)	
Time Index 5 (June 2017)	0.199***	1.220	0.521***	1.685	-1.608***	0.200
	(0.0165)		(0.0335)		(0.0145)	
Time Index 6 (December 2017)	3.172***	23.861	3.549***	34.79138	0.927***	2.526
	(0.0140)		(0.0277)		(0.00864)	
Time Index 7 (June 2018)	1.591***	4.908	2.946***	19.031	3.198***	24.473
	(0.0146)		(0.0290)		(0.0104)	
Census Block Fixed Effect	YES		YES		YES	
Observations	456,032		184,942		858,555	
Number of Census Blocks	94,121		37,453		176,050	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C1-4: Conditional Fixed Effects Logit Regression Disaggregated by Rural, Urban Cluster, and Urbanized Area Census Blocks **(2 Time Periods Imputed)**

	Dependent Variable: *Block Entry*					
VARIABLES	Rural	Rural	Urban Cluster	Urban Cluster	Urbanized Area	Urbanized Area
	Coefficients	Odds Ratios	Coefficients	Odds Ratios	Coefficients	Odds Ratios
Number of Incumbents (Lag 1)	0.139***	1.149	0.563***	1.755	0.0201**	1.020
	(0.00794)		(0.0128)		(0.00814)	
Adjacent Threat Index (Lag 1)	0.947***	2.577	2.323***	10.209	1.443***	4.234
	(0.0207)		(0.0517)		(0.0240)	
Municipal ISP Presence (Lag 1)	**-1.454*** **	**0.234**	**-2.769*** **	**0.062**	**-1.666*** **	**0.189**
	(0.205)		**(0.239)**		**(0.208)**	
Cooperative ISP Presence (Lag 1)	**-1.647*** **	**0.193**	**-2.215*** **	**0.109**	**-2.282*** **	**0.102**
	(0.0211)		**(0.0419)**		**(0.0797)**	
Municipal Non-ISP Presence (Lag 1)	**-0.713** **	**0.490**	0.458	1.581	0.370	1.448
	(0.361)		(0.956)		(0.270)	
Cooperative Non-ISP Presence (Lag 1)	**0.748*** **	**2.113**	0.465	1.591	**2.616*** **	**13.681**
	(0.242)		(0.494)		**(0.519)**	
Block Housing Density (Lag 1)	-0.000564***	0.999	-0.000889***	0.999	-0.000310***	1.000
	(0.000160)		(0.000284)		(6.88e-05)	
Median Household Income (Block Group) (Lag 1)	-1.05e-05***	1.000	-1.99e-06*	1.000	3.56e-06***	1.000
	(8.03e-07)		(1.19e-06)		(5.52e-07)	
Time Fixed Effects						
Time Index 4 (December 2016)	1.697***	5.457	2.679***	14.574	-0.143***	0.866
	(0.0133)		(0.0271)		(0.00949)	
Time Index 5 (June 2017)	0.229***	1.257	0.499***	1.647	-1.615***	0.199
	(0.0168)		(0.0338)		(0.0147)	
Time Index 6 (December 2017)	3.189***	24.255	3.552***	34.894	0.945***	2.572
	(0.0142)		(0.0278)		(0.00869)	
Time Index 7 (June 2018)	1.628***	5.095	2.917***	18.484	3.219***	25.010
	(0.0148)		(0.0290)		(0.0104)	
Census Block Fixed Effect	YES		YES		YES	
Observations	453,409		183,860		858,100	
Number of Census Blocks	93,562		37,229		175,926	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C2-1: Baseline Fixed Effects Regression

	Dependent Variable: *Log Block Maximum Speed*		
VARIABLES	Uncleaned data	1 time period imputed	2 time periods imputed
Number of Entrants (Block)	0.421***	0.395***	0.393***
	(0.00141)	(0.00144)	(0.00145)
Number of Exits (Block)	0.00437***	0.0260***	0.0261***
	(0.00135)	(0.00137)	(0.00138)
Number of Incumbents (Block)	0.439***	0.384***	0.376***
	(0.00144)	(0.00140)	(0.00140)
Adjacent Threat Index (Block)	-0.381***	-0.423***	-0.420***
	(0.00264)	(0.00266)	(0.00266)
Municipal ISP Presence Dummy (Block)	-0.0386	**-0.0624****	**-0.222*****
	(0.0314)	**(0.0307)**	**(0.0244)**
Cooperative ISP Presence Dummy (Block)	**-0.342*****	**-0.286*****	**-0.282*****
	(0.00404)	**(0.00397)**	**(0.00395)**
Municipal Non-ISP Presence Dummy (Block)	**-0.164*****	**-0.171*****	**-0.105*****
	(0.0392)	**(0.0384)**	**(0.0375)**
Cooperative Non-ISP Presence Dummy (Block)	**-0.259*****	**-0.241*****	**-0.213*****
	(0.0289)	**(0.0283)**	**(0.0281)**
Housing Density (Block)	5.08e-05***	4.49e-05***	4.30e-05***
	(9.88e-06)	(9.69e-06)	(9.65e-06)
Median Household Income (Block Group)	2.18e-06***	1.98e-06***	1.94e-06***
	(8.69e-08)	(8.51e-08)	(8.48e-08)
Time Fixed Effects			
Time Index 3 (June 2016)	-0.00267*	0.0203***	0.0226***
	(0.00156)	(0.00153)	(0.00153)
Time Index 4 (December 2016)	0.896***	0.890***	0.889***
	(0.00160)	(0.00157)	(0.00157)
Time Index 5 (June 2017)	1.053***	1.087***	1.087***
	(0.00159)	(0.00156)	(0.00155)
Time Index 6 (December 2017)	1.240***	1.221***	1.221***
	(0.00171)	(0.00168)	(0.00167)
Time Index 7 (June 2018)	1.472***	1.429***	1.423***
	(0.00188)	(0.00186)	(0.00186)
Constant	2.918***	3.062***	3.079***
	(0.0122)	(0.0120)	(0.0119)
Census Block Fixed Effect	YES	YES	YES
Observations	2,310,473	2,316,174	2,317,845
Number of Census Blocks	415,076	415,104	415,113
R-squared	0.448	0.451	0.451

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

Table C2-2: Fixed Effects Regression Disaggregated by Rural, Urban Cluster, and Urbanized Area Census Blocks **(Uncleaned Data)**

	Dependent Variable: *Log Block Maximum Speed*		
VARIABLES	Uncleaned Data (Rural)	Uncleaned Data (Urban Cluster)	Uncleaned Data (Urbanized Area)
Number of Entrants (Block)	0.493***	0.522***	0.306***
	(0.00231)	(0.00374)	(0.00181)
Number of Exits (Block)	-0.0215***	-0.0884***	0.0837***
	(0.00217)	(0.00336)	(0.00176)
Number of Incumbents (Block)	0.469***	0.553***	0.436***
	(0.00230)	(0.00370)	(0.00179)
Adjacent Threat Index (Block)	-0.253***	-0.303***	-0.413***
	(0.00372)	(0.00865)	(0.00357)
Municipal ISP Presence Dummy (Block)	0.0302	0.00755	**-0.165*****
	(0.0503)	(0.180)	**(0.0365)**
Cooperative ISP Presence Dummy (Block)	**-0.0366*****	**-0.447*****	0.0141
	(0.00523)	**(0.00882)**	(0.0105)
Municipal Non-ISP Presence Dummy (Block)	-0.0268	-0.126	**-0.371*****
	(0.0635)	(0.155)	**(0.0465)**
Cooperative Non-ISP Presence Dummy (Block)	-0.0482	**-0.186****	**-0.193*****
	(0.0391)	**(0.0942)**	**(0.0543)**
Housing Density (Block)	-6.07e-05*	-0.000249***	-6.73e-05***
	(3.35e-05)	(5.82e-05)	(8.51e-06)
Median Household Income (Block Group)	5.27e-07***	2.79e-06***	7.43e-07***
	(1.78e-07)	(2.72e-07)	(8.74e-08)
Time Fixed Effects			
Time Index 3 (June 2016)	0.0366***	0.0383***	-0.0402***
	(0.00263)	(0.00446)	(0.00180)
Time Index 4 (December 2016)	0.249***	0.621***	1.435***
	(0.00269)	(0.00455)	(0.00183)
Time Index 5 (June 2017)	0.510***	0.905***	1.514***
	(0.00273)	(0.00464)	(0.00180)
Time Index 6 (December 2017)	0.680***	1.232***	1.653***
	(0.00301)	(0.00497)	(0.00192)
Time Index 7 (June 2018)	0.935***	1.594***	1.866***
	(0.00298)	(0.00485)	(0.00257)
Constant	2.084***	3.061***	3.624***
	(0.0179)	(0.0464)	(0.0156)
Census Block Fixed Effect	YES	YES	YES
Observations	877,565	282,767	1,150,141
R-squared	0.242	0.463	0.693
Number of Blocks	161,491	49,323	204,262

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

Table C2-3: Fixed Effects Regression Disaggregated by Rural, Urban Cluster, and Urbanized Area Census Blocks **(1 Time Period Imputed)**

	Dependent Variable: *Log Block Maximum Speed*		
VARIABLES	1 time period imputed (Rural)	1 time period imputed (Urban Cluster)	1 time period imputed (Urbanized Area)
Number of Entrants (Block)	0.496***	0.424***	0.286***
	(0.00238)	(0.00376)	(0.00185)
Number of Exits (Block)	-0.0142***	-0.00100	0.0915***
	(0.00221)	(0.00337)	(0.00179)
Number of Incumbents (Block)	0.437***	0.377***	0.419***
	(0.00225)	(0.00344)	(0.00177)
Adjacent Threat Index (Block)	-0.277***	-0.493***	-0.426***
	(0.00376)	(0.00829)	(0.00361)
Municipal ISP Presence Dummy (Block)	**-0.00550**	**0.0660**	**-0.170*** **
	(0.0498)	**(0.166)**	**(0.0361)**
Cooperative ISP Presence Dummy (Block)	**-0.0139*** **	**-0.300*** **	**0.0327*** **
	(0.00517)	**(0.00823)**	**(0.0104)**
Municipal Non-ISP Presence Dummy (Block)	-0.0329	-0.130	**-0.380*** **
	(0.0628)	(0.144)	**(0.0461)**
Cooperative Non-ISP Presence Dummy (Block)	-0.0402	**-0.168***	**-0.195*** **
	(0.0387)	**(0.0874)**	**(0.0539)**
Housing Density (Block)	-6.49e-05**	-0.000259***	-6.74e-05***
	(3.31e-05)	(5.40e-05)	(8.43e-06)
Median Household Income (Block Group)	7.38e-07***	1.71e-06***	6.80e-07***
	(1.75e-07)	(2.51e-07)	(8.67e-08)
Time Fixed Effects			
Time Index 3 (June 2016)	0.0575***	0.0512***	-0.0150***
	(0.00261)	(0.00415)	(0.00178)
Time Index 4 (December 2016)	0.252***	0.597***	1.434***
	(0.00266)	(0.00423)	(0.00182)
Time Index 5 (June 2017)	0.532***	1.043***	1.521***
	(0.00270)	(0.00423)	(0.00178)
Time Index 6 (December 2017)	0.670***	1.149***	1.653***
	(0.00296)	(0.00449)	(0.00192)
Time Index 7 (June 2018)	0.929***	1.490***	1.858***
	(0.00297)	(0.00458)	(0.00258)
Constant	2.129***	3.585***	3.671***
	(0.0177)	(0.0432)	(0.0154)
Census Block Fixed Effect	YES	YES	YES
Observations	880,561	283,858	1,151,755
R-squared	0.239	0.485	0.691
Number of Blocks	161,506	49,327	204,271

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

Table C2-4: Fixed Effects Regression Disaggregated by Rural, Urban Cluster, and Urbanized Area Census Blocks **(2 Time Periods Imputed)**

	Dependent Variable: *Log Block Maximum Speed*		
VARIABLES	2 time periods imputed (Rural)	2 time periods imputed (Urban Cluster)	2 time periods imputed (Urbanized Area)
Number of Entrants (Block)	0.496***	0.420***	0.285***
	(0.00238)	(0.00377)	(0.00185)
Number of Exits (Block)	-0.0135***	-0.000379	0.0918***
	(0.00222)	(0.00338)	(0.00180)
Number of Incumbents (Block)	0.430***	0.364***	0.416***
	(0.00225)	(0.00343)	(0.00177)
Adjacent Threat Index (Block)	-0.275***	-0.482***	-0.424***
	(0.00377)	(0.00830)	(0.00362)
Municipal ISP Presence Dummy (Block)	**-0.0218**	**-0.271*** **	**-0.171*** **
	(0.0374)	**(0.0530)**	**(0.0361)**
Cooperative ISP Presence Dummy (Block)	**-0.0128** **	**-0.292*** **	**0.0340*** **
	(0.00514)	**(0.00819)**	**(0.0104)**
Municipal Non-ISP Presence Dummy (Block)	-0.0234	-0.131	**-0.381*** **
	(0.0618)	(0.143)	**(0.0461)**
Cooperative Non-ISP Presence Dummy (Block)	-0.0398	-0.108	**-0.197*** **
	(0.0383)	(0.0823)	**(0.0539)**
Housing Density (Block)	-6.71e-05**	-0.000253***	-6.83e-05***
	(3.29e-05)	(5.36e-05)	(8.43e-06)
Median Household Income (Block Group)	7.77e-07***	1.60e-06***	6.41e-07***
	(1.74e-07)	(2.49e-07)	(8.67e-08)
Time Fixed Effects			
Time Index 3 (June 2016)	0.0611***	0.0538***	-0.0138***
	(0.00260)	(0.00413)	(0.00178)
Time Index 4 (December 2016)	0.255***	0.597***	1.430***
	(0.00265)	(0.00420)	(0.00182)
Time Index 5 (June 2017)	0.536***	1.046***	1.517***
	(0.00269)	(0.00421)	(0.00178)
Time Index 6 (December 2017)	0.675***	1.151***	1.649***
	(0.00295)	(0.00446)	(0.00192)
Time Index 7 (June 2018)	0.929***	1.485***	1.851***
	(0.00296)	(0.00455)	(0.00258)
Constant	2.137***	3.613***	3.685***
	(0.0176)	(0.0427)	(0.0154)
Census Block Fixed Effect	YES	YES	YES
Observations	881,554	283,927	1,152,364
R-squared	0.239	0.487	0.690
Number of Blocks	161,509	49,327	204,277

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

Appendix D: Summary Statistics

Table D1: Summary Statistics for Uncleaned Data

VARIABLES	Mean	SD	Min	Max	Obs	# blocks	T-bar
Ln(Block Maximum Speed)	4.5	1.9	-1.4	6.9	2882887	431416	6.7
Number of Entrants (Block)	0.3	0.5	0.0	4.0	2476814	431015	5.7
Number of Exits (Block)	0.3	0.5	0.0	4.0	2403195	427444	5.6
Number of Incumbents (Block)	2.1	1.0	0.0	8.0	2476814	431015	5.7
Adjacent Threat Index (Block)	0.2	0.4	0.0	7.0	2888464	431800	6.7
Municipal ISP Dummy (Block)	0.1	0.2	0.0	1.0	2888464	431800	6.7
Cooperative ISP Dummy (Block)	0.1	0.3	0.0	1.0	2888464	431800	6.7
Municipal Non-ISP Dummy (Block)	0.1	0.3	0.0	1.0	2888464	431800	6.7
Cooperative Non-ISP Dummy (Block)	0.3	0.4	0.0	1.0	2888464	431800	6.7
Housing Density (Block)	683.0	4981.4	0.0	2024096.4	2822215	420839	6.7
Median Household Income (Block)	62064.7	28605.3	3041.0	249444.0	2849908	431291	6.6

Table D2: Summary Statistics for 1 Time Period Imputed Dataset

VARIABLES	Mean	SD	Min	Max	n	# blocks	T-bar
Ln(Block Maximum Speed)	4.5	1.9	-1.4	6.9	2885103	431417	6.7
Number of Entrants (Block)	0.3	0.5	0.0	4.0	2479072	431016	5.8
Number of Exits (Block)	0.3	0.5	0.0	4.0	2409393	427472	5.6
Number of Incumbents (Block)	2.1	1.0	0.0	8.0	2479072	431016	5.8
Adjacent Threat Index (Block)	0.2	0.4	0.0	7.0	2890723	431801	6.7
Municipal ISP Dummy (Block)	0.1	0.2	0.0	1.0	2890723	431801	6.7
Cooperative ISP Dummy (Block)	0.1	0.3	0.0	1.0	2890723	431801	6.7
Municipal Non-ISP Dummy (Block)	0.1	0.3	0.0	1.0	2890723	431801	6.7
Cooperative Non-ISP Dummy (Block)	0.3	0.4	0.0	1.0	2890723	431801	6.7
Housing Density (Block)	694.0	8756.5	0.0	4575757.5	2824362	420840	6.7
Median Household Income (Block)	62059.7	28601.0	3041.0	249444.0	2852139	431292	6.6

Table D3: Summary Statistics for 2 Time Periods Imputed Dataset

VARIABLES	Mean	SD	Min	Max	n	# blocks	T-bar
Ln(Block Maximum Speed)	4.5	1.9	-1.4	6.9	2885947	431417	6.7
Number of Entrants (Block)	0.3	0.5	0.0	4.0	2479907	431016	5.8
Number of Exits (Block)	0.3	0.5	0.0	4.0	2411169	427480	5.6
Number of Incumbents (Block)	2.1	1.1	0.0	8.0	2479907	431016	5.8
Adjacent Threat Index (Block)	0.2	0.4	0.0	7.0	2891558	431801	6.7
Municipal ISP Dummy (Block)	0.1	0.2	0.0	1.0	2891558	431801	6.7
Cooperative ISP Dummy (Block)	0.1	0.3	0.0	1.0	2891558	431801	6.7
Municipal Non-ISP Dummy (Block)	0.1	0.3	0.0	1.0	2891558	431801	6.7
Cooperative Non-ISP Dummy (Block)	0.3	0.4	0.0	1.0	2891558	431801	6.7
Housing Density (Block)	693.9	8755.3	0.0	4575757.5	2825157	420840	6.7
Median Household Income (Block)	62057.9	28599.3	3041.0	249444.0	2852963	431292	6.6

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