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The fibre broadband housing premium across three US States

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ABSTRACT

This paper meshes 1.7 million housing transactions across three US states (Iowa, Minnesota and Texas) between 2015 and 2021 with data on broadband infrastructure to evaluate the impact of fibre broadband availability on home prices. This was a period of dramatic fibre growth in these states: prior to 2019, fibre was only available to roughly 24% of the houses sold but rose to 54% in later years. A traditional hedonic pricing model that includes a wide array of housing characteristics and census block group-level fixed effects estimates the fibre premium at around 1% in all three states for the full 2105–2021 period. The fibre premium was higher in the earlier part of this period, likely reflecting its novelty during that time. A more rigorous instrumental variable approach estimates the fibre premium at 2% in Minnesota and 9% in Texas. A conservative national estimate of the increase in housing value from deploying ubiquitous fibre is $36 billion.

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Fibre broadband; hedonic pricing model; instrumental variables

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1. INTRODUCTION

The internet has become an essential part of everyday life for most Americans. 77% of US households had a broadband internet connection as of 2021, up from less than 25% in 2004 (Pew Research, 2023). The importance of a reliable, high-speed residential internet connection was made clear during the COVID-19 pandemic, as schools, businesses and healthcare systems across the country transitioned to at-home environments. Recent studies have shown that residential broadband access is crucial for increasing employment among low-income Americans (Zuo, 2021), entrepreneurial opportunities in rural and minority-dominant locations (Deller et al., 2022; Prieger, 2023), civic engagement (Whitacre & Manlove, 2016) and personal health (Benda et al., 2020; Early & Hernandez, 2021). Even prior to the pandemic, a wide body of evidence documented that home broadband adoption and use was linked to a variety of positive economic outcomes, including employment growth (Kolko, 2012; Whitacre et al., 2014a), productivity (Gallardo et al., 2021; Mack & Faggian, 2013), women's labour force participation

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(Dettling, 2017), household income (Gallardo & Whitacre, 2018; Whitacre et al., 2014b) and student academic achievement (Caldarulo et al., 2023).

However, not all broadband connections are equal. Decades-old digital subscriber line (DSL) technology can result in download speeds slower than 10 megabits per second (MBPS), significantly slower than the current Federal Communications Commission (FCC) broadband threshold of 25 MBPS and well below what is typically required for a household with multiple internet users (FCC, 2022).[1] Fixed wireless connections improved dramatically during the late 2010s and in some cases can offer 100 MBPS, but are still slower than the average urban household wired connection of 300 MBPS in 2021 (FCC, 2023; Flamm & Varas, 2021; Hardesty, 2022) and remain susceptible to technical constraints such as line-of-sight propagation and latency issues (Abozariba et al., 2019). In contrast, fibre – generally considered the 'gold-standard' broadband technology – offers speeds exceeding 1 GBPS (1000 MBPS) in both upload and download directions, is highly scalable and has comparatively high reliability with low latency (Cyphers, 2019). The median download speed achieved by urban consumers using four major fibre providers was over 500 MBPS in 2021, which includes households that paid only for lower-tier (slower) connections (FCC, 2023). This compares to 300 MBPS for five major cable providers over the same time. The value that households place on the types of internet connections available to them is relatively understudied, even as the usefulness of those connections grows.

Housing prices have long been used in studies documenting the value of specific amenities (Bishop et al., 2020; Blomquist et al., 1988; Oates, 1969; Roback, 1982; Rosen, 1974). As broadband access has grown in importance, the real estate industry has taken notice (Angelone & Danekar, 2021). Several recent articles have used variations in housing prices to quantify the value of broadband availability in the US, with conflicting results. For example, Molnar et al. (2019) found a 3% increase in housing prices in locations with access to 25 MBPS when compared to similar houses with access to only 1 MBPS during the 2011–2013 period; however, Conley and Whitacre (2020) found no impact of faster broadband speeds on housing prices in two rural Oklahoma counties during 2011–2017. A more recent analysis by Wolf and Irwin (2023) found that fibre availability added roughly 2% to house sale prices in Wisconsin between 2013 and 2017. This paper builds on these prior efforts and estimates the 'fibre premium' using comprehensive data on housing transactions and broadband availability between 2015 and 2021 across three distinct states (Iowa, Minnesota and Texas). This period covers a dramatic increase in fibre broadband availability in these regions, while other forms of broadband access were more ubiquitous. In relation to earlier efforts, the contribution of this study is the use of updated broadband availability data (through 2021), the inclusion of a wide array of distinct broadband technologies, and the extension to three states with over 1.7 million housing transactions. It also develops a brief theoretical framework for why such a premium may exist, building on prior frameworks in the regional science literature.

The baseline results from a traditional hedonic model provide evidence that the presence of fibre added 2–3% to the housing prices in all three states during the 2015–2018 period when fibre was less common. The aggregate impact over the full seven-year period was smaller, at around 1%. A more rigorous instrumental variable approach removes problems associated with reverse causality and finds a 2% premium in Minnesota and a nearly 9% premium in Texas. Slightly larger estimates are obtained when the analysis is restricted to the largest metropolitan area in those states. Fibre availability was also valued as COVID-19 unfolded: estimates using transactions that took place after March 2020 demonstrate impacts ranging from 0.5–2.7% in two states.

Recent US policy has emphasised broadband infrastructure, with $42 billion of the Broadband Equity, Access, and Deployment (BEAD) programme dedicated to connecting 'unserved' households and businesses and requiring technologies that can offer at least 100 MBPS speeds (NTIA, 2022). The fibre premium documented here is one example of how the returns on such an investment may be quantified.

2. LITERATURE REVIEW

A wide body of empirical evidence documents the positive impacts of 'some' internet access on a host of economic and social outcomes. Holt and Jamison (2009) offer an early synopsis and emphasise relationships with innovation and broad measures of economic growth; however, they also note the potential for these impacts to change over time. Whitacre and Gallardo (2022) and Mack et al. (2023) summarise much of the literature since the early 2000s, largely finding that both availability and adoption matter for economic development – but also noting that most US studies were based on outdated speed thresholds. More recent research has shifted the question to whether 'speed matters', including looking at the rollout of fibre networks. Most of these studies are performed using data from European countries, with generally positive evidence on the value-added nature of higher speeds for specific economic outcomes like business births, employment levels or productivity (Duvivier & Bussiere, 2022; Falk & Hagsten, 2021; Hasbi & Bohlin, 2022). Importantly, these studies only consider broadband availability prior to 2018, and are unable to speak to the impact of infrastructure improvements since that time.

Only a select few studies have focused explicitly on the potential impact of broadband availability on local housing prices. Perhaps the earliest example is Ahlfeldt et al. (2017), who document a 2.8% increase in property prices for upgrading from dial-up to an 8 MBPS connection in England between 1995 and 2010. The study also finds diminishing returns to speed, however, with 24 MBPS only increasing property value by an additional 1%. The housing data is relatively thorough, with more than one million (1,000,000) observations and includes characteristics such as building age, floor space, and property type. One interesting (and relevant) finding is that the biggest impacts to property prices occurred for houses closest to where the broadband upgrade occurred (i.e., with other houses close by who did not have access to the higher speeds). In a more recent example from a European country, Klein (2022) examines fibre broadband rollout in a single German county on monthly rental prices for apartments and houses between 2014 and 2018.[2] He finds a treatment effect of 3–4% on the monthly price per square foot across over 7000 observations; this impact continued up to four years after the initial fibre rollout.

Moving to a US context, a pioneering study by Molnar et al. (2015) used a random sample of over 500,000 housing transactions from all 50 states to estimate the impact of fibre availability between 2011 and 2014. Their hedonic model controls for house characteristics such as size, number of bathrooms, and the presence of a pool, fireplace and garage; they also estimate the impact of neighbourhood (census block group) characteristics such as local education and income levels. The results found a fibre premium of approximately 3%. The paper was cited in the popular press (Koebler, 2014; Lightwave, 2015); however, this version was never published in a peer-reviewed journal. The version of this paper that eventually was published (Molnar et al. (2019)) used the same broadband data but differed in several important ways: (1) it no longer looked at specific house prices, but rather average housing price per census block group; (2) the sample size was accordingly reduced to 4500 block groups across 37 states; and (3) the primary result focused on the impact of speed via any technology (as opposed to fibre only). The 2019 paper found a similar 3% increase for a 25 MBPS connection compared to similar homes in neighbourhoods with only a 1 MBPS connection. Similar to Ahlfeldt et al. (2017), diminishing returns to speed were evident: the premium for a 100 MBPS connection was less than 1% when compared to a home with 50 MBPS. The paper also (perhaps surprisingly) found a larger impact of speed in more urban locations.

I am aware of only three other published studies looking at this issue with US data, two of which are focused on rural areas. Deller and Whitacre (2019) estimate a three-stage least squares estimator using average housing value and characteristic data from all 887 remote rural counties as of 2016. Similar to Molnar et al. (2019), they account for both average housing characteristics within the county and local economic characteristics that might also affect housing value. Their results show that the impacts are largest for relatively slow connections (200 KBPS) – suggesting that moving from *no* connectivity to *some type* of connection is highly valued in more rural locations. Speeds up to 100 MBPS displayed positive, though diminishing, impacts on local housing values. At that time, no premium was found for speeds at levels exceeding 100 MBPS. However, typical download speeds for rural households were less than 50 MBPS during the period of analysis, and use of now-commonplace technologies like Zoom meetings, telehealth appointments or even Netflix was much more limited.[3] In contrast, average North American fixed broadband speeds are anticipated to reach 141.8 MBPS, a 150% increase from the 2018 average of 56.6 MPBS (Cisco, 2023).

Conley and Whitacre (2020) focus on two rural counties in Oklahoma that experienced dramatic increases in broadband access between 2011 and 2017. They used a spatial hedonic model that accounted for the impact of neighbouring house values. With 490 housing transactions in one county and 2200 in the other, they found no evidence that access to higher broadband speeds led to higher housing prices after controlling for household characteristics and block-group-level demographics.

One recent paper on this topic is noteworthy. Wolf and Irwin (2023) studied more than 280,000 housing transactions in Wisconsin between 2013 and 2017 to document a 2% fibre premium. Their study used block group-level fixed effects, which allowed each neighbourhood to have a unique impact on the price of each sale. It also included a relatively comprehensive list of housing characteristics and distance to local amenities like lakes or airports. They found no differences in the fibre premium between rural and urban areas of the state.

An important consideration for each of these studies is how they attempted to handle potential endogeneity, since internet provision may be correlated with other factors not included in the model that may also influence housing prices. Reverse causality is also a potential concern since some providers may be choosing to upgrade service in areas with high housing prices. Ahlfeldt et al. (2017) used border discontinuities *across* Local Exchanges (which provide broadband to households within their service area) and variation *within* those same exchanges over time to address this issue. Molnar et al. (2019) used an instrumental variable approach that first estimates the speed available to a block group by looking at the percentage of blocks that have fibre deployment and then used that estimated speed in their base specification. They found similar results for the base model and the instrumental variable version. Conley and Whitacre (2020) listed potential endogeneity as a limitation of their study and did not directly address it in their modelling. Wolf and Irwin (2023) also took an instrumental variable approach, estimating fibre availability in a particular block group by its presence in the three closest block groups. This is similar to the method used by LoPiccalo (2022) where a weighted average of broadband availability in all neighbouring counties was used to estimate broadband penetration for the second-stage model. Wolf and Irwin also argued that including block group level fixed effects helped limit the extent of the endogeneity issue because they controlled for neighbourhood differences that did not change over time.

Importantly, none of the studies listed above proposed a theoretical framework for why such a premium might exist. I hypothesise that homebuyer preference for a fibre connection has developed as more everyday tasks take place online and consumers come to value the time saved and lack of frustration associated with a higher-speed, reliable internet connection. Early studies on this topic documented a high consumer willingness-to-pay for both internet speed and reliability (Rosston et al., 2010; Savage & Waldman, 2005) and recent surveys have shown dramatic increases in both the total number of connected devices (Deloitte, 2022) and time spent online (Lebow, 2022) for US households. Purchasing a home where connectivity is known to be good is likely to be valued by potential buyers, who are willing to pay for the perceived benefit. In effect, this connectivity preference is a type of amenity priced out by households as they make their purchase decisions. As such, it fits in nicely with earlier regional science theories such as the environmental preference hypothesis (Svart, 1976; Wang & Lee, 2022) or revealed preferences for quality of life (Berger et al., 1987) / specific amenity types (Carson et al., 1996).

Overall, only a handful of studies have explored the relationship between housing prices and US broadband availability and even fewer have used data where the unit of observation is an individual household. Most of these studies include broadband data that is somewhat dated: Molnar et al. (2015) used National Broadband Map data from 2011–2013; Conley and Whitacre (2020) used a combination of the earlier National Broadband Map (2011–2013) data and the later Federal Communications Commission (FCC) Form 477 data through 2017; and Wolf and Irwin (2023) used FCC broadband data between 2013 and 2017. Further, the number of housing observations are relatively limited (500,000 in the original Molnar study, fewer than 3000 total in Conley and Whitacre, and 280,000 in Wolf and Irwin). This paper expands prior work by extending the geographical reach of the analysis and updating the broadband availability data through 2021. It includes a total of over 1.7 million housing transactions across three states during a period when fibre availability increased dramatically (2015–2021). The analysis that follows helps paint a more complete picture about the recent US real estate market and the continued existence of a fibre premium.

3. DATA AND METHODS

3.1. Data

Three distinct data sources are used for this study: (1) housing transactions, purchased from the real estate company CoreLogic; (2) broadband availability data, taken at the census block level from the FCC Form 477; and (3) local demographic characteristics, sourced from relevant American Community Survey data at the block group level. The housing transaction data contains the latitude and longitude of the property and date of sale for the years 2015–2021, allowing it to be meshed with block-level broadband availability information when the sale took place. Along with the actual sale price, the CoreLogic data contains a wide array of property characteristics including when the house was built, square footage of the main residence, garage and basement, total number of bedrooms and bathrooms, the date of any remodelling that took place, indicators for fireplace and pool, a building quality code as rated by the property assessor and specific typologies of air conditioning/heating systems in use.[4] The data was purchased for housing transactions that occurred between 2015 and 2021 for three states: Iowa, Minnesota and Texas. These states were selected for several reasons: first, because they experienced a large increase in fibre availability during the period of analysis (2015–2021); and second, because all three states possess both sizeable rural populations and large metropolitan areas. The Iowa and Minnesota data capture every transaction that occurred during those states during that time; Texas is a 'non-disclosure' states (where disclosing the final sale price is not required) and so the data gathered is only a subset.[5] Berrens and McKee (2004) examined these non-disclosure clauses and noted that the rationale for such laws are common-law privacy arguments. They further argued that their use is connected to tax revenue leakage and ineffective tax rates and that establishing market value is more difficult in non-disclosure states. The Texas data thus only represents sales where the parties involved agreed to disclose the sale price. This self-selection may be a source of bias for the analysis that follows. I use transactions coded as single-family residential or townhomes and remove any transactions coded as mobile homes. I also remove observations with missing data or errant data (i.e., > 15 bed / bathrooms) and priced under $40,000 (more likely to be salvage opportunities) or in the top 1% of all houses sold. In the final dataset, there are roughly 290,000 observations in Iowa; 490,000 observations in

Minnesota, and 940,000 observations in Texas. Figure 1 demonstrates the locations of these sales in each state and makes clear that Iowa and Minnesota are much more comprehensive. The transactions captured in Texas (the non-disclosure state) seem to be much more urban-focused with relatively few observations in more rural areas. The data for transactions in Iowa and Minnesota cover nearly all their respective states.

The broadband data was sourced from the FCC's Form 477, which requires all internet providers to report the census blocks they serve and the available download/upload speeds in each block twice per year (June and December). This is notably different from the precursor National Broadband Map data (used in Molnar et al. (2019)), which was only voluntary for providers. There are several problems with the Form 477 data, including its self-reported nature and the 'one-served, all-served' assumption where all blocks listed by a provider are assumed to have service throughout the entire block, when in reality this is not the case (Major et al., 2020). The FCC transitioned to a 'serviceable location' based map in late 2022 that seeks to address many of these acknowledged problems (Whitacre & Biedny, 2022); however, even given its recognised constraints, the Form 477 data remains the most consistent and comprehensive data set available for the period 2015–2022. For this study, the data is aggregated to the maximum speed available across four distinct technology types (fibre, cable, DSL[6] and fixed wireless) in each block; I also capture the total number of distinct providers that serve the block.[7] I use block level data from the June 30 and December 31 iterations each year and match them to the appropriate housing transaction (i.e., a sale taking place in April 2020 would use the December 2019 broadband availability).[8] Figure 2 demonstrates the increase in fibre availability for each state between 2015 and 2021. While these maps only show fibre, Figure 3 plots the availability of different broadband technologies over time for the transactions in each state.

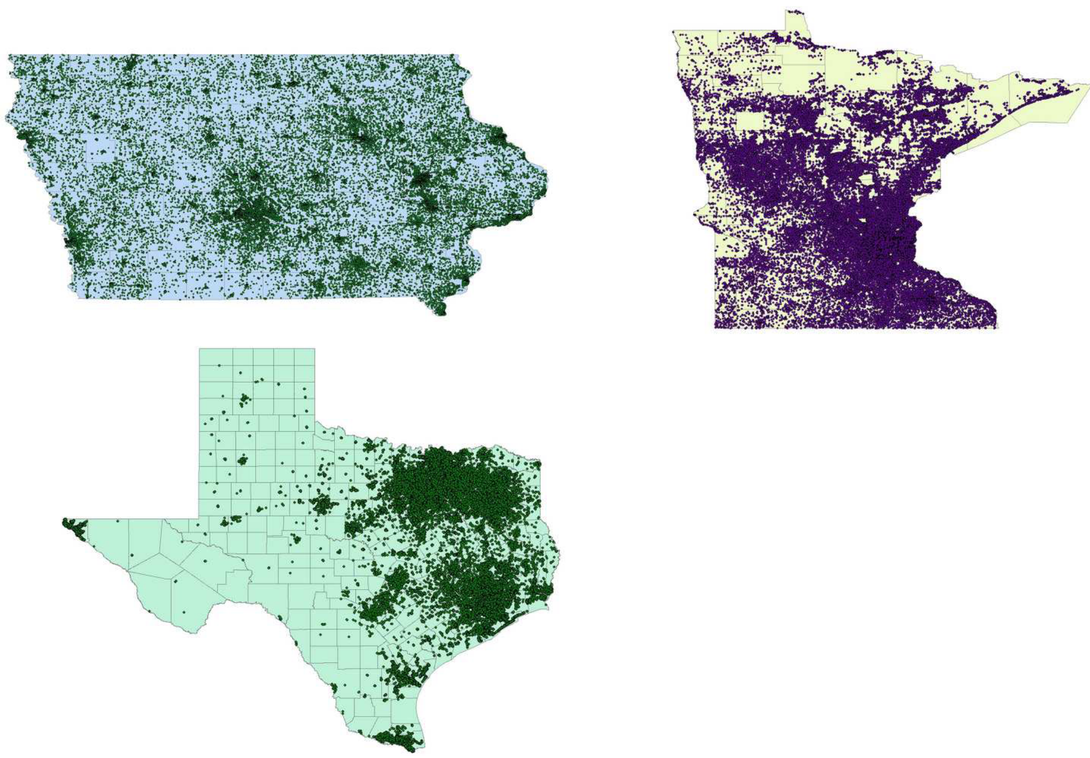

Figure 1. CoreLogic Housing Transactions between 2015–2021 in Iowa (a), Minnesota (b), and Texas (c).
Source: Author's analysis of CoreLogic housing transaction data.

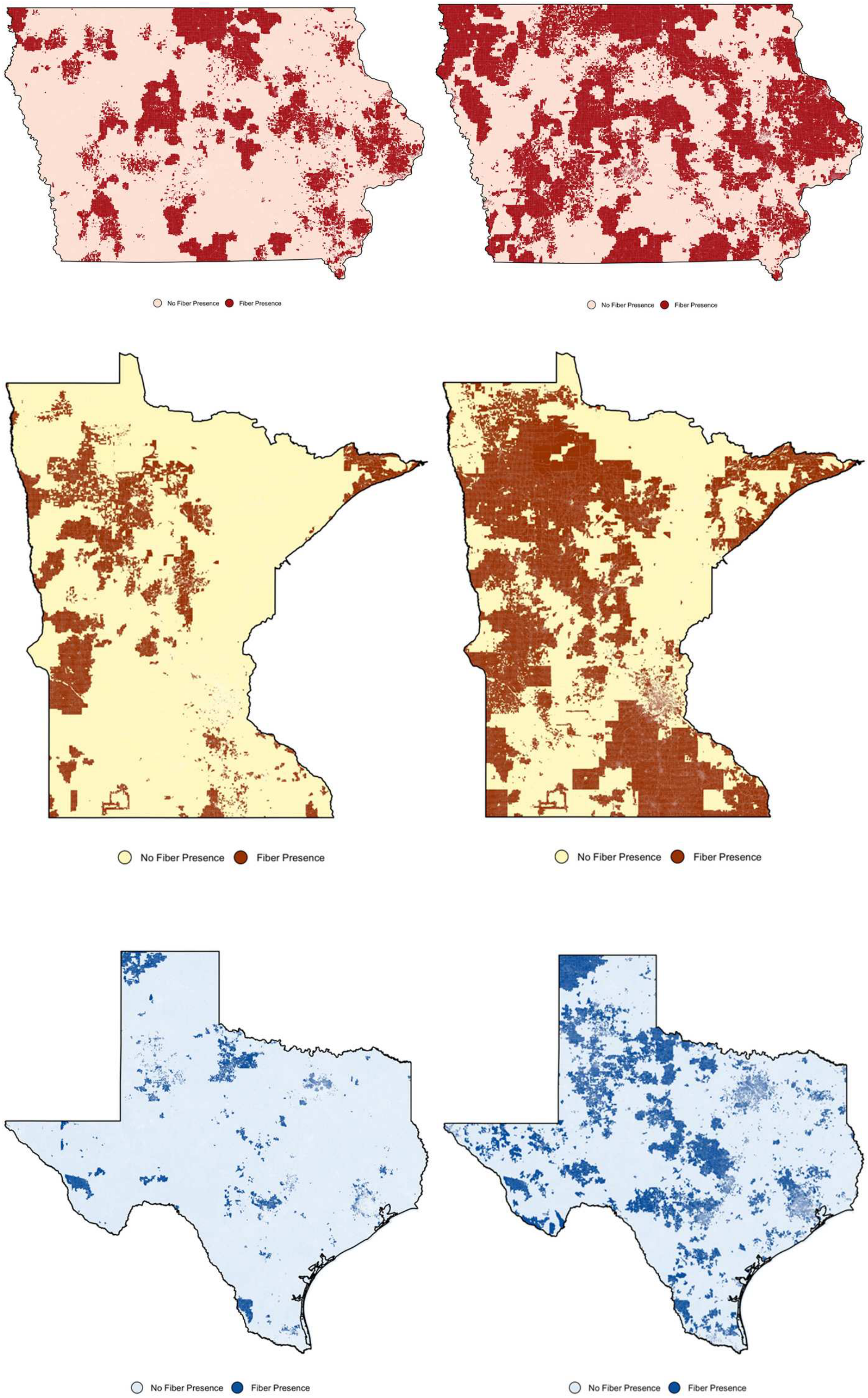

Figure 2. Fibre availability changes between 2015 and 2021 in Iowa (a), Minnesota (b), and Texas (c).
Source: Federal Communications Commission (FCC) Form 477; December 2014 & December 2020.

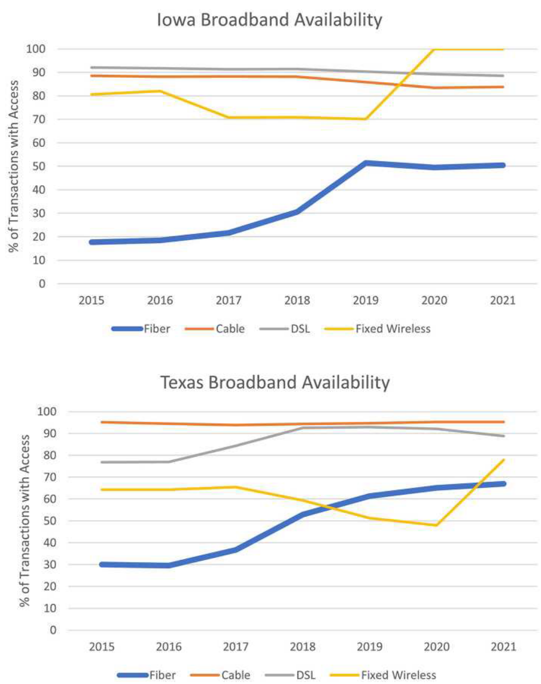

Figure 3. Broadband Technology Availability for Housing Transactions between 2015 and 2021 in Iowa (a), Minnesota (b), and Texas (c).
Source: Author's analysis of housing transaction data and FCC Form 477.

Finally, some specifications include the 2016–2020 American Community Survey block-group socioeconomic data since local community characteristics may factor into housing price. These characteristics include the median age and household income, a count of the total number of housing units, the total population in the block group and the percentage of the population over the age of 24 holding a bachelor's degree or more.

Table 1 summarises the aggregate dataset for each state. The sale price is deflated to 2015 dollars using the US Consumer Price Index. While the average sale price is notably lower in Iowa, the average number of bed/bathrooms is relatively consistent across states.[9] The housing data includes a dummy variable for a lack of central air conditioning (relatively common in Iowa and Minnesota) and for whether the construction quality was rated as below average (less than 3% of houses in all states). In terms of broadband access, the average house had three or four distinct providers available to them. Fibre was the least available technology, with cable and DSL having higher average availability rates. In terms of sociodemographics, the Texas transactions took place in census block groups that were typically younger, with higher incomes and in more urban locations.

Not shown in Table 1 is how the maximum advertised download and upload speeds available to home buyers have increased over time. The improvements have been dramatic, including an increase from an average of 144 / 35 MBPS (download / upload) for housing transactions that took place in 2016 to 1428 / 911 MBPS by 2021 in Minnesota. Much of this explosion in speed availability is due to the increase in fibre. In Minnesota, for example, fibre was only available for 6% of housing transactions in 2016 but increased to 45% by 2021 (Figure 3(b)).

3.2. Initial hedonic model

My initial hedonic pricing specification takes the form:

$$\ln\left(P_{ijt}\right) = \alpha_0 + \alpha_1 X_{it} + \alpha_2 BBTech_{ijt} + \delta_t + \gamma_j + u_{ijt} \tag{1}$$

where the dependent variable is the natural log of the recorded sale price for house i (in 2015

Table 1. Housing summary statistics.

	Iowa				Minnesota				Texas			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Housing characteristics												
Sale price (2015 $)	172,603	108,872	40,000	860,829	254,808	140,674	44,672	1,054,789	287,066	178,654	40,000	1,399,900
Bedrooms	3.08	0.89	1	15	3.17	0.94	1	15	3.48	0.74	1	15
Bathrooms	2.12	1.13	1	14	2.18	0.94	1	15	2.58	0.93	1	14
Square footage (100)	16.97	7.58	0.52	217.44	17.97	8.45	0.10	192.06	23.34	9.19	0.67	168.13
Remodel (0/1)	0.03	0.18	0	1	0.45	0.50	0	1	0.06	0.23	0	1
House age (10)	6.05	3.70	0.10	22.20	5.32	3.27	0.10	22.20	3.02	2.14	0.10	22.20
Basement (0/1)	0.51	0.50	0	1	0.36	0.48	0	1	0.00	0.02	0	1
Garage Sq. Foot (100)	4.67	3.58	0	201.30	4.32	3.53	0	138.60	4.62	1.81	0	95.13
Fireplace (0/1)	0.40	0.49	0	1	0.20	0.40	0	1	0.52	0.50	0	1
Pool (0/1)	0.03	0.17	0	1	0.01	0.10	0	1	0.14	0.35	0	1
No Central Air (0/1)	0.60	0.49	0	1	0.57	0.49	0	1	0.08	0.27	0	1
Below Avg Quality	0.00	0.01	0	1	0.02	0.15	0	1	0.01	0.09	0	1
Broadband Availability												
Distinct providers	3.62	1.34	1	11	3.37	1.19	1	11	3.33	1.22	1	10
Max Ad Down (MBPS)	696.56	640.93	0.26	10,000	711.90	1061.70	0.26	10,000	680.49	418.89	0.00	10,000
Fibre (0/1)	0.36	0.48	0	1	0.28	0.45	0	1	0.50	0.50	0	1
Cable (0/1)	0.86	0.34	0	1	0.92	0.28	0	1	0.95	0.22	0	1
DSL (0/1)	0.91	0.29	0	1	0.94	0.24	0	1	0.87	0.34	0	1
Fixed Wireless (0/1)	0.85	0.36	0	1	0.82	0.38	0	1	0.62	0.49	0	1

Sociodemographics (Block-group level)												
Population	1794	1814	88	19,236	1776	1216	11	9734	3726	5716	9	59,947
Housing Units	756	706	5	7359	706	420	4	3401	1256	1726	4	17,470
Median Age	39.84	8.02	13.20	78.40	39.69	7.78	12.50	86.40	37.13	7.62	8.80	84.10
Median HH Income	68,664	26,689	2499	250,001	83,887	33,839	9342	250,001	95,407	42,617	2466	250,001
Pct Bach Degree or more	0.31	0.18	0	0.93	0.38	0.19	0	0.97	0.41	0.21	0	1.00
Pct HS Degree or less	0.36	0.16	0	0.97	0.29	0.14	0	0.86	0.30	0.19	0	1.00
Metro	0.70	0.46	0	1	0.89	0.32	0	1	0.99	0.11	0	1
Number of observations	291,174				488,308				935,296			

dollars) in census block group j at time t; X_{it} is a vector of housing characteristics, $BBTech_{it}$ is a dummy vector of broadband technologies available to household i at the time of the sale, δ_t are time fixed effects that include both annual and quarter of year (i.e., seasonal) dummies, γ_j is a block-group level fixed effect, and u_{ijt} is an error term. $BBTech_{it}$ includes dummy variables for each of the four primary technology categories: cable internet, DSL, fibre and fixed wireless. Positive and significant coefficients on the different broadband technologies would represent the premium that house buyers would pay for a specific type of connection. In practice, the specification is estimated via ordinary least squares (OLS).

The inclusion of block-group level fixed effects (γ_j) essentially allows individual neighbourhoods (a typical block group contains between 1000 and 2000 people) to have their own unique impact on housing price. This should have a sizable influence on the fit of the models, since they capture difficult-to-quantify features such as the 'feel' or curb appeal of the local community. Kuminoff et al. (2010) show that the inclusion of such spatial fixed effects can mitigate omitted variable bias. When these fixed effects are included, there is no need to include the block-group level characteristics shown in Table 1; however, as a robustness check, I include no spatial fixed effects and instead control for specific block group features like population, income and education. Among other existing hedonic studies using transaction-level data, only Wolf and Irwin (2023) included block-group level fixed effects in their primary specification. Molnar et al. (2015) used state fixed effects but control for block-group characteristics such as those identified here, and Conley and Whitacre (2020) also used block-group characteristics for their analysis of two Oklahoma counties.[10]

Even with high-resolution spatial fixed effects, endogeneity may still be a problem due to other potentially omitted variables. Iowa, for example, passed a 'dig-once' policy in 2015 which affected fibre rollout after that time (Biedny et al., 2022); however, I do not have data on which neighbourhoods were influenced by this policy. Other coordinating efforts between service providers and local governments (for example, permitting policies for fixed wireless providers) may also have affected how specific technologies were distributed. Molnar et al. (2015) also point out that any unobserved factors that are correlated with both housing prices and fibre availability – such as crime rates or local business activity – will bias the parameters estimated in Equation (1). Addressing this problem requires construction of an appropriate instrumental variable that is correlated with the regressor in question (fibre availability) but *not* with housing price. I follow Wolf and Irwin (2023) in using the availability of fibre access in nearby neighbourhoods (block groups) for this purpose. The rationale here is that the proximity of a local fibre network should impact the cost of extending service, with unserved locations close to neighbourhoods where fibre service is currently offered being more likely to gain service quickly than those further away. Alternatively, the presence of fibre in these neighbouring communities should *not* affect housing prices in the focal community since a house in that location could not connect to the neighbouring network. The identifying assumption, then, is that housing prices in a focal neighbourhood are not influenced by fibre availability in the surrounding neighbourhoods – but the provision of local fibre service is. I can then reconstruct the original model using a two-stage approach where the first stage estimates fibre availability:

$$Fiber_{ijt} = \beta_0 + \beta_1 Z_{ijt} + \delta_t + \gamma_j + u_{ijt} \tag{2}$$

$$\ln(P_{ijt}) = \alpha_0 + \alpha_1 X_{it} + \alpha_2 BBTech_{ijt} + \alpha_3 \widehat{Fiber}_{ijt} + \delta_t + \gamma_j + u_{ijt} \tag{3}$$

where Z_{ijt} captures fibre availability in the five closest[11] census block groups (measured as the percentage of blocks in each group that have fibre) at time t. Thus Z_{ijt} serves as an instrument for $Fiber_{ijt}$ in this first-stage equation, and I use the predicted values ($\widehat{Fiber}_{ijt}$) as part of the independent variables in the second stage.[12] Note that while other broadband technologies

$BBTech_{ijt}$ are still included, this vector no longer includes fibre. The main benefit of using this two-stage approach is that the associated coefficient for $\widehat{Fiber_{ijt}}$ (α_3) can now be interpreted as causal (Angrist et al., 1996); however, the causal relationship only holds for households where the first-stage regression accurately predicts fibre availability. Importantly, the IV approach here does not attempt to deal with potential endogeneity in other broadband technology types (DSL, cable, fixed wireless). As such, the resulting coefficients for these technologies should not be interpreted as causal.

I run each of the specifications separately for the three states being analysed, due to market and price differences across states. Bishop et al. (2020) note that the use of such a large geography may not satisfy the 'law of one price function' and recommend instead that the model should be run on geographies smaller than a single metropolitan area. I run the specifications for distinct metropolitan statistical areas within each state to assess if the results remain consistent when the definition of a market is more restricted.

4. RESULTS

4.1. Initial hedonic model results

Table 2 reports the results of three basic specifications for each state: model (1a) uses no geographical fixed effects and instead controls for specific block group demographic characteristics; model (1b) uses the block group-level fixed effects specified in Equation (1); and model (1c) uses the instrumental variable approach with block group fixed effects from Equations (2) and (3).

The adjusted R^2 values in models (1a) and (1b) are on par with other fixed effect-specifications from the hedonic literature (Boyle & Taylor, 2001; Harding et al., 2003; Von Graevenitz & Panduro, 2015). I initially focus on the results of model (1b) since the inclusion of block group-level fixed effects generally improves the overall fit.[13] The impacts of specific housing characteristics on sale price are largely as expected and relatively consistent across states. For example, an additional 100 square feet adds roughly 3% to the housing price (\$5700 –9900), while an extra bathroom adds between 1.2% or \$3500 (Texas) to more than 5% or \$14,000 (Minnesota). Pools generally add between 6–10% to the sale price, while being classified as below-average-quality construction can reduce the price by up to 9% (~\$25,000). An additional 10 years in housing age reduces price by 5–10% and remodelling a house typically adds 4–7% to the final sale price. These relationships are in line with those from other hedonic studies and suggest that the model is working as expected.

Turning to the broadband technology variables of interest, the 'fibre premium' for the full 2015–2021 period is estimated at 0.9–1.6% for all three states in the sample. That is, the presence of fibre availability for houses in all three states is associated with higher housing prices on the order of 1–1.5%. Cable and DSL have negative relationships with price for most of the specifications. Fixed wireless availability demonstrates mixed results, as it is associated with a 1.4% increase in housing price in Iowa and Minnesota but a 1.8% decrease in Texas. It is worth noting that model (1a) suggests a markedly higher fibre premium in Minnesota (3.7%) and Texas (5.4%) – values that are well above the estimates for any other type of broadband technology. The inclusion of block group-level fixed effects captures some of the variation in housing price and lowers the fibre premium; however, the fact that model (1b) documents around a 1% price increase in all three states indicates that this main result is relatively robust. Evaluated at the average housing price in Texas, the premium equates to \$4708 in 2015 dollars.

4.2. Instrumental variable model results

The results from model (1b) discussed above employed block group-level fixed effects that partially deal with concerns that fibre availability may be correlated with unobserved factors like local amenities or schools. However, the results may still be biased due to other unobservable

Table 2. Hedonic house price regression results, 2015–2021.

	Iowa			Minnesota			Texas		
	(1a)	(1b)	(1c)	(1a)	(1b)	(1c)	(1a)	(1b)	(1c)
Bedrooms	0.0363***	0.0285***	0.0286***	0.0298***	0.0293***	0.0293***	0.0393***	0.0070***	0.0071***
	0.0024	0.0022	0.0022	0.0016	0.0013	0.0013	0.0018	0.0012	0.0012
Bathrooms	0.0311***	0.0359***	0.0358***	0.0704***	0.0560***	0.0560***	0.0399***	0.0123***	0.0125***
	0.0024	0.0018	0.0019	0.0023	0.0017	0.0017	0.0020	0.0013	0.0013
Square feet (100)	0.0302***	0.0335***	0.0336***	0.0311***	0.0340***	0.0340***	0.0354***	0.0346***	0.0346***
	0.0018	0.0023	0.0023	0.0008	0.0009	0.0009	0.0005	0.0004	0.0004
Square feet ^2	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001
Remodel (0/1)	0.1271***	0.0677***	0.0677***	0.0238***	0.0411***	0.0411***	0.1114***	0.0657***	0.0667***
	0.0098	0.0066	0.0067	0.0052	0.0031	0.0031	0.0057	0.0032	0.0032
House age (10)	0.0808***	0.0811***	0.0814***	0.0155***	0.0537***	0.0539***	0.1010***	0.0985***	0.1004***
	0.0028	0.0022	0.0023	0.0025	0.0019	0.0019	0.0033	0.0025	0.0025
House age^2	0.0025***	0.0030***	0.0030***	0.0005***	0.0017***	0.0017***	0.0117***	0.0085***	0.0086***
	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0038	0.0002	0.0003
Basement (0/1)	0.0033	0.0113**	0.0114**	0.0684***	0.0640***	0.0640***	0.0086	0.0054	0.0055
	0.0049	0.0051	0.0051	0.0041	0.0035	0.0035	0.1358	0.2581	0.2674
Garage square feet (100)	0.0168***	0.0159***	0.0159***	0.0096***	0.0148***	0.0148***	0.0266***	0.0263***	0.0263***
	0.0006	0.0007	0.0007	0.0005	0.0004	0.0004	0.0006	0.0005	0.0005
Fireplace (0/1)	0.0814***	0.0765***	0.0767***	0.0721***	0.0724***	0.0723***	0.0275***	0.0207***	0.0202***
	0.0045	0.0036	0.0042	0.0055	0.0037	0.0038	0.0042	0.0029	0.0029
Pool (0/1)	0.0546***	0.0654***	0.0651***	0.0655***	0.0797***	0.0797***	0.1095***	0.1001***	0.1001***
	0.0091	0.0111	0.0110	0.0161	0.0075	0.0075	0.0023	0.0013	0.0013
No central air (0/1)	0.0617***	0.1052***	0.1052***	0.0121*	0.0673***	0.0672***	0.1433***	0.0637***	0.0635***
	0.0064	0.0067	0.0067	0.0054	0.0043	0.0043	0.0094	0.0032	0.0032
Below avg quality (0/1)	0.0731	0.0735	0.0654	0.1110***	0.0394***	0.0394***	0.1482***	0.0921***	0.0912***
	0.1012	0.0900	0.0891	0.0120	0.0086	0.0087	0.0147	0.0134	0.0134
Fibre (0/1)	**0.0072**	**0.0090****	**0.0024**	**0.0374*****	**0.0109*****	**0.0212*****	**0.0542*****	**0.0164*****	**0.0876*****
	0.0046	**0.0036**	**0.0097**	**0.0044**	**0.0023**	**0.0038**	**0.0035**	**0.0022**	**0.0086**
Cable (0/1)	0.0543	0.0589***	0.0588***	0.0639***	0.0854***	0.0854***	0.0511***	0.0291***	0.0261***
	0.0102	0.0093	0.0092	0.0111	0.0087	0.0087	0.0081	0.0057	0.0058

DSL (0/1)	0.0086	0.0078	0.0088	0.0074	0.0126***	0.0109***	0.0096**	0.0071**	0.0084***
	0.0102	0.0079	0.0080	0.0089	0.0036	0.0037	0.0053	0.0031	0.0032
Fixed wireless (0/1)	0.0071	0.0138***	0.0138***	0.0202***	0.0098***	0.0101***	0.0030	0.0183***	0.0181***
	0.0061	0.0042	0.0042	0.0061	0.0035	0.0036	0.0042	0.0028	0.0027
Constant	10.2559***	11.5290***	11.5269	9.5570***	11.7604***	11.7609***	10.3075***	11.6817***	11.6619
	0.1761	0.0273	0.0281	0.1206	0.0162	0.0163	0.1144	0.0111	0.0112
Year fixed effects	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)	yes (6)
Quarter fixed effects	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)
Block group demographics	yes (7)	–	–	yes (7)	–	–	yes (7)	–	–
Block group fixed effects	–	yes (2424)	yes (2424)	–	yes (3289)	yes (3289)	–	yes (7980)	yes (7980)
IV approach	–	–	yes	–	–	yes	–	–	yes
Adjusted R^2	0.598	0.655	–	0.576	0.675	–	0.788	0.890	–
# observations	286,911	291,174	291,174	483,662	488,308	488,308	919,094	935,296	935,296

Notes: *, **, and *** denotes significance at the $p < 0.10$, $p < 0.05$, and $p < 0.01$ levels, respectively. Standard errors are clustered at the block group level.

characteristics that change over time – such as local leadership or road/electricity improvements – that could affect fibre rollout. This concern is handled with the IV specification in Equation (2) where fibre availability is estimated based on fibre availability in the five nearest census block groups. These first stage results are available in Appendix A in the online supplemental data, and the second stage results are displayed as model (1c) in Table 2. As the Appendix shows, the first stage Kleibergen-Paap (KP) F-statistics are quite high (over 580) for each state, much higher than the threshold of 10 suggested for strong instruments (Staiger & Stock, 1997).[14] The coefficients on fibre availability in each of the five neighbouring block groups are highly significant and generally decrease with distance as expected. Because the first stage includes multiple instruments, I can also test their exogeneity in the second stage regression via the Sargan-Hansen overidentification test (Sargan, 1975; Wooldridge, 2012). Here the null hypothesis is that the included instruments are not correlated with the second stage error term and I cannot reject this null in any of the three states. Finally, I use Wald and Hausman tests for the exogeneity of fibre (as opposed to their instruments). The null hypothesis for these tests is that the first-stage residuals do not influence housing prices, in which case fibre would be exogenous and model (1b) would be preferred. Appendix A shows, however, that this test is rejected at traditional significance levels in each state, indicating that fibre is *not* exogenous. The results of the KP F-statistics, Sargan-Hansen overidentification tests, and Wald/Hausman test suggest that the IV approach in model (1c) is preferred and that the instruments used are appropriate. Note that R^2 is not reported for the IV specifications in Table 2 given the problematic nature of the standard errors due to the first-stage prediction (Pesaran & Smith, 1994).

The takeaway results from the IV approach in Table 2 are more nuanced. In Iowa, there is no longer a significant impact of fibre availability on housing prices – likely due to differences in methodology discussed below. Alternatively, it may be due to the ‘plateauing’ of premiums over time as fibre presence evolved from a novelty to a widespread feature – particularly in rural areas of the state.[15] In Minnesota, however, the fibre impact is now stronger (2.12% vs. 1.09% in model (1b)) and the control variable coefficients remain similar. The results for Texas are now even larger, suggesting that fibre adds 8.8% to housing values over the full 2015–2021 period. These premiums would be valued at $5325 in Minnesota and $25,146 in Texas in 2015 dollars. For context, the fibre premium in Minnesota is above the estimated value of an additional 100 square feet of garage space; in Texas the premium is close to that provided by a pool.

There are important reasons why the fibre coefficients from the IV approach (model (1c)) differ from those using the OLS fixed effect approach (model (1b)). In general, the fibre coefficient in the OLS specification is attempting to measure the average treatment effect (ATE) of fibre availability across the entire state population. Alternatively, the IV approach estimates the <u>local</u> average treatment effect (LATE) *only for the subpopulation that is influenced by the instrument* (Heckman & Urzua, 2010; Imbens & Angrist, 1994). In the context here, this implies that the IV fibre coefficient only represents the effect for households in blocks where the local fibre provision decision was actually induced by nearby fibre availability. This will not hold universally. For example, other research has shown that Iowa’s ‘Dig Once’ and permitting policies resulted in increased fibre availability in the state (Biedny et al., 2022) and intuitively may have spurred fibre provision in locations *without* fibre nearby. These ‘defiers’ (who get treatment even though the IV suggests they would not) are not included in the LATE estimate – even though these households might have benefitted the most. Alternatively, the IV approach may represent a broader portion of the transactions in Texas, where 99% of the observations are in metropolitan areas (and are therefore more likely to be influenced by nearby fibre availability). Aronow and Carnegie (2013) argued that this heterogeneity in treatment effects can cause different values for ATE vs. LATE – and makes interpretation more difficult.

4.3. Subset robustness tests

Table 3 limits the sample in each state to three distinct subsets: (1) sales that took place between 2015–2018 (i.e., pre-2019); (2) sales that took place after March 2020 (i.e., post-COVID) and (3) sales that took place only in the largest metropolitan area in each state (MSA-only). Each is estimated using the predicted fibre availability from the IV approach in Equations (2) and (3). These results show that the fibre premium was somewhat higher in each of the three states prior to 2019: 1.6% in Iowa, 7.1% in Minnesota and 9.1% in Texas. These are higher than for other broadband technologies during that period, likely because fibre availability was scarcer (and thus commanded a larger premium).[16] Moving to the post-COVID period, the model results demonstrate a 2.7% fibre premium in Minnesota, but not in Iowa or Texas. When looking at the largest MSA in each state over the full 2015–2021 period, the results are not significant for the Des Moines MSA, which is expected given the similar outcome for Iowa generally over this time. In the remaining two states, however, fibre has a higher premium than those reported for all state transactions (i.e., the fibre coefficients are higher for the MSA column of Table 3 than for model (1c) of Table 2), and ranges from 3.6% in the Minneapolis/St. Paul region to over 11% in Dallas/Ft. Worth. This suggests that the fibre premium may be somewhat larger if the 'law of one price function' is rigorously adhered to; however, use of these smaller geographies makes it more difficult to generalise about larger-scale impacts.

Appendix B (in the online supplemental data) displays the results of these same specifications using the OLS model (1b). The findings are qualitatively similar to those in Table 3 but have values closer to the smaller fibre premiums estimated by this methodology (and displayed in Table 2's model (1b) for the full sample). Here again, the premiums in the pre-2019 sample are larger than those for the full sample in all three states. They also find some evidence of a post-COVID fibre premium of around 0.5% in two states (Minnesota and Texas).

As one final robustness check, Appendix C (in the online supplemental data) demonstrates the broadband results of interest for models (1b) and (1c) with the natural logarithm of maximum available download speed (any technology) as an additional control variable. The results confirm that speed is positively associated with housing price, and that the main findings on the broadband technology variables remain largely unaffected.

5. DISCUSSION AND CONCLUSIONS

Fibre internet is broadly considered to be superior to other broadband modalities (Gerencer, 2020), and recent US policy initiatives have appeared to prioritise fibre investment (Engebretson, 2022). Early empirical work documented the existence of a 'fibre premium' in US housing prices, however it is unclear if such a premium has persisted as fibre has become more common. The work here considers housing prices across three states where fibre expanded greatly between 2015 and 2021. A variety of econometric specifications find that housing values are positively affected by the presence of fibre. This impact was largest during the pre-2019 period, when fibre was only available to a relatively small share of households in the study area. However, the results persist throughout the seven years contained in the study and suggest that fibre continued to be an important consideration for some houses that sold in the immediate aftermath of COVID-19.

The preferred IV specifications demonstrate markedly different fibre housing premiums across states during the period of analysis, with no measurable impact in Iowa, 2% in Minnesota and over 8% in Texas. The subdued impact in Iowa may reflect differences in the methodologies and to whom the resulting treatment effects apply. As previously discussed, the fibre coefficients from the IV specification only represent treatment effects for households where the instrument

Table 3. Hedonic house price regression results for specific sub-samples (pre-2019; post-COVID; MSA only) – IV approach.

	Iowa			Minnesota			Texas		
	Pre-2019	**Post-COVID**	**MSA Only**	**Pre-2019**	**Post-COVID**	**MSA Only**	**Pre-2019**	**Post-COVID**	**MSA Only**
Fibre (0/1)	**0.0160*****	**0.0299**	**0.0203**	**0.0706*****	**0.0271*****	**0.0356*****	**0.0906*****	**0.0190**	**0.1114*****
	0.0019	**0.0252**	**0.0202**	**0.0106**	**0.0053**	**0.0048**	**0.0084**	**0.0150**	**0.0098**
Cable (0/1)	0.0819***	0.0758***	0.0293*	0.1017***	0.0894***	0.0669***	0.0478***	0.0161**	0.0034
	0.0116	0.0125	0.0170	0.0098	0.0121	0.0132	0.0074	0.0065	0.0085
DSL (0/1)	0.0116	0.0097	0.0075	0.0063	0.0076	0.0091**	0.0071***	0.0074	0.0049
	0.0095	0.0128	0.0152	0.0061	0.0050	0.0041	0.0035	0.0062	0.0049
Fixed wireless (0/1)	0.0156***	0.0215***	0.0242***	0.0144**	0.0197***	0.0234***	0.0268***	0.0113***	0.0228***
	0.0054	0.0025	0.0060	0.0063	0.0056	0.0045	0.0025	0.0019	0.0029
House charac. Controls	Yes	yes	yes	yes	yes	yes	yes	yes	yes
Year fixed effects	yes (3)	yes (1)	yes (6)	yes (3)	yes (1)	yes (6)	yes (3)	yes (1)	yes (6)
Quarter fixed effects	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)	yes (3)
Block group fixed effects	yes (2195)	yes (2405)	yes (440)	yes (3245)	yes (3256)	yes (2040)	yes (7456)	yes (7283)	yes (2592)
# Observations	152,648	89,192	93,487	273,521	133,200	320,884	509,778	261,630	295,032

*, **, and *** denotes significance at the $p < 0.10$, $p < 0.05$, and $p < 0.01$ levels, respectively. Standard errors are clustered at the block group level.
Post-COVID represents sales after March 2020.
MSA = Metropolitan Statistical Area: Des Moines (Iowa), Minneapolis / St. Paul (Minnesota), Dallas / Ft. Worth (Texas).

actually induced local fibre availability (i.e., LATE instead of ATE). This exclusion of households where the instrument failed to predict fibre (for example, more remote neighbourhoods that may have benefitted from a 'dig once' policy) is at least partially responsible for the fibre coefficient differences from OLS (model (1b)) and IV (model (1c)) in Table 2. Some researchers have even argued that the LATE estimate is not the actual parameter of interest (Deaton, 2009). While the Wald and Hausman tests in Appendix A suggest that the OLS results are biased due to the endogeneity of fibre, more work is likely needed to uncover the true full-sample ATE vs. the LATE provided in this analysis. In particular, Aronow and Carnegie (2013) suggested an inverse compliance score weighting approach that may be appropriate in this case.

The large state-level differences in the IV fibre housing premium estimate suggest that local context is important. The Minnesota result of 2.12% is similar to the 1.83% documented by Wolf and Irwin (2023) for Wisconsin and is reassuring given the proximity of the two states. The much higher premium in Texas may be due to self-selection issues associated with their non-disclosure data. For example, if sales where fibre was available – but no fibre premium was paid – were systematically less likely to be included in the data, this would bias the premium upwards. The Texas result may also be a factor of the nearly universal (99%) metropolitan location of the sales (with notoriously spread-out cities and high expectations for remote work ability) and/or the relatively smooth ramp-up in fibre availability over time (Figure 2). Alternatively, the lack of a significant result in Iowa may be because the LATE is excluding households that stand to benefit the most (i.e., those with fibre themselves but that did not have neighbouring communities with fibre). Another important consideration is that the other broadband technologies considered were much more ubiquitous than fibre – particularly in the earlier years of analysis. For most houses being sold, the expectation was that *some* type of broadband would be available. However, the insignificant or negative coefficients for cable and DSL in Table 2 suggest that consumers generally did not value these technologies. Alternatively, the consistent positive coefficient on fibre across a variety of states provides strong evidence that consumers were willing to pay extra for a house with this amenity. Table 3 demonstrates that this effect was even stronger in earlier years of the fibre rollout, with larger fibre premiums in all three states studied prior to 2019.

The fact that the fibre premium appears to have diminished as overall fibre availability increased reinforces that consumer expectations and valuations change over time. However, this premium still exists in some states as of 2021. Further, the post-COVID housing market is still adjusting to factors like increased levels of working from home, remote healthcare options and higher numbers of devices per household. Since BEAD funding – a large portion of which will be dedicated to fibre rollout – will be distributed from 2024 to 2028, fibre's 'premier' broadband qualities will likely continue to command value in the near future of the US housing market.

To quantify this potential impact, Table 4 considers the total rural housing market and annual rural home sales in the US. Recent data puts the total number of single-family housing units at around 84 million (Neal et al., 2020). With approximately 20% of the US population located in rural areas as of the 2020 Census (Census Bureau, 2022) and roughly 60% of those rural locations still lacking fibre (Brodkin, 2019), over 10 million rural homes could benefit from fibre upgrades. To estimate the potential impact of universal fibre availability, the average LATE estimate from the instrumental variable approach in model (1c) (which only applies to households in areas where fibre availability was in fact induced by the chosen instrument) *and* the fibre ATE estimates from model (1b) are used. While these latter estimates are potentially biased due to endogeneity, they are representative of the entire sample (and, notably, are more conservative). Assuming a 1.2% increase in housing value once fibre is deployed (the average OLS coefficient values from Table 2) and a median rural housing value of $235,000 in 2015

Table 4. Total potential rural housing market value increase from adding fiber.

Total market		**Number of homes**	
Total detached single family homes in US		84,000,000	
% Rural	20%	16,800,000	
% Needing fibre	60%	10,080,000	
MHV (rural only)	$235,000		
Fibre adds to each sale (OLS: 1.2%):	$2844	$28,662,480,000	Potential increase in rural housing value (total) – 2015 dollars
Fibre adds to each sale (IV: 3.6%):	$8460	$85,276,800,000	
Annual market			
Total annual home sales in US		6,000,000	
% Rural	20%	1,200,000	
% Needing fibre	60%	720,000	
MHV (rural only)	$235,000		
Fibre adds to each sale (OLS: 1.2%):	$2844	$2,047,320,000	Potential Increase in Rural Housing Value (Annually) – 2015 dollars
Fibre adds to each sale (IV: 3.6%):	$8460	$6,091,200,000	

Note: MHV = Median Housing Value (in 2015 $).

dollars (the average across the three states in this data), the total potential increase in rural housing value from deploying ubiquitous fibre is over $28 billion in 2015 dollars, or $36.9 billion in 2023. With the more aggressive instrumental variable estimate of 3.6% (the average of the three state estimates in Table 2: (0% (Iowa), 2.12% (Minnesota) and 8.76% (Texas))), the potential impact is even larger at over $85 billion in 2015 dollars ($109 billion in 2023). Alternatively, roughly six million houses are sold each year (Freddie Mac, 2022). Applying the same percentages (20% rural, and 60% lacking fibre) leads to over 700,000 annual sales in rural areas that are currently without fibre. A 1.2% increase in price for those locations leads to an estimate of $2.0 billion ($2.6 billion in 2023 dollars) in increased value each year, while a 3.6% increase leads to over $6.0 billion ($7.8 billion in 2023).

The analysis here adds to the growing body of evidence that investment in fibre broadband has measurable impacts on local housing values. Future work may consider implementing hedonic methods (such as geographically weighted regression (GWR)) that would allow these premiums to vary over space. Sachdeva et al. (2022) performed this type of analysis for a single county in Washington State in an attempt to quantify 'intrinsic value' and Chun et al. (2021) examined heterogeneity in foreclosure spillover impacts in three Ohio metropolitan areas. While the computational intensity of GWR will likely limit the geographic scope of this type of work (and thus prevent the ability to give broad-scale generalisations like those in Table 4), allowing the fibre premium to vary at lower geographies would be a useful extension. Another relatively unexplored arena would be to test whether the fibre premium differs between homebuyers and renters, similar to Wang and Lee's (2022) study of air quality preferences. While Klein (2022) finds a similar 3% fibre premium for rental properties in Germany, I am aware of no rental-focused studies using US data.

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NOTES

1 The current FCC definition of broadband was set in 2015 and requires speeds of at least 25 MBPS down and 3 MBPS up. However, recent US broadband funding programmes require 100 MBPS down and 20 MBPS up (NTIA, 2022), reflecting Federal recognition of evolving/growing speeds.
2 Bishop et al. (2020) point out that while rental prices may be used for hedonic work, they are often more complicated because of ambiguities about payment for items like utilities or maintenance.
3 Only around 50% of US households subscribed to a streaming service in 2016, compared to roughly 89% in late 2022 (Ng, 2018; Kantar, 2023)
4 Malpezzi (2002) suggests many of these characteristics for inclusion in hedonic house pricing models.
5 Kalfrin (2021) lists twelve states where non-disclosure is still in practice: Alaska, Idaho, Kansas, Louisiana, Mississippi, Missouri (parts), Montana, New Mexico, North Dakota, Texas, Utah and Wyoming.
6 Digital Subscriber Line (DSL) technology as referenced in the Form 477 technology codes includes older asymmetric xDSL and ADSL2 / ADSL2+, which use mostly copper cabling, as well as newer VDSL which typically uses a fibre middle-mile (and has significantly higher speeds).
7 In keeping with other studies on this topic, I do not include satellite availability.
8 This is notably different from the approach in Molnar et al. (2015) and Wolf and Irwin (2023), who assume fibre availability for an entire block *group* if any block within that group is denoted as having fibre. The approach here is more precise and is more likely to accurately depict the technology available for each house being sold.
9 Interestingly, fireplaces and pools were both most common in Texas houses.
10 Molnar et al. (2019) use block group-level fixed effects, but no longer use transaction-level data.
11 The five nearest block groups are calculated in GIS using Census' Centres of Population by Block Group centroids for each of the three states.
12 All four broadband technologies (fibre, DSL, cable, fixed wireless) are included in both Equations (1) and (3). Fiber is broken out separately in Equation (3) due to the use of fitted values from Equation (2).
13 Note that the adjusted R^2 values increase by between 0.05 and 0.11 when moving from model (1a) to model (1b). Note also that the number of observations is slightly lower for model (1a) due to some block groups with specific characteristics missing from the American Community Survey.
14 Lee et al. (2022) argue that first-stage F-statistics should be larger than 104.7 for valid inferences.
15 The Iowa Communications Alliance reports that 94% of rural locations in the state are served by fibre broadband, representing 23% of total broadband deployments in the state (ICA, 2023). However, 70% of the housing transactions in Iowa took place in the remaining metro areas that embrace 75.4% of the state.
16 Prior to 2019, fibre was only available for 13%, 22% and 37% of the Minnesota, Iowa and Texas transactions, respectively.

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