

# Title: An Empirical Investigation of the Connection Between Broadband Provision, Speed and Adoption in the United States

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**Highlights**

- Analyze link between broadband provision, speed and adoption in the United States.
- Increased provision at higher speeds does not increase adoption.
- Higher income household adoption more sensitive to speed in rural areas.
- Adoption by poorer households more sensitive to speed in urban areas.
- Link between higher speeds and adoption strongest in urban commuting zones.

## **Abstract**

The Broadband Equity, Access, and Deployment program aims to provide access to 100/20 Mbps Internet speeds throughout the United States. Under this metric, many rural areas in the United States are considered unserved or underserved, often with fewer providers offering lower speeds. This paper estimates the associations between broadband speeds and broadband adoption in areas across the United States. Lack of access to Internet connections sufficiently fast to meet a household's needs may be a disincentive for Internet adoption. Additionally, more unique providers offering higher speed plans could increase adoption through local price and quality competition. We find two main results. First, increases in broadband provision do not always increase adoption rates, especially at higher speeds. Second, adoption rates for higher income households are less sensitive to increases in higher speed provision in urban areas, but more sensitive in rural areas, suggesting they are often the first adopters of higher speed technologies. Poorer households are the inverse (sensitive in urban areas, insensitive in rural areas), suggesting price or preference changes with income across rurality. The relationship between provision and adoption is strongest in urban commuting zones, where markets are less saturated than urban cores but demand remains sufficiently high to respond to expanded provision.

## 1. Introduction

At the dawn of the Internet era, computer speeds were a fraction of what they are today. Households now stream movies, music, games, and other forms of entertainment over the Internet, often simultaneously. Businesses conduct video calls and move large quantities of data to and from cloud storage throughout the day. Without faster speeds, these everyday actions become time intensive or impossible for users. This need for speed has changed what it means to be covered by the Internet. People that access the Internet over now-inferior platforms such as DSL or satellite and that cannot connect at sufficient speeds find themselves left behind in the digital age.

The present study endeavors to investigate whether increased provision at higher speeds affects adoption rates. In doing so, we connect and build on three distinct but related strands of work about broadband and societal impacts. The first strand of work examines disparities in access between people and places in terms of provision levels, broadband technologies and access speeds (Strover, 2003; Grubestic, 2006, Grubestic, 2008; Whitacre, Strover, & Gallardo, 2015). This line of work has established that historically, and to this point in time, urban areas enjoy a higher level of competition for service, as proxied by the number of providers (Grubestic, 2006) and greater availability of faster broadband technologies (Lee & Leonard, 2023).

The second strand of work examines broadband speed availability and associated economic impacts. Early work by Rosston et al. (2010) found diminished willingness to pay for faster broadband speeds. Bauer et al (2023) also found that tribal areas have lower download speeds for both mobile and fixed broadband technologies compared to neighboring nontribal areas. A large proportion of studies examine the economic impacts of broadband speed and find evidence that faster speeds positively impact the economy in a variety of ways ranging from firm productivity (Aldashev & Batkeyev, 2021; Gallardo et al, 2021), business startup rates (Deller & Whitacre, 2019; Duvivier et al, 2021; Hasbi 2020), regional growth (Briglauer et al, 2021; Briglauer & Gugler, 2019), and employment (Lobo et al, 2020).

The third strand of work examines broadband adoption rates. There is a large body of work at the country level about factors impacting broadband adoption (Lin & Wu, 2013; Haucap, Heimeshoff, & Lange, 2016; Briglauer et al., 2025). Findings from these studies note that rural residents have lower valuations of broadband access and e-services which are likely to impact adoption decisions (Thomas & Finn, 2018). Tariff diversity promotes broadband adoption (Haucap, Heimeshoff, and Lange, 2016) as do demand-side policies (Belloc, Nicato, & Rossi, 2012), that have more enduring impacts than do supply-side policies, which are more effective when broadband adoption rates are low.

The number of adoption studies focused on the United States is comparatively smaller than country-level studies. U.S. focused studies have identified key factors impacting adoption including income and education (Mills & Whitacre, 2003). They have also examined mobile broadband adoption (Prieger, 2013; Manlove & Whitacre, 2019a) and conducted evaluations of the efficacy of policies aimed at raising adoption rates (Manlove & Whitacre, 2019b; Rosston & Wallsten, 2020). Case studies of adoption in specific states including Oklahoma (Whitacre, 2008), North Carolina (Boik, 2017), Indiana and Arkansas (Lai et al., 2020), and Arkansas (Manlove et al., 2021) provide some insights about platform prices and adoption (Boik, 2017) and the willingness to pay for broadband services.

Studies that span the entire United States and examine the link between broadband availability at specific speed tiers and adoption rates are sparse. We hypothesize that such a link exists given the findings of prior work which indicate that speed is a factor in the demand for

broadband services (Glass & Stefanova, 2010). Specifically, this study estimates models to test three hypotheses related to broadband speed and adoption. First, we test whether the increased availability of faster broadband is associated with higher adoption rates for all households. Second, we test whether the increased availability of faster broadband is associated with higher adoption rates for rural residents compared to urban residents. Third, we test whether the increased availability of faster broadband is associated with higher adoption rates for lower income households.

## **2. Related Literature**

Papers have demonstrated gaps between urban and rural areas when it comes to broadband access (Strover, 2003; Prieger, 2003; Whitacre, Strover, & Gallardo, 2015) and use (Horrigan, Stolp, & Wilson, 2006). In general, studies agree that the broadband technologies in rural areas will always lag those of urban areas because of the economics behind broadband deployment (Greenstein, 2004) which involve high fixed costs to deploy the infrastructure and the ability to charge more to customers in particular places to recoup these costs and/or the ability to spread the cost of service over many customers in more residentially dense areas, thereby lowering the per customer cost. More recent work on the availability of broadband technologies finds this to be the case. There is lower availability of newer broadband technologies (e.g. Cable Modem-DOCSIS 3.1) in rural compared to urban areas (Lee & Leonard, 2023). The technologies that are available in rural areas are also slower than those in urban areas (Lee & Leonard, 2023).

That said, prior work has uncovered subtle nuances to broadband availability in rural areas. Grubestic (2006) notes that not all rural areas are equal, these “islands of availability” have good broadband access and provider choice. The same study also notes that it is not just some rural areas that suffer from poor service, low-income areas also tend to have worse service because of unfavorable demand conditions (Grubestic, 2006). Previous case studies of xDSL broadband service have also found evidence of “platform dominance”, meaning that a company providing service over a particular platform type had acquired a dominant market share, making the entry of other companies providing services over alternative platforms unattractive (Grubestic, 2003).

In terms of broadband speed, Rosston et al. (2010) examined willingness to pay for broadband speed and found diminishing returns. Consumers were willing to pay \$45 to move from slow to fast broadband service. They were only willing to pay \$3 more or \$48 for further speed improvements to very fast broadband service. Bauer et al (2023) also found that tribal areas have lower download speeds for both mobile and fixed broadband technologies compared to neighboring nontribal areas.

Within the body of work examining broadband speed, a large segment is devoted to assessing the economic impacts of access to faster broadband connections (see Abarardi & Cambini, 2020 for a review). Researchers have found evidence that faster broadband increases housing prices (Ahfeldt et al., 2017; Molnar et al., 2019; Deller & Whitacre, 2019). They have also found however that there are diminishing returns to broadband speed. For example, Ahfeldt et al. (2017) found evidence of a speed premium up to speeds of 24 mbps in England. In rural areas, Deller and Whitacre (2019) found evidence of diminishing returns to speed; basic access to broadband had a bigger impact on housing prices than did faster broadband speeds. Other studies find broadband positively impacts a range of other economic activity including firm productivity (Aldashev & Batkeyev, 2021; Gallardo et al, 2021), business startup rates (Deller et

al, 2022; Duvivier et al, 2021; Hasbi 2020), regional measures of growth (Briglauer et al, 2021; Briglauer & Gugler, 2019), and employment (Lobo et al, 2020).

A critical aspect to realizing economic gains from broadband is adoption by businesses and people and there are many studies conducted at the country level that provide insights about factors impacting broadband adoption and the economic impacts of broadband adoption (Thomas & Finn, 2018; Belloc, Nicato, & Rossi, 2012; Lin & Wu, 2013; Haucap, Heimeshoff, & Lange 2016; Briglauer et al., 2025). These studies have provided important insights about the positive impact of tariff diversity on adoption (Haucap, Heimeshoff, & Lange 2016) and the relative efficacy of demand vs. supply-side policies to promote adoption Belloc, Nicato, & Rossi, 2012).

The number of adoption studies focused on the United States is smaller than country-level studies. U.S. focused studies about broadband adoption find education and income are drivers of differential adoption rates between metropolitan and non-metropolitan counties (Mills & Whitacre, 2003). Case study work in the state of Oklahoma between 2000 and 2006 focusing on cable and DSL service adoption found that income was more of an influence than infrastructure availability; education also increased adoption (Whitacre, 2008). These findings suggest demand-side policies are more likely to be successful than supply-side policies. Although case study work in North Carolina suggests platform price matters in terms of the broadband technology adopted (Boik, 2017), other case study work in Indiana and Arkansas produces some estimates of willingness to pay for Internet services. Results of the Indiana study found that the WTP for broadband was between 0.06/Mbps and \$0.10/Mbps per month (Lai et al., 2020). An Arkansas study of agricultural producers produced estimates of \$1.07 to \$1.34 per Mbps of upload speed and \$0.02 to \$0.03 per Mbps of download speed (Manlove et al., 2021). Producers also indicated that the reliability of connections was important, as are symmetrical connections, which are necessary for precision agriculture applications.

Given the historical differences between urban and rural areas in Internet access, some U.S. based studies are looking at drivers of mobile Internet connections as a viable alternative to more expensive fixed broadband connections (Prieger, 2013; Manlove & Whitacre, 2019a). The Prieger (2013) study found no gap in mobile broadband adoption between urban and rural households indicating that if available, the likelihood of adoption is similar for both urban and rural residents. This same study did find an adoption gap for fixed broadband technologies; rural areas lagged urban areas, especially low-income rural households. The Manlove and Whitacre (2019a) study provides some insight into who is adopting mobile-only Internet connections. Their study findings indicate that the main driver of mobile adoption was an increase in mobile network download speeds. They also found that people aged 55 and above were partial drivers of the increase in mobile-only adoption.

Lastly, some studies have conducted evaluations of U.S. policies to improve broadband adoption. Manlove and Whitacre (2019b) evaluated the impact of the Connected Nation program on broadband adoption in 5 states between 2012 and 2013. The results indicated no impact on broadband adoption in the states evaluated. This could be the result of the short time period over which the analysis was conducted. Nevertheless, there remains limited understanding about the efficacy of programs designed to improve broadband adoption. Rosston and Wallsten (2020) evaluated the efficacy of the Comcast Internet Essential programs at promoting broadband adoption among low-income households. They found that the program was effective at promoting adoption but that the program encouraged adoption among households who would have adopted broadband anyway.

### 3. Data

The tract-level panel dataset used in our analysis comprises three data sources and a crosswalk which are summarized in Table 1. The analysis dataset spans the years 2017-2021 because it is the time period for which data are available for broadband provision, adoption, and socio-demographic characteristics. The first of these sources is the Federal Communications Commission (FCC) Form 477 database on fixed broadband deployment. This portion of FCC data provides information about broadband from 2014 until 2021 (FCC, 2022). We use this database because it contains publicly available block level data about the count of Internet service providers (ISPs), information about advertised speeds, and the associated delivery technology (e.g. fiber and DSL). This database includes information about satellite providers as well. Per the precedent of prior work on broadband availability in the United States (Grubestic, 2006; 2008; Prieger, 2013) we tabulated the count of broadband providers in each Census block.

Although there are other sources of data from the FCC, such as the Broadband Fabric, these data are not in the public domain and are not readily available for analysis. Data are in the public domain from the national broadband map (NBM) from June 2022-December 2025. The NBM database provides point-based information that can be aggregated to Census geographies, while the Form 477 data are limited to the Census block level of resolution. There are likely to be differences that represent discontinuities between Form 477 and the more recent NBM data.

As FCC Form 477 is at the census block level, we followed a procedure to aggregate the observations to the tract level. First, we identified unique plans for each holding company in a census block. A plan is a unique combination of upload speed, download speed, and delivery technology for each holding company. Then, we identified which blocks in each tract each provider serves. From there, we constructed a population-weighted provider count at the tract level. For each provider, we calculated the share of the tract's total population residing in blocks served by that provider, using 2010 Census block-level population counts. This fractional value was then summed across all providers meeting a given speed threshold to produce the tract-level broadband provision measure. The resulting variable is continuous and can be interpreted as the expected number of providers available to a randomly selected resident of the tract. This approach addresses a known limitation of binary presence measures, which tend to overstate provision in tracts where a provider serves only a small fraction of the population — a pattern that is particularly common in large, sparsely populated rural tracts where a single provider may serve only one or two blocks at the tract's periphery.

The speed thresholds used in this analysis are based on the three definitions of broadband speed provided by the FCC since 2010. In 2010, the FCC defined broadband as Internet with 4mbps download speeds and 1mbps upload speeds. In 2014, the FCC changed their definition to 25 Mbps down, 3 Mbps up. Most recently, the FCC changed their definition to 100 Mbps down, 20 Mbps up in 2024. Plans must reach both the download and upload threshold to be considered a broadband plan in our analysis.

The second dataset we used came from the American Community Survey (ACS) 5-Year Estimates conducted by the U.S. Census Bureau. Starting in 2013, ACS started recording responses related to Internet adoption and use, including the platform of the Internet connection (e.g. cellular data plan, satellite, dial-up, and broadband delivered over cable, DSL, or fiber). For the all-household model, the dependent variable is constructed from ACS table S2801 as the share of households subscribing to broadband delivered over cable, fiber optic, DSL, or satellite, excluding cellular-only subscriptions. This definition was chosen to maximize alignment with the FCC Form 477 provider count variables, which capture fixed broadband and satellite

providers but do not include mobile or cellular coverage. For the income band models, ACS table S2801 provides counts of households with any broadband subscription *including* cellular for three income groups: households earning less than \$20,000, households earning between \$20,000 and \$74,999, and households earning \$75,000 or more. Data using 2020 tracts were harmonized to 2010 tracts using the IPUMS tract-to-tract crosswalk.

Finally, we merge data from the U.S. Department of Agriculture (USDA) Economic Research Service (ERS) on terrain ruggedness and rurality at the tract level. Specifically, we compiled Terrain Ruggedness Index values, expressed in meters, as a measure of physical topography, though this time-invariant baseline is ultimately absorbed by the tract-level effects in our final empirical specifications. Rural-Urban Commuting Area (RUCA) Codes are used to determine if a tract is Urban (1), Urban Commuting (2 and 3), and Rural (4-10). Urban, Urban Commuting, and Rural tracts are treated as distinct categories for several reasons. Urban commuting zones are tracts whose residents commute predominantly to urban centers, and they occupy an intermediate position in broadband market structure: they are less densely served than urban cores and face higher per-unit deployment costs yet have demand profiles closer to urban areas than remote rural tracts due to their economic integration with urban labor markets.

#### **4. Conceptual and Empirical Framework**

How availability of higher speed Internet interacts with adoption behaviors is analogous to how supply changes may affect an equilibrium outcome in a market setting. Indeed, one can consider local levels of broadband adoption as local market outcomes or equilibriums. There are many avenues through which additional entrants in a local market or the introduction of faster (and more reliable) technologies might affect the price of broadband as well as preferences for it. If broadband plans among Internet service providers (ISPs) are similar in reliability and speed, more entrants in an area might drive the price of broadband down to its marginal costs. Places offering higher broadband speeds might also price their lower speed offerings at lower prices. As a result, consumers with lower willingness to pay might adopt. However, changes in adoption due to price competition might be rather small: as the literature suggests, demand for Internet is price inelastic and small changes in speed availability are unlikely to result in large demand changes (Glass & Stefanova, 2010). As a result, prices would need to change dramatically to change adoption patterns. Additionally, more remote and rugged areas might incur higher costs for broadband infrastructure, driving even the competitive price higher than its counterparts in urban or developed local markets.

ISPs could also quality-compete. As ISPs often use newer and more reliable broadband technologies to serve areas with higher speeds, potential adopters may be attracted to these plans because of their improved attributes. Indeed, the literature suggests that demand is quite reliability elastic, meaning people change their willingness-to-pay when reliability changes (Glass & Stefanova, 2010). This suggests households would adopt broadband if higher speeds and more reliable plans are introduced into a local market (e.g. buried fiber). Empirical research supports this: adoption rates increase markedly for fiber when municipal providers make it available (Sundaesan et al., 2013).

Research also indicates that broadband provided over fiber is superior to other platforms in terms of speed. While speeds for broadband technologies have improved over time, fiber remains the best equipped to provide reliable service and the fastest upload and download speeds. (Lee & Leonard, 2023; Fann, 2025). If many ISPs offer higher speed services using more reliable platforms like fiber, then they may have to resort only to price competing.

However, it is important to acknowledge that ISPs may participate in anticompetitive behaviors, limiting price and quality competition. ISPs could limit public disclosure of prices, enact contractual obligations that make switching costly, and even collude with one another. These tactics would make it costly for consumers to make informed decisions between providers and in turn promote higher prices. There is evidence that such behaviors take place in the United States. The telecommunications market is oligopolistic in structure, which limits consumer choice and exposures them to prices above the providers' marginal costs (Crawford, 2013). The industry's powerful lobby in Congress helps maintain market power (Dellinger, 2019). Additionally, technical attributes of ICT technologies, such as the quality-distance tradeoff (Grubestic & Murray, 2002), may also shrink local market areas, making providers more likely to act with spatial market power, limiting local competition. Any of these anticompetitive strategies would limit gains to consumers that would change adoption habits, even if there are more providers or reliable technologies in an area.

Although we cannot observe the actual price at which broadband is available, we do have data on the speeds at which broadband has been made available. These speeds do provide some indication of the cost of broadband: higher speeds are generally more expensive than slower speeds, both to the provider and to the consumer. This relationship informs the overarching hypothesis of this paper:

**H1:** *Increased availability of faster broadband is associated with higher adoption rates for all households.*

Using the models specified below, we also attempt to examine some of the nuances behind the availability of broadband speed and adoption trends. One of these nuances is the geographic location in terms of the relative rurality of households, which is operationalized using the RUCA codes outlined in Table 1. Recent studies have found that the demand for better broadband is higher among rural consumers than for urban consumers (Worden & Hambly, 2022). This suggests that the improved availability of reliable broadband Internet may act as a preference shock and, as a result, change demand. As Internet is a network good, meaning its perceived value increases as more people in one's network participate in it, increases in the availability of broadband in an area might help demonstrate its value to skeptical adopters who believed its usefulness to be limited (Thomas & Finn, 2018). Alternatively, people may have different preferences based on where they live: rural residents may feel that broadband access will always have limited benefits to their daily lives compared to urban residents, perhaps limiting adoption effects. For example, it is possible rural people enjoy outdoor recreation more than urban people, possibly limiting the benefit of better-quality screen time.

Additionally, it is more expensive to deploy broadband in rural areas (Conley & Whitacre, 2020). This higher cost of deployment, which ultimately gets passed on to consumers, is referred to as the "rural penalty" (Malecki, 2003). Areas with rugged terrain are also more likely to have higher deployment costs, which can exacerbate the penalty for some rural areas. As a result, a rural market with more providers may prove more beneficial for a consumer of broadband. The potential for increased speeds to change adoption behavior, particularly among rural residents, leads to the second hypothesis that will be tested:

**H2:** *Increased availability of faster broadband is associated with higher adoption rates for rural residents compared to urban residents.*

New and improved technology is often more expensive than its predecessors, regardless of rurality. As a result, households may be willing to adopt faster broadband plans, but may not be financially able to do so. Recent data indicate that about 57% of households making less than \$30,000 annually have broadband at home as compared to 83% of households that make between \$30,000 and \$99,999 annually and 93% of households that make more than \$99,999 annually (Vogels, 2021).

In general, higher income households have higher willingness to pay for faster speeds and are often more likely to adopt broadband in general (Whitacre, 2008; Mack et al, 2023). As a result, higher income households will be less sensitive to changes in price once the newer technology is introduced. Therefore, we propose our third hypothesis:

**H3:** *Increased availability of faster broadband is associated with higher adoption rates for lower income households.*

We estimate the following unobserved effects model using the pooled fractional probit quasi maximum likelihood estimator (QMLE):

$$E[Adopt_{it}|BB_{it}, x_{it}, HH_{it}, a_t, c_i] = \Phi(\beta BB_{it} + x_{it}\gamma + HH_{it}\eta + c_i + a_t) \quad (1)$$

where  $Adopt_{it}$  is the share of households that adopt broadband in tract  $i$  at time  $t$ ,  $BB_{it}$  is a vector of measures related to the number of providers offering broadband speeds (depending on the FCC's definitions) including quadratics and interactions with the rurality variable, formally

$$\begin{aligned} \beta BB_{it} = & \beta_1 BB_{it} * 1[Urban_i] + \beta_2 BB_{it}^2 * 1[Urban_i] + \beta_3 BB_{it} * 1[Urban Commuting_i] \\ & + \beta_4 BB_{it}^2 * 1[Urban Commuting_i] + \beta_5 BB_{it} * 1[Rural_i] + \beta_6 BB_{it}^2 \\ & * 1[Rural_i] \end{aligned} \quad (2)$$

where  $1[\cdot]$  is the indicator function that equals 1 when the tract has a certain rurality designation (e.g.  $1[Urban] = 1$  when the tract is urban, zero otherwise),  $x_{it}$  are measures of total ISPs in an area including quadratics, formally

$$x_{it}\gamma = \gamma_1 ISP_{it} + \gamma_2 ISP_{it}^2 \quad (3)$$

$HH_{it}$  are the number of households,  $c_i$  is time-invariant unobserved heterogeneity, and  $a_t$  are year dummies. Standard errors are clustered at the census tract level to account for serial correlation within tracts over the panel period. To avoid the incidental parameters problem, we use the following Mundlak-Chamberlain device:

$$\begin{aligned} c_i = & \overline{BB}_i \zeta_1 + \overline{x}_i \zeta_2 + \overline{HH}_i \zeta_3 + 1[Urban_i] \zeta_4 + 1[Urban Commuting_i] \zeta_5 \\ & + 1[Rural_i] \zeta_6 \end{aligned} \quad (4)$$

where a bar over a term denotes a time average for tract  $i$ . This captures any unobserved time invariant heterogeneity at the tract level that may confound the estimates of interest. Average partial effects (APE) are then estimated for ease of interpretation.

Essentially, this regression demonstrates whether higher broadband counts are associated with higher adoption in an area. It is difficult to justify that this model estimates a causal

parameter. The principal issue is simultaneity: because adoption and availability are jointly determined in a local market, one cannot capture the effect estimating just this regression. At worst, it is simply a regression of equilibrium outcomes in different areas. While a long-difference specification relating changes in adoption to changes in provision over the full analysis period would offer a simpler alternative, it would discard the within-period temporal heterogeneity documented in Figure 4, preclude identification of heterogeneous effects across income groups and rurality categories simultaneously, and be less suited to a fractional outcome variable with a substantial share of observations near the upper boundary of the unit interval. The panel fractional probit specification with Mundlak devices is therefore preferred as it preserves both the temporal and cross-sectional dimensions of the data while accounting for the bounded nature of the outcome.

In addition, we explored the use of terrain ruggedness as an instrumental variable for provider counts, as rugged terrain plausibly raises deployment costs and creates exogenous variation in provision. However, this approach was not feasible in our panel setting: terrain ruggedness is time-invariant, and the Mundlak within-tract mean of the provider count absorbs all cross-sectional variation that the instrument would need to identify the first stage. The excluded instruments were therefore collinear with the Mundlak devices and provided no identifying variation in the first stage. To capture heterogeneity in the effect based on the income of households, we estimate separate regressions based on four different samples: households earning under \$20,000, households earning between \$20,000 and \$74,999, households earning more than \$75,000, and all households.

## 5. Results

### 5.1. Descriptive Results

Table 2 presents the summary statistics of the main variables of interest for the entire sample, as well as subsamples delineated by rurality. As a reminder, 2010 broadband speeds are plans with 4mbps download and 1mbps upload speeds or higher, 2015 speeds are plans with 25mbps download and 3mbps upload speeds or higher, and 2024 speeds are plans with 100mbps download and 20mbps upload speeds. The information presented is a pooled average across the 2017-2021 panel. For this period, on average, 73% of households adopted broadband. This adoption rate falls as one moves from urban to rural tracts. Table 2 also provides descriptive statistics about household income and broadband adoption in urban, urban commuting and rural locations. Urban households with the lowest incomes are more likely to have broadband than are rural households with equivalent incomes. The same is true for the higher income tiers: between \$20,000 and \$74,999 and \$75,000 plus.

The pooled averages in Table 2 for average provision in an area offer a nuanced story. Pooled averages suggest that there are more total Internet service providers (ISPs) in urban tracts, and more providers with 2010 and 2015 broadband speeds. In addition, urban tracts have more providers offering the fastest broadband speeds, as indicated by the 2024 speeds.

Figure 1 presents a series of histograms detailing the summed number of population-weighted providers in each tract over time and across rurality. Histograms are binned into five categories: tracts with 0-1 providers, 1-2 providers, 2-3 providers, 3-5 providers, and more than 5 providers. Different fill colors denote whether the tracts presented are urban, urban commuting, or rural. Each panel of the figure represents a different broadband threshold.

Across the analysis period, most tracts have at least three to five providers under the 2010 and 2015 speed thresholds. For the 2024 speed threshold, 91% of tracts had at least one provider in 2017. By 2021, the percentage increased to approximately 99%. Over time, there is a marked increase in the number of providers serving both urban and rural areas at faster speeds. This is most evident in the histograms for the 2015 speed threshold: the majority of tracts across all rurality types have 3-5 providers in 2017. By 2021, almost all tracts have greater than 5. The 2024 speed thresholds are more even across bins. Figure 1 corroborates the sentiment that Internet is available for most areas in the United States, it is just a matter of speed and how many providers serve an area. Figure 1 also reveals a decline in the number of tracts served by more than five population-weighted providers between 2020 and 2021, accompanied by a corresponding uptick in the 3-5 provider bin. This pattern may reflect provider consolidation activity in the U.S. telecommunications market during this period, though changes in FCC Form 477 reporting practices between data vintages may also contribute to year-to-year discontinuities of this kind.

## 5.2. Estimation Results

Because the model we estimate has several interactions between the number of providers and the rurality designations, we present visuals for APEs rather than tables of point estimates. Each figure plots the APEs for each income sample at different broadband designations. As the outcome variable is the share of households with broadband, one can interpret the APE estimates by multiplying them by 100 and considering that as a percentage point increase. For example, if an APE is 0.005, that is a 0.5 percentage point increase in tract-level broadband adoption rates. Note that we separate the all-household model results from the income band results because the ACS data underpinning them differs slightly, as explained above. In all figures, shaded ribbons and error bars represent 95% confidence intervals constructed from tract-clustered standard errors.

Figure 2 presents the average partial effect of an increase in providers across income groups and for all households. We allow for quadratic effects across all three broadband speed categories, as we hypothesize diminishing marginal adoption as provision counts increase. Before proceeding, it is important to note that the all-household and income band panels are not directly comparable because they use different outcome variables. The all-household model measures fixed broadband adoption, including cable, fiber, DSL, and satellite, while the income band models measure total broadband adoption including cellular subscriptions. Where the two panels diverge, this likely reflects a substitution effect: additional fixed providers draw households away from cellular-only connections toward fixed broadband, a shift that increases the all-household fixed broadband measure but does not appear in the income band measure, which treats cellular and fixed subscriptions as equivalent. This interpretive caveat applies to Figures 3 and 4 as well, wherever the two panels show divergent patterns. For the all-household model, increases in the number of providers meeting 2010 speed thresholds are associated with small but consistently positive effects on fixed broadband adoption across the full range of provider counts, rising from near zero at low provision levels to approximately one percentage point at the upper end. The income band models show similarly modest positive effects at 2010 speeds, with all three income groups clustered near zero across the distribution of providers, suggesting that marginal increases in 2010-speed provision have limited differential effects across income levels.

At 2015 speeds, the all-household model shows a slight positive trend in adoption across the provider count distribution, though effects remain small and close to zero throughout. The income band results tell a more nuanced story: effects are near zero at low provider counts but turn modestly negative at higher counts, particularly for lower income households, consistent with the diminishing returns pattern hypothesized. The divergence between the all-household and income band panels at 2015 speeds may reflect the differing outcome variable definitions, with the income band measure capturing cellular broadband substitution effects that the fixed broadband measure excludes (more on this in the Discussion, below).

The 2024 speed threshold produces the most pronounced effects. For all households, adoption of fixed broadband declines steeply with provider count, falling from near zero at low provision levels to approximately nine percentage points below zero at the upper end of the distribution. Higher income households show the largest negative effects at 2024 speeds, while lower income households show somewhat smaller but still substantial negative effects. These results suggest that in markets with many providers offering 2024-speed service, adoption rates are in fact lower; a finding that may be consistent with these being areas where high-speed infrastructure has been deployed, but where price and demand barriers remain substantial, particularly for lower income households who may face both price and preference constraints.

Figure 3 presents APE estimates based on rurality for the three speed thresholds. Several consistent patterns emerge across both the all-household and income band panels. For the all-household fixed broadband model, the effect of an additional provider is negative in urban areas across all three speed thresholds, modest and positive in commuting zones, with the largest effects observed at 2024 speeds, reaching approximately three percentage points, and small but positive in rural areas. This urban-to-commuting gradient suggests that provider competition has its strongest positive adoption effects in commuting zones, where fixed broadband infrastructure is less saturated than in urban cores but demand remains relatively high.

In the income band models, the pattern across rurality types varies meaningfully by income group and speed threshold. At 2010 speeds, lower income households are the most sensitive to additional provision in commuting zones, while higher income households show near-zero effects across all rurality types, consistent with H3, that higher income households have likely already adopted once service becomes available and are insensitive to further increases in provision. At 2015 speeds, lower income households again show the largest positive effects in commuting zones, while higher income households remain relatively insensitive, and all income groups show near-zero or slightly negative effects in urban areas. The 2024 speed threshold produces the starkest differentiation: commuting zone effects are strongly positive for lower and middle income households, while higher income households remain largely insensitive across all rurality types. Taken together, these results are broadly consistent with H2, that provision increases have stronger adoption effects outside urban areas. They also suggest that commuting zones rather than strictly rural areas may be the locus of the strongest provision-adoption relationship.

To see whether there are changes in the associations over time, the specification in Equation (1) was re-estimated with years interacted with the provision variables. Figure 4 presents the results. Several notable patterns emerge across the three speed thresholds and two household groups. For 2010 speeds, the all-household model shows positive effects throughout the analysis period, with a pronounced uptick between 2020 and 2021, consistent with increased reliance on fixed broadband during COVID-19 lockdowns. The income band results at 2010 speeds show a similar trajectory, with all three income groups displaying positive and relatively

stable effects from 2017 through 2020, followed by a modest increase in 2021. Effects are small throughout, remaining well below 0.5 percentage points across most of the period, suggesting that marginal increases in 2010-speed provision continue to have only limited adoption effects.

The 2015 speed threshold tells a more complex story. The all-household model shows negative effects in 2017 and 2018, trending upward through 2019 and turning positive by 2021, again with a sharp increase in the final year consistent with COVID-19 demand effects. The income band results at 2015 speeds mirror this trajectory. This pattern of initially negative effects becoming positive over time may reflect the maturation of 2015-speed markets, where early periods of provider entry were associated with market disruption before competition ultimately benefited adopters.

The 2024 speed threshold shows the most consistent pattern across the analysis period. The all-household model displays steadily positive and growing effects from 2017 through 2020, plateauing around one percentage point before declining slightly in 2021. The income band results are similarly positive throughout, with lower- and middle-income households showing somewhat larger effects than higher income households possibly suggesting that higher income households had already adopted once 2024-speed service became available, leaving lower income households as the marginal adopters responding to additional provision. Unlike the 2010 and 2015 speed thresholds, there is no sharp 2021 uptick at 2024 speeds in either the all-household or income band models, suggesting that households requiring the fastest connections had already adopted prior to the COVID-19 period rather than being driven to adopt by lockdown conditions.

## **6. Discussion**

The goal of this paper was to analyze the relationship between improved availability of faster broadband speeds and broadband adoption. As households and providers face different constraints due to geographic location, local topography, and income, the present empirical analysis allows for different statistical associations across these dimensions using interactions. This paper also presents models that estimate changes in this relationship over time, as preference and demand for faster speeds have evolved over the course of the analysis period (2017-2021).

The results of this analysis suggest that provider counts do not always increase adoption rates, especially at higher speeds. The results also indicate that the relationship between provision and adoption varies meaningfully across rurality categories, with commuting zone tracts showing the strongest positive adoption responses to additional providers across all three speed thresholds and income groups. This pattern is consistent with commuting zones occupying a middle ground, less saturated than urban cores, but with sufficient demand and income levels to respond to expanded provision. Higher income households in commuting and rural areas show limited sensitivity to increases in provision at 2010 and 2015 speeds, suggesting they have already adopted once service became available. Lower income households, by contrast, remain more responsive to additional provision in commuting zones across all speed thresholds, suggesting that price competition driven by additional providers continues to matter for this group.

The finding that negative adoption effects emerge at higher provider counts, particularly at 2024 speeds, is notable. Rather than indicating that provision harms adoption, these effects likely reflect market saturation dynamics: tracts with many providers meeting the 2024 speed threshold tend to be dense urban areas where adoption rates are already high, leaving a smaller

pool of non-adopters who are less price-sensitive or face non-price barriers to adoption. The population-weighted provider count measure used here captures the expected number of providers available to a randomly selected resident, and its continuous nature means that high values are concentrated in densely served urban tracts.

The oligopolistic structure of the broadband market and documented anticompetitive behaviors in the United States may further limit price competition even where provider counts are high, meaning that additional providers do not necessarily result in lower prices. As Figure 1 demonstrated, many areas have fewer than three population-weighted providers regardless of rurality designation, and to the extent that FCC Form 477 data indicate providers could offer service rather than actively do so, the effective number of competitive providers in many markets is likely lower still. This mismatch likely attenuates the estimated provision-adoption relationship for income subgroups relative to the all-household model, which uses a fixed broadband outcome measure more closely aligned with the supply-side data.

Finally, the relationship between adoption and provision levels at higher speeds does not appear to change substantially over time, with the notable exception of 2021, when the need for broadband was heightened for all households during the COVID-19 pandemic. This uptick is most visible at 2010 and 2015 speeds in both the all-household and income band models, consistent with the notion that households of all income levels sought connectivity during lockdown conditions. The Emergency Broadband Benefit program, which provided subsidies of up to \$50 per month for qualifying households on non-tribal lands and \$75 for those on qualifying tribal lands, may have facilitated adoption among lower income households during this period (FCC, 2023). The absence of a comparable 2021 uptick at 2024 speeds suggests that households requiring the fastest connections had already adopted broadband prior to the pandemic rather than being driven to adopt by lockdown conditions, consistent with faster speeds functioning as a premium product with an existing base of early adopters. Combined, these findings indicate that the provision-adoption relationship is heterogeneous across rurality, income, and speed threshold in ways that complicate simple supply-side policy prescriptions. Expanding provider counts increases adoption most reliably in commuting zones and among lower income households, while urban markets and higher income households appear increasingly saturated at conventional speed thresholds.

From a policy perspective, the results have implications for the most current initiative to improve broadband access in the United States, the Broadband Equity, Access and Deployment (BEAD) program. Although this study is historical in nature, there is inertia to broadband service, and the BEAD program is evidence for a need to improve broadband access in many parts of the United States. The overarching goal of the originally proposed program was to provide unserved areas with fiber connections at speeds of 100mbps downstream and 20mbps upstream (Knittel et al., 2024). Funds were also available for digital equity initiatives to foster the adoption of broadband “at a speed, quality, and capacity that is necessary for the individual to accomplish common tasks; and such that the access qualifies as an advanced telecommunications capability; with the digital skills that are necessary for the individual to participate online; and on a— personal device; and secure and convenient network” (SEC. 60302 of the Digital Equity Act of 2021). This was an important component to the program because historically, there has been little funding for programs that facilitate the use of digital technologies (Whitacre & Mills, 2003). Program implementation was slow and because of this slow pace, BEAD was restructured in 2025 (NTIA, 2025). As part of this restructuring, several changes were made, including the elimination of the digital equity component and the elimination of the fiber technology

requirement. BEAD is now technology agnostic and allows service to be provided to underserved and underserved communities by any type of technology, including satellite broadband. While these changes may mean progress for broadband deployment in the short-term, there are longer term speed and connection quality issues associated with this technology agnostic approach. There are also adoption implications of BEAD changes; it may mean people will not adopt broadband even if it is available because they lack the skills to participate in online activities.

That said, it is important to note some limitations to this analysis. The first limitation is associated with the use of the FCC broadband data which is noted to overstate availability because it indicates broadband is available to households but cannot guarantee that every household is covered. As noted by prior work “regions that *could have* broadband are much different than regions that *have* broadband in the U.S.” (Grubestic, 2012 pg. 121). Unfortunately, in the United States, data from other publicly available sources where the data collection process is transparent are lacking. Thus, while imperfect, for this time period, these data are the source of information about broadband provision.

A second limitation of data about broadband in the United States is a lack of detailed pricing information, which would yield important insights about the cost of broadband and particular speeds and associated adoption trends. While data are available via the Urban Rates Survey (FCC, 2024), this information is limited to urban areas only and is therefore not useful for studies seeking to analyze broadband questions across the urban-rural continuum. A third limitation concerns the measurement of broadband adoption in the income band models. ACS table S2801 provides counts of households with any broadband subscription, including cellular data plans, for the three income groups used in this analysis. A technology-specific breakdown analogous to the fixed broadband measure used in the all-household model is not available at the census tract level for income subgroups in any publicly available ACS table. As a result, the income band dependent variables include cellular-only subscribers, who are not captured by the FCC Form 477 provider count variables used on the supply side. This mismatch between the supply- and demand-side measures for income subgroups likely weakens the estimated provision-adoption relationship relative to the all-household model and may contribute to the divergent patterns observed between the two at certain speed thresholds. Generating technology-specific adoption rates by income group at the tract level would require use of Public Use Microdata Sample (PUMS) data, which is not available at the tract level of geographic granularity, representing a gap in publicly available data that limits income-stratified broadband adoption research more broadly.

Future work should aim to further investigate how increased provision of faster speeds may affect adoption. Because there is no data on the price of advertised plans in an area, it is difficult to see whether the relationship between adoption and provision is due to price competition. In the future, it may be possible to capture this relationship by leveraging a datamining approach or new datasets as they become available. Emerging approaches that dynamically web scrape ISP websites to verify advertised service availability at specific addresses offer a promising avenue for producing more accurate coverage measures than Form 477 data allow, and future work leveraging such data could meaningfully refine the supply-side measures used in analyses of this kind. As for investigating quality competition, one may attempt to see whether the introduction of new broadband technologies with faster speeds in an area changes the services offered by other providers, whether it be the elimination of lower speed plans or the adoption of similar technologies. Providing empirical evidence to better understand

the nuances of the industrial organization of the U.S. broadband industry in this way could greatly augment this area of research. Future work could also investigate whether there are discontinuities between the Form 477 data and more recent broadband data available from the FCC's Broadband Data Collection (BDC repository) and if it is possible to integrate these two datasets to produce a longer time series of data about broadband for public use.

## **7. Conclusion**

The ability to access reliable and fast broadband is becoming necessary for many aspects of daily life. Thus, it is important to monitor progress and costs of this crucial infrastructure. At the same time, it will be important to monitor emerging technologies such as improved satellites and 5G wireless connectivity that have potential to reduce fixed costs associated with reliable broadband provision. Finally, while some rural areas are growing, a large percentage of rural communities are in long term decline. Better Internet access can help supplement services such as health care or education when the local population is no longer large enough to support local face to face provision of such essential services.

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**Table 1: Variable Legend**

| Source                                                               | Source Description                                                                                                                                                                                                                                                                                                                                                   | Years Available | Variables Used/Generated                                                                                                        | Variable Description                                                                                                                                                     |
|----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Federal Communications Commission Form 477 database                  | Internet plans offered by facilities based providers in a Census block that can or do offer Internet service at speeds exceeding 200 kbps in at least one direction. Starting in 2014, each plan has information on download speeds, upload speeds, and delivery technology.                                                                                         | 2014-2021       | Providers with 2010 Broadband Speeds                                                                                            | Number of unique providers at the tract level offering a plan with speeds of at least 4mbps/1mbps                                                                        |
|                                                                      |                                                                                                                                                                                                                                                                                                                                                                      |                 | Providers with 2015 Broadband Speeds                                                                                            | Number of unique providers at the tract level offering a plan with speeds of at least 25mbps/3mbps                                                                       |
|                                                                      |                                                                                                                                                                                                                                                                                                                                                                      |                 | Providers with 2024 Broadband Speeds                                                                                            | Number of unique providers at the tract level offering a plan with speeds of at least 100mbps/20mbps                                                                     |
|                                                                      |                                                                                                                                                                                                                                                                                                                                                                      |                 | Total Internet Service Providers                                                                                                | Number of unique providers at the tract level offering a plan with speeds exceeding 200 kbps in at least one direction.                                                  |
| American Community Survey (ACS) 5-Year Estimates, U.S. Census Bureau | The ACS includes questions about Computer and Internet Use starting in 2013. Respondents answer a question about whether their household pays for Internet services. If they respond "Yes," they answer a follow-up question about the plan they purchase. Respondents choose a combination of Cellular Data plans, broadband plans, satellite service, and dial-up. | 2017-2022       | Households (HHs) with Internet                                                                                                  | Share of HHs in a tract that use Internet<br>Share of HHs in a tract that subscribe to broadband plans, including satellite plans, excluding cellular-only subscriptions |
|                                                                      |                                                                                                                                                                                                                                                                                                                                                                      |                 | HHs with Broadband<br>HHs earning less than \$20,000 with Broadband<br>HHs earning between \$20,000 and \$74,999 with Broadband | Share of HHs with broadband, including satellite and mobile plans at defined income level                                                                                |

|                                                                                |                                                                                                                                                                                                             |      |                                               |                                                                                                               |                                              |
|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------|----------------------------------------------|
|                                                                                |                                                                                                                                                                                                             |      | HHs earning more than \$75,000 with Broadband | Total HHs                                                                                                     | Total Households in a tract                  |
|                                                                                |                                                                                                                                                                                                             |      | HHs earning less than \$20,000                |                                                                                                               |                                              |
|                                                                                |                                                                                                                                                                                                             |      | HHs earning between \$20,000 and \$74,999     |                                                                                                               | Total HHs in a tract at defined income level |
|                                                                                |                                                                                                                                                                                                             |      | HHs earning more than \$75,000                |                                                                                                               |                                              |
| United States Department of Agriculture (USDA) Area and Road Ruggedness Scales | Dataset of the topographic variation of census tract in the United States                                                                                                                                   | 2010 | Rural Urban Commuting Area Codes (RUCA)       | The ten codes are aggregated to indicator variables: Urban (1), Urban Commuting (2 and 3), and Rural (4-10)   |                                              |
|                                                                                |                                                                                                                                                                                                             | 2023 | Area Ruggedness Scale                         | Continuous measure of topographic variation expressed as mean Terrain Ruggedness Index (TRI) values in meters |                                              |
| IPUMS NHGIS Geographic Crosswalks                                              | 2020 Block to 2010 Tract Crosswalk, 2020 Tract to 2010 Tract Crosswalk. The analysis dataset is harmonized to 2010 tracts. The block level crosswalk was used when data at that granularity were available. | N/A  | N/A                                           | N/A                                                                                                           |                                              |

**Table 2: Summary Statistics**

|                                                       | All                    | Urban                  | Urban Commuting      | Rural                |
|-------------------------------------------------------|------------------------|------------------------|----------------------|----------------------|
| Households (HHs) with Internet (%)                    | 0.82<br>(0.12)         | 0.84<br>(0.12)         | 0.80<br>(0.11)       | 0.75<br>(0.11)       |
| HHs with Broadband (%)                                | 0.73<br>(0.16)         | 0.77<br>(0.15)         | 0.69<br>(0.15)       | 0.64<br>(0.14)       |
| Total Households                                      | 1,678.49<br>(825.77)   | 1,723.11<br>(866.33)   | 1,672.05<br>(773.72) | 1,505.34<br>(647.76) |
| HHs earning less than \$20,000<br>with Broadband (%)  | 0.61<br>(0.21)         | 0.65<br>(0.21)         | 0.55<br>(0.20)       | 0.52<br>(0.17)       |
| HHs earning less than \$20,000                        | 247.65<br>(187.49)     | 242.25<br>(192.62)     | 217.07<br>(152.74)   | 286.52<br>(178.98)   |
| HHs earning \$20,000 - \$74,999<br>with Broadband (%) | 0.80<br>(0.11)         | 0.82<br>(0.11)         | 0.76<br>(0.11)       | 0.74<br>(0.11)       |
| HHs earning \$20,000 - \$74,999                       | 720.65<br>(392.52)     | 711.59<br>(408.27)     | 733.09<br>(368.97)   | 749.41<br>(336.29)   |
| HHs earning \$75,000+<br>with Broadband (%)           | 0.92<br>(0.09)         | 0.93<br>(0.09)         | 0.91<br>(0.08)       | 0.90<br>(0.09)       |
| HHs earning \$75,000+                                 | 710.21<br>(556.79)     | 769.26<br>(599.50)     | 721.92<br>(476.53)   | 469.43<br>(299.73)   |
| Providers with 2010 Broadband Speeds                  | 4.62<br>(1.16)         | 4.78<br>(1.13)         | 4.17<br>(1.08)       | 4.22<br>(1.16)       |
| Providers with 2015 Broadband Speeds                  | 4.34<br>(1.19)         | 4.57<br>(1.14)         | 3.81<br>(1.07)       | 3.74<br>(1.13)       |
| Providers with 2024 Broadband Speeds                  | 1.69<br>(0.84)         | 1.95<br>(0.74)         | 1.07<br>(0.69)       | 1.01<br>(0.72)       |
| Total Internet Service Providers                      | 5.51<br>(1.08)         | 5.65<br>(1.03)         | 5.09<br>(1.06)       | 5.23<br>(1.19)       |
| Population density, 2010                              | 5,259.23<br>(11754.68) | 7,160.85<br>(13410.19) | 363.75<br>(1,020.91) | 529.01<br>(1,110.20) |
| Mean Area TRI values, meters                          | 18.52<br>(21.35)       | 15.27<br>(15.79)       | 26.14<br>(27.96)     | 27.03<br>(30.64)     |
| Tracts                                                | 72146                  | 51657                  | 7456                 | 13033                |
| Observations                                          | 360730                 | 258285                 | 37280                | 65165                |

**Figure 1: Histogram of Number of Providers by Rurality, 2017-2021**

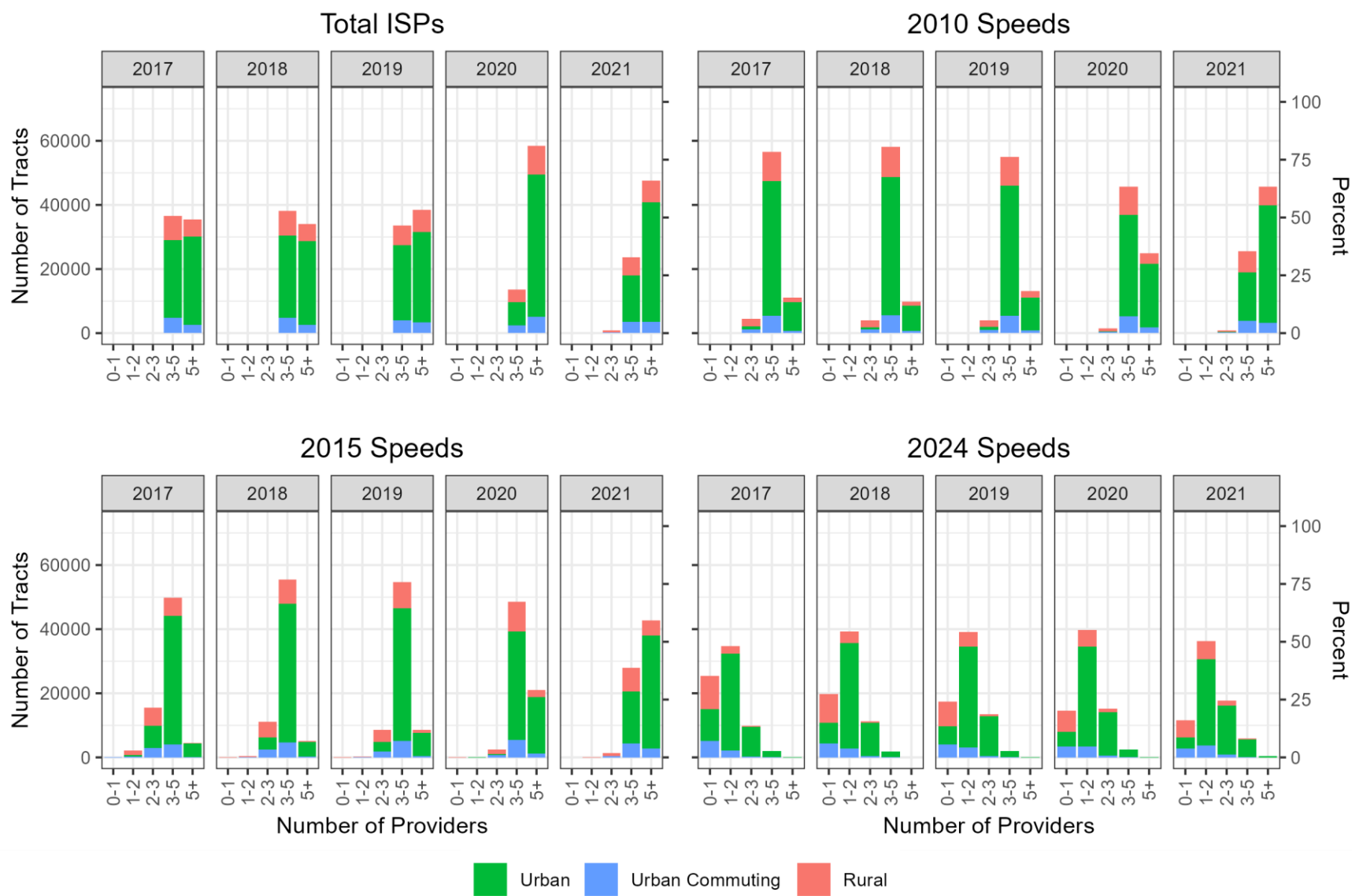


Figure 2: Average Partial Effect, Number of Providers

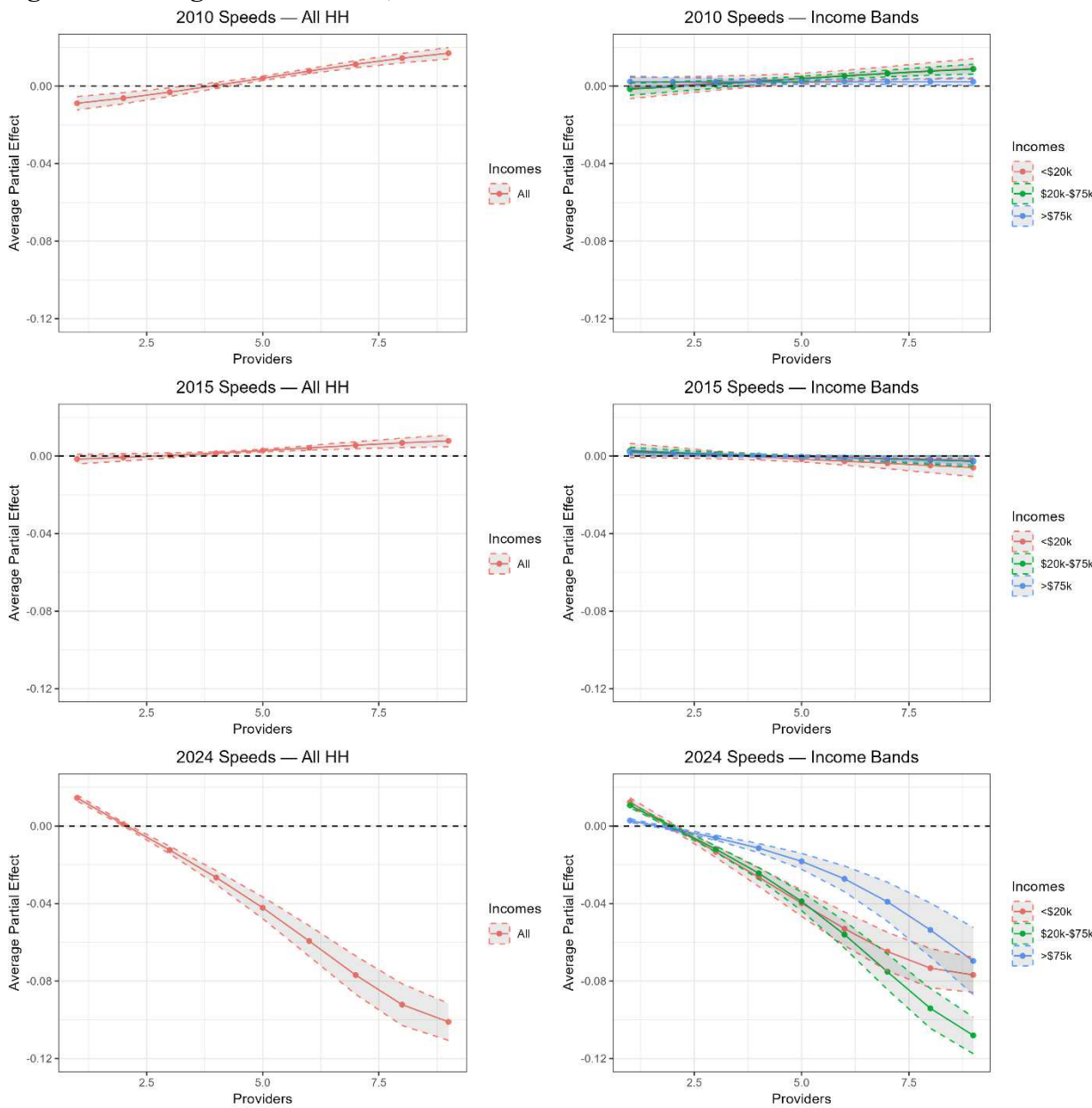


Figure 3: Average Partial Effect, Rurality

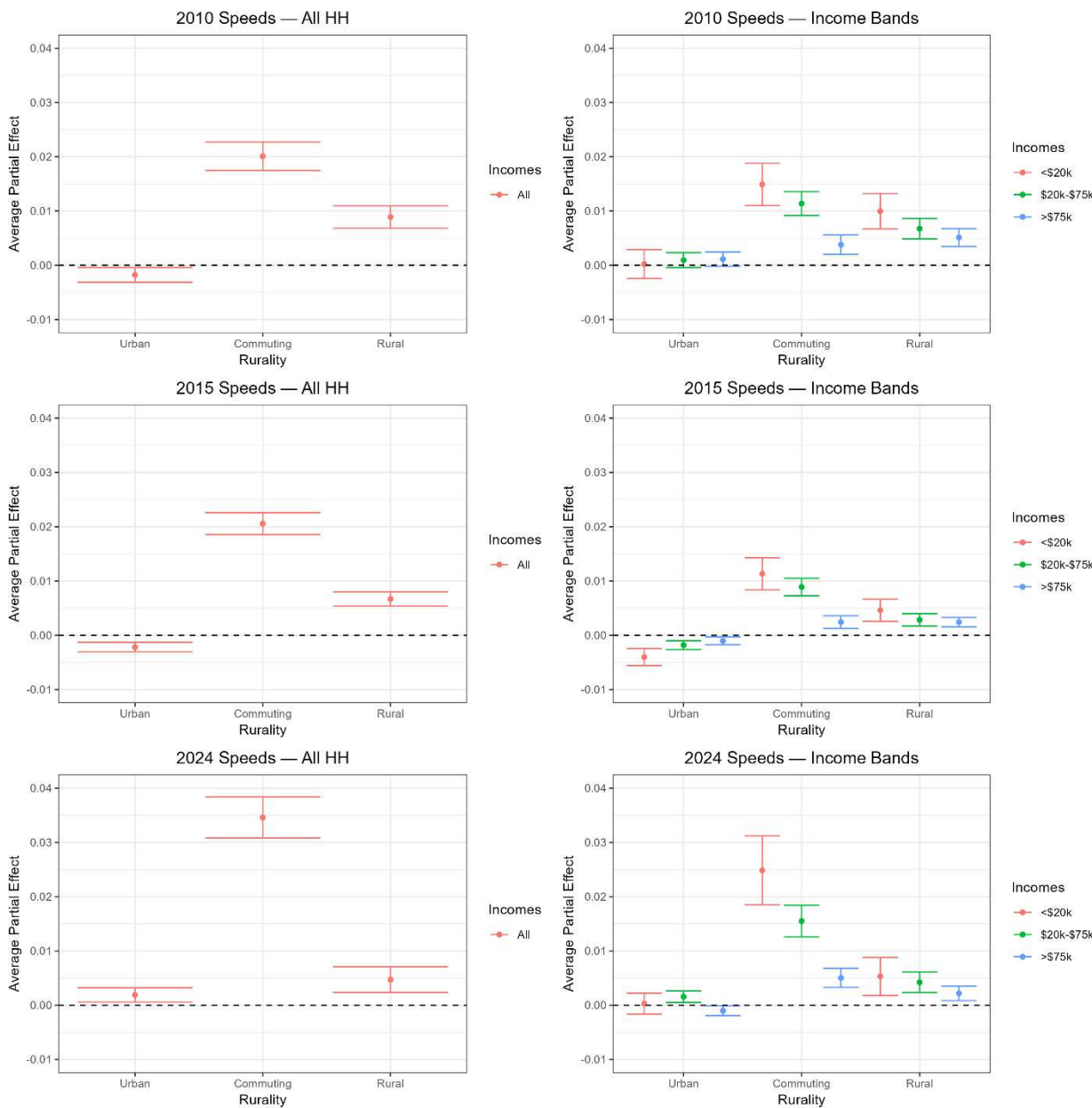


**Figure 4: Average Partial Effect, Year**

