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**Does Public Competition Crowd Out Private Investment?
Evidence from Municipal Provision of Internet Access**

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Does Public Competition Crowd Out Private Investment? Evidence from Municipal Provision of Internet Access

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Abstract

Government investment in infrastructure may crowd out private investment that would have otherwise occurred. But, the threat of government intervention may also induce private firms to invest preemptively in infrastructure, in order to maintain their market position. This leaves the net effect of public competition on private investment unclear. This paper investigates the tension between these competing effects by providing evidence from the setting of internet service provision.

Using household survey data and a novel data set of internet plan characteristics, I provide nationwide estimates of demand for internet technologies. I then use these results to estimate a dynamic oligopoly model of private and public internet service providers' entry and technology adoption decisions, where private firms are driven by profits and municipalities by some (as yet) unknown combination of profits and consumer welfare. Finally, I simulate firms' actions under a ban on public provision and find evidence that public competition partially, but not completely, crowds out private investment. Ultimately, I find that a ban on municipal provision in 30 states would result in a loss in consumer welfare of \$1.11 billion over 20 years.

JEL-Classification: L13, L21, L33, L96, H32, H44

Keywords: Broadband, Demand, Dynamic, Public, Crowding Out, Preemption

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1 Introduction

Government investment often reduces the level of private investment in an economy. This crowding out phenomenon has been studied thoroughly in the context of fiscal policy and aggregate investment spending, with economic thought on the matter dating back to David Ricardo. However, the effects of specific government investments in infrastructure, in a strategic (game-theoretic) dynamic setting, are much less clear. On the one hand, government investment may displace private investment that would have occurred in the absence of government involvement. On the other hand, the threat of government intervention may also induce private firms to invest preemptively, in order to retain maintain their current market position. This paper investigates the tension between these competing effects by providing evidence from the setting of internet service provision.

Traditionally, internet access has been provided by private firms, typically telephone and cable television providers. However, in some areas, desire for cutting-edge speeds has outpaced providers' willingness to invest in new technology. This has led to the growth of publicly provided internet access, with 2.1 million households gaining access to high-speed fiber-to-the-premises (FTTP) technology through municipal broadband providers between 2010 and 2014. As of 2016, twenty states have passed legislation banning or restricting public provision of internet access^{1 2}. In February 2015, the Federal Communications Commission (FCC) issued an injunction overturning state laws which obstructed public provision of internet access in North Carolina and Tennessee, but in August 2016, the 6th Circuit Court of Appeals ruled that the FCC lacks the authority to preempt state laws. With the future of municipal broadband so uncertain, an important question arises: should public entities be allowed to enter the broadband market? The White House has taken a definitive stand in favor of municipal broadband³, but the case for public provision demands a thorough analysis.

To provide an economic argument, it is essential to measure the effects of public provision on private investment. If public provision simply crowds out private investment that would have otherwise occurred, then municipalities may not provide a significant economic benefit. However,

¹<http://apps.fcc.gov/ecfs/document/view?id=7521826169>

²The private firms lobbying for these regulations have argued that public entities have access to additional funding sources, that public provision is likely to be a financial failure, and have appealed to political sentiment about the appropriate role of government institutions.

³https://www.whitehouse.gov/sites/default/files/docs/community-based_broadband_report_by_executive_office_of_the_president.pdf

if public provision does increase consumers' access to next-generation technology, either directly or through spurring private investment, then they may play an important role in this market. Moreover, given both the importance of widely available high-speed internet and the current regulatory uncertainty of municipal broadband, understanding the welfare implications of the presence of public providers is paramount. Therefore, a core objective of this paper is to measure the effect of public competition on consumer surplus and private and municipal profits.

The primary economic argument for public provision of internet access is that private firms may underinvest in new technology, relative to the social optimum. The market for internet service provision is typically characterized as a monopoly or a duopoly, served by firms with market power but which cannot perfectly price discriminate. As such, upon investment in new technology, they set prices which achieve a sub-optimal market quantity and therefore generate less surplus than would a welfare-maximizing social planner. Furthermore, a private firm's incentive to make such an investment is limited to only the resulting increase in producer surplus, while the social planner's incentive is the whole of an already larger welfare increase⁴.

With this in mind, it is not a foregone conclusion that public provision represents an improvement over private provision, because the objective of municipal internet service providers is still unknown. If municipalities seek only to maximize profits, then their incentives to invest in new technology mirror those of private firms. If, instead, municipalities directly value the consumer surplus generated by such investments, then they are able to capture the resulting infra-marginal gains, and therefore their incentives approach those of a social planner. To that end, a key component of this paper involves estimating the extent to which public entities value the gain in consumer surplus resulting from the availability of FTTP technology.

In order to measure consumer surplus, I first estimate demand for internet technologies. Specifically, I estimate a discrete choice model, augmented to allow consumers' choice sets to vary according to the local availability of DSL, cable, and FTTP. I obtain market share data from the Current Population Survey Internet Supplement, I construct a novel data set on prices and other plan characteristics from an internet service plan search engine, and I utilize data on technology

⁴This argument outlines the intuition behind why private firms *might* underinvest in new technology. The theoretical support for this reasoning can be found in Arrow (1962) and Tirole (1988). Under alternative models, particularly those which incorporate patent protection, private firms may even overinvest in new technology. See Dasgupta and Stiglitz (1980), Gilbert and Newbery (1982) and Ericson and Pakes (1995) for examples of such models.

availability from the National Broadband Map, which catalogs the universe of firm-census block level broadband availability. Importantly, I allow consumer preferences for each technology to vary with demographic characteristics. I find that preference for FTTP (over cable and DSL) increases rapidly with both income and household size, while preference for cable (over DSL) increases with income but decreases with household size.

Next, in order to identify the objective function of municipalities, I estimate a dynamic supply-side model. In this model, private and public entities make entry and technology adoption decisions to maximize long-run utility. The dynamic nature of the model allows firms to form expectations over rivals' future actions and to best respond in the present, an essential feature for allowing firms to act preemptively in response to the threat of future public provision. I impose that private firms are motivated solely by profits, but allow municipalities to place some (as yet) unknown weight on consumer surplus. I then use a panel of data from the National Broadband Map to estimate this weight, as well as the costs of entering, exiting, and adopting FTTP. I find that municipalities value consumer surplus in their decision-making at a rate of 23 cents on the dollar. This suggests that they operate quite differently from a firm, but do not come close to making decisions as a welfare-maximizing social planner.

Finally, I simulate a counterfactual under which municipalities are banned from providing internet service. I then compare firms' actions with and without this ban in order to calculate the effect of public competition on private investment. I find that placing a ban on public provision decreases the probability of public provision of FTTP by 1.43 percentage points but increases the probability of private provision of FTTP by 0.66 percentage points. I then decompose this effect on private firms into its component parts, and find that public competition decreases the probability of private investment in FTTP by 0.76 percentage points through crowding out and increases the probability of private investment in FTTP by 0.10 percentage points through preemption. Since net private provision increases in the absence of public competition but does not fully compensate for the loss in public provision, I conclude that public competition in the market for internet service partially, but not completely, crowds out private investment in new technology.

Ultimately, I find evidence that public competition in the market for internet service provides a significant economic benefit to communities, as a ban on public provision in 30 states would result in a loss in consumer welfare of \$1.11 billion over 20 years. The determination of this paper

is that a ban on public provision of internet access serves to benefit incumbent private firms, to the detriment of both consumers and local governments. This finding may generalize to other environments in which local governments compete directly with private firms, such as education, healthcare, water, and waste management. However, the economic benefits of public provision of necessity goods are likely tempered by near complete crowding out of private provision.

1.1 Literature

This paper is related to the existing literature on public investment crowding out private investment. The canonical argument is that, at the national level, expansionary fiscal policy financed by debt will increase interest rates and thereby decrease investment undertaken by private firms⁵. Empirical tests of this hypothesis abound. Hoelscher (1986), Watchel and Young (1987), Bovenberg (1988), Aaschauer (1989), and Mitra (2006) find evidence that suggests that increased government spending by borrowing decreases private investment. On the contrary, Canto and Rapp (1982), Plosser (1982), Dewald (1983), Hoelscher (1983), Makin (1983), Mascaro and Meltzer (1983), Motley (1983), and Evans (1985) find that interest rates are not significantly impacted by federal deficit spending. In an laboratory experiment, Eckel, Grossman, and Johnston (2005) find evidence that public charity giving does not crowd out private giving. Cumming and MacIntosh (2006) demonstrate that Canadian public venture capital has fully crowded out private venture capital. I contribute to this literature by empirically measuring the extent to which specific public infrastructure investments crowd out corresponding private infrastructure investments.

This paper is also related to the literature on entry threat and strategic preemption. Wilson (1992) provides a review of theoretical models of strategic entry deterrence. Ellison and Ellison (2000), Dafny (2005), Goolsbee and Syverson (2006), and Conlin and Kadiyali (2006) demonstrate empirically that incumbent firms deter potential entrants by changing prices, output, technology, and capacity. Seamans (2012) finds evidence that cable television operators were more likely to begin providing internet service in areas with an existing municipal electric utility. I build upon this finding by estimating the extent to which private internet service providers preemptively upgrade to FTTP in response to public competition, and I weigh this effect against the potential crowding

⁵ More nuanced theoretical analyses are provided by Blinder and Solow (1973), Carlson and Spencer (1975), and Buiter (1977).

out effect.

This paper also adds to the existing literature on demand for internet access. Edell and Variara (1999), Varian (2002), and Rosston, Savage, and Waldman (2010) estimate demand for internet plan characteristics using experimental data. Goolsbee and Klenow (2006) use data on internet usage time and wages to infer the value of broadband. Hitt and Tambe (2007) find that switching from dial-up internet to broadband increases data consumption. Greenstein and McDevitt (2011) estimate the effect of broadband access on national economic output. Lambrecht, Seim, and Skeira (2007) and Nevo, Turner, and Williams (2016) use data generated by three-part tariff pricing to understand consumer behaviors. Lambrecht et al. focus on the effect of demand uncertainty on plan selection; Nevo et al. estimate a fully dynamic model of demand for internet content and focus on the effect of data caps on consumers' intertemporal substitution of internet usage. Nevo et al. also find empirical evidence that there is indeed a gap between the private and social incentives to provide FTTP, which suggests the possibility of a role for municipal internet service provision. The demand estimation in this paper is most closely related to that of Dutz, Orszag, and Willig (2009), who estimate demand for internet technologies using nationwide U.S. household survey data. I build upon their work by allowing households' demographics to affect their preference for each technology, and critically, in the spirit of Rysman (2004), I modify the standard discrete choice framework to account for a choice set that varies across households within each market.

More generally, this paper is related to the literature on entry and public policy in the telecommunications industry. Economides (1999) finds that the 1996 Telecommunications Act did little to improve entry and competition in local exchange markets. Greenstein and Mazzeo (2006) find evidence of significant product differentiation from competitive local exchange carriers. Economides, Seim, and Viard (2008) find that households' welfare increases in response to entry of new telephone carriers, mainly as a result of increased product differentiation. Goldfarb and Xiao (2011) find that heterogeneity in telephone carriers' managerial ability is a significant determinant of entry decisions and long-run success. Fan and Xiao (2015) consider various subsidy policies intended to encourage entry of telephone carriers, and find that restricting subsidies to small markets and early periods are most effective.

Finally, the supply side model in this paper draws on the literature related to solving and estimating dynamic games. Pakes and McGuire (1994) propose an algorithm for computing equi-

libria in dynamic games, which will be used in this paper. More recently, Aguirregabiria and Mira (2007), Bajari, Benkard, and Levin (2007), Pakes, Ostrovsky, and Berry (2007), and Pesendorfer and Schmidt-Dengler (2008) have proposed two-step estimators for dynamic games. Ryan (2012), Collard-Wexler (2013), Igami (2015), and Fan and Xiao (2015) have estimated dynamic games of entry and investment using these techniques.

2 Industry and Data

This section provides a brief background on the internet service provision industry, describes the data used in this analysis, and highlights some of the key features of the data which serve to motivate my research question.

2.1 Internet Access in the United States

American households first began accessing the internet in the early 1990s using dial-up technology, which transmitted data over standard telephone lines at speeds of up to 56 kilobits per second (kbps)⁶. By the late 1990s, the United States saw the advent of broadband internet. The direct successor to dial-up internet, digital subscriber line (DSL) access, became commercially viable and initially offered download speeds of up to 768 kbps over the same telephone lines. Concurrently, cable television operators began upgrading their networks to allow subscribers to send and receive data over coaxial cable. Early cable modem access offered download speeds of up to 40 megabits per second (Mbps)⁷. Even today, most household internet access is achieved using DSL or cable modem technology, although tremendous advances have been made in data transmission speeds. Under the modern internet architecture, data travels between internet service providers' central offices over high-speed fiber-optic cables, and between internet providers' central offices and subscribers' homes and businesses using a combination of fiber-optic cables and either telephone lines or coaxial cable. This hybrid fiber approach gives both DSL and cable technology the potential to offer download speeds of over 100 Mbps by extending the use of fiber-optic cables closer to subscribers' premises. The natural evolution of this network is to deliver internet access using exclusively fiber-optic cables

⁶1 kbps = 1 megabit per second (Mbps); Mbps is the standard unit of speed used today

⁷In practice, subscribers would only achieve speeds at a fraction of this rate, as the nature of a cable network dictates that subscribers share bandwidth with other nearby subscribers.

Figure 1: Download Speeds Available by Technology

Source: National Broadband Map, June 2014

in what is known as fiber-to-the-premises (FTTP). FTTP allows for download speeds of over 1 gigabit per second (Gbps), or 1,000 Mbps, and unlike cable access, this bandwidth is not shared with neighbors. The dramatic differences in data transmission speeds across these technologies are captured in figure 1. Gigabit speeds are almost exclusively limited to FTTP subscribers. Also, over 80% of FTTP installations offer download speeds of at least 100 Mbps, compared to 60% of cable installations and just 0.2% of DSL installations. Households benefit from FTTP, as household bandwidth consumption is rapidly increasing, due in large part to a shift towards video streaming services, and because a typical home often has multiple simultaneous internet users. Businesses also take advantage of FTTP, as commerce has shifted online and cloud storage is quickly replacing conventional data storage.

Due to the increased usage of these bandwidth-intensive services, availability of FTTP is steadily increasing. As shown in figure 2, FTTP penetration has increased at a constant rate from 18% in June 2010 to 33% in June 2014. However, FTTP availability still lags far behind that of both DSL and cable modem access, which have hovered at about 95%.

In many cities, desire for FTTP has outpaced private firms' willingness to make the costly investment required to improve infrastructure. In response, some municipalities have taken it upon themselves to invest in providing internet service directly to their constituents⁸. Figure 3 shows the distribution of technologies chosen by both private and public providers for new installations

⁸As of June 2014, there were 133 distinct municipal providers of internet service in the U.S.

Figure 2: Technology Penetration

Source: National Broadband Map

Figure 3: Technology Used by Ownership

Source: National Broadband Map

between 2010 and 2014. Overwhelmingly, public providers choose to provide internet access using FTTP, while only 19% of private installations use FTTP, suggesting that municipalities are fundamentally different from private firms.

2.2 Data

I obtain technology market share data from the 2014 Current Population Survey (CPS) Internet Supplement. In this questionnaire, respondents are asked whether the household accesses the internet using dial-up, DSL, cable, fiber-optic, mobile, or satellite technology. I then aggregate these responses to the metropolitan statistical area (MSA) level⁹. Summary statistics for DSL, cable, and FTTP market shares are reported in table 1. Cable overwhelmingly has the highest rate of subscribership, though there is considerable variation in market shares across all three technologies, and for FTTP in particular. FTTP subscribership lags far behind both DSL and cable, but this is explained (at least in part) by its limited availability.

⁹This is the finest geographic level that the CPS identifies in the data.

Table 1: 2014 Subscribership by Technology

	Cable	DSL	FTTP	None
Mean	0.57	0.21	0.08	0.13
Std. Dev.	0.10	0.07	0.08	0.06
Min	0.29	0.04	0.01	0.03
Median	0.59	0.22	0.05	0.12
Max	0.83	0.41	0.38	0.38
# Markets	99	99	99	99

Source: Current Population Survey, 2014

I construct a novel data set of internet plan characteristics scraped from an online telecommunications provider search engine in October 2014. This data contains information on the plans offered by the 14 largest internet service providers in the United States. Of primary interest, this data includes the prices and advertised download speeds of each plan¹⁰ offered by each provider at the zip code level. Since there are often many providers offering a variety of plans within an MSA, in order to match plan characteristics to market shares, I aggregate this data to the technology-MSA level¹¹. Summary statistics for the aggregated plan characteristics data are reported in table 2. On average, cable offers the fastest and most expensive median plan, while DSL typically offers the slowest and least expensive option. FTTP technology is capable of offering the fastest possible speeds, but its median offering is generally slower and less expensive than that of cable. A noteworthy feature of this data is that for a given plan, a firm prices it identically in all markets¹². Therefore, variation in prices at the MSA level come from the identities of the firms in each market and, to a lesser extent, variation in the plans offered in each market.

I also utilize data from the National Broadband Map. This data details the technology deployed by every U.S. internet service provider in every census block, biannually from 2010 through 2014. Since this data allows me to track a firm’s technology choices over time, I can identify entry, exit, and upgrades to FTTP. Some of the key trends in this data were highlighted in section 2.1.

I compile the most comprehensive available catalog of municipal internet service providers in

¹⁰A plan is one particular offering from a firm. For example, Comcast’s “Blast Internet” plan advertised download speeds of up to 50 Mbps and was priced at \$74.99 per month.

¹¹I aggregate the data by selecting the median priced plan for each provider and then averaging across providers.

¹²Firms do offer discounts to new customers, and these discounts can vary across markets, but they are not observed in this data.

Table 2: Mean (Std. Dev) Plan Characteristics by Technology

	Cable	DSL	FTTP
Median Plan Price (\$)	54.95 (17.32)	32.91 (3.92)	37.63 (13.11)
Median Plan Download Speed (Mbps)	41.57 (15.65)	5.32 (1.40)	24.33 (15.08)
# Markets	98	98	98

Source: Telecommunications Provider Search Engine, October 2014

the U.S. by combining data from Broadband Communities Magazine¹³, a White House report¹⁴, and a manual search of each internet service provider listed in the National Broadband Map. In total, there are 150 municipal internet service providers cataloged in the National Broadband Map. The areas served by municipal providers share very similar characteristics with areas not served by municipal providers. Table 3 compares the average characteristics of zip codes both with and without municipal providers. Zip codes with municipal providers have lower incomes, are less educated, and are younger. These differences are statistically significant, but are quite small in magnitude.

Finally, I utilize demographic data from the 2014 American Community Survey (ACS) and geospatial data from the U.S. Census Bureau.

3 Demand

A central component of this paper involves estimating the extent to which public entities value the consumer surplus derived from the availability of FTTP. Thus, in order to develop a measure of consumer surplus, I begin by estimating demand for internet technologies using a static discrete choice model.

When I estimate this model of demand, I define a market to be an MSA, since technology market shares can only be observed at the MSA level in the CPS data. However, within an MSA, households' choice sets can vary tremendously. In particular, FTTP is typically only available to a small subset of an MSA's population. Without controlling for this, any model I estimate

¹³<http://www.bbpmag.com/search.php>

¹⁴https://www.whitehouse.gov/sites/default/files/docs/community-based_broadband_report_by_executive_office_of_the_president.pdf

Table 3: Mean Characteristics of Zip Codes with Municipal Broadband

	Municipal Broadband	No Municipal Broadband	Difference
# Households	3,649.63	3,566.81	82.81 (128.93)
Average Household Size	2.56	2.56	0.00 (0.01)
Median Household Income (\$)	49,775.47	52,751.79	-2,976.32 (435.66)***
High School Diploma (%)	88.12	89.00	-0.88 (0.38)**
Bachelors Degree (%)	22.56	24.75	-2.19 (0.47)***
Median Age	40.89	41.78	-0.89 (0.21)***

Standard errors in parentheses

, **, and * denote statistical significance at the 10%, 5%, and 1% levels*

Source: American Community Survey, 2014

would incorrectly attribute FTTP's low observed market shares to undesirable characteristics. Therefore, following in the spirit of Rysman (2004), I divide each market into a mutually exclusive and exhaustive set of *submarkets*. I define a submarket to be a subset of the population of an MSA with access to a particular choice set¹⁵. Figure 4 displays a map of the submarkets present in Tucson, Arizona.

3.1 Model

Each consumer chooses to subscribe to cable, DSL, FTTP, or not to purchase wired internet access. However, of course, each consumer may only choose to subscribe to a technology which is available in their submarket. Consumers choose the product which will maximize their utility, given by

$$u_{ikmj} = \alpha_j + Y_{km}\gamma_j - \psi p_{mj} + \eta D_{mj} + \varepsilon_{ikmj} \quad (1)$$

where i indexes individuals, k indexes submarkets, m indexes markets, and j indexes technologies. α_j is a fixed effect measuring the unobservable quality of each product, Y_{km} are demographic

¹⁵For example, one submarket is the set of consumers with access to cable and DSL technology; another submarket is the set of consumers with access to only DSL technology.

Figure 4: Tucson Submarkets

Source: National Broadband Map

characteristics¹⁶, p_{mj} is the product's price, and D_{mj} is the product's download speed¹⁷. ε_{ikmj} is an unobservable individual-specific error term which is assumed to follow a type 1 extreme value distribution.

An important feature of the utility function is that demographics influence individuals' preferences differently for each technology through γ_j . The combined effect of α_j and $\gamma_j Y_{km}$ is central to understanding consumers' preferences for each technology. Including price and download speed in the utility function is not sufficient because they are characteristics of the technology's median plan, while consumers' decisions are likely influenced by the entire range of product offerings within a given technology.

For ease of notation, I define the mean utility to be

$$\delta_{kmj} \equiv \alpha_j + Y_{km}\gamma_j - \psi p_{mj} + \eta D_{mj} \quad (2)$$

I also normalize δ_{km0} to be equal to 0, which implies that consumers receive zero mean utility from choosing the outside option.

Then, given the distribution of ε_{ikmj} , the probability that an individual chooses a particular product, and therefore the expected submarket share of that product, is given by

$$S_{kmj} = \begin{cases} \frac{\exp(\delta_{kmj})}{1 + \sum_{j' \in J_k} \exp(\delta_{kmj'})} & \text{if } j \in J_k \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where j' indexes technologies and J_k is the set of all technologies available in submarket k . However, since submarket shares are not observed in the data, this equation does not directly lead to an estimable equation - another step is needed. The expected market share is a weighted average over the the market's submarket shares, given by

$$S_{mj} = \sum_{k \in K_m} \omega_{km} S_{kmj} \quad (4)$$

where K_m is the set of all submarkets in market m and ω_{km} is the proportion of market m that

¹⁶The demographic characteristics I include are income and household size.

¹⁷Given the data constraints, price and download speed are measured at the market level while demographics are measured at the submarket level.

lives in submarket k . Critically, each ω_{km} is directly observable, since the National Broadband Map provides data at the census block level.

3.2 Estimation

Rysman (2004) recommends using a contraction mapping to solve explicitly for each δ_{mj} and using ordinary least squares to estimate the parameters in the mean utility. However, this process relies on the assumption that $\delta_{kmj} = \delta_{mj} \forall k$, that consumer preferences for a given product do not vary across submarkets within a market. This assumption is unrealistic for the broadband market, as the demographic characteristics in areas with access to particular technologies are often quite different. For example, on average, submarkets with FTTP earn \$8,136 more per year than submarkets without FTTP. Neglecting to account for these demographic differences would then bias my estimates as a result of systematic measurement error.

Therefore, I take an alternative approach which allows me to incorporate submarket demographics. For any given value of the model's parameters, each δ_{kmj} can be evaluated. From these, each S_{kmj} , and therefore each S_{mj} can to be calculated. I then construct the following log-likelihood function

$$L(\alpha, \gamma, \psi, \eta; X) = \sum_{m=1}^M Households_m \sum_{j \in J_m} \log(S_{mj}) MarketShare_{mj} \quad (5)$$

where α and γ are vectors containing each α_j and γ_j , J_m is the set of all products available in market m , $Households_m$ is the number of households in market m , $MarketShare_{mj}$ is the observed market share of product j in market m , and X is data containing $Households_m$ and $MarketShare_{mj}$ for each market. I then perform a non-linear search over possible values of the model's parameters to maximize the likelihood function.

3.3 Endogeneity

Firms set plan prices at a national level. Therefore, market level characteristics should not be correlated with prices. As a result, the usual concern about price endogeneity does not apply. Since price variation is instead driven by the composition of firms within a market, one could argue that it is plausible that consumers value certain firm characteristics and that these characteristics

are correlated with prices, creating some endogeneity. However, after controlling for firm technology, price, and download speed, it is reasonable to view firms as identical.

It is likely that the demographic characteristics I have included in the model are correlated with other omitted characteristics. For example, income is certainly correlated with education. As a result, the coefficients on the interactions between product fixed effects and demographic characteristics should be interpreted as representing the combined effect of the included characteristics as well as any correlated characteristics. However, this is not a problem, as the role of these demand estimates is to construct a measure of consumer surplus that varies with the demographic characteristics of markets.

3.4 Results

Results from estimating the model of demand described in the previous section are reported in table 4. I use data from 98 markets for which there is data on market shares, plan characteristics, and technology availability. Specification 1 is a standard multinomial logit demand model which does not account for a choice set that varies within each market. Specification 2 implements Rysman (2004) and therefore accounts for a choice set that varies within markets. Specification 3 implements the maximum likelihood approach described in section 3.1 and accounts for a varying choice set and household characteristics which vary within a market. This is the preferred specification and its results are used for the remainder of the paper.

One check to ensure that the modified demand models perform as intended is to compare the models' predicted market shares for FTTP. Specifically, I calculate each model's predicted market share for FTTP in a market with all products available, average product characteristics, and average demographic characteristics. Specification 1 predicts an FTTP market share of 0.08, specification 2 predicts an FTTP market share of 0.32, and specification 3 predicts an FTTP market share of 0.23. This suggests that accounting for availability is important in accurately estimating preferences, and that failing to account for within-market demographic differences exaggerates the extent to which demographics impact consumers' technology preferences.

In order to better understand consumers' technology preferences, for each product I define a function which represents the average preference for product j at all levels of income and household

Table 4: Demand Parameter Estimates

		(1)	(2)	(3)
α	Cable	2.44 (0.84)***	3.37 (1.02)***	3.50 (0.33)***
	DSL	1.30 (0.84)	1.51 (1.01)	1.55 (0.27)***
	Fiber	-0.86 (0.82)	-1.78 (0.99)*	-2.22 (0.69)***
γ	Cable * Income	0.06 (.05)	0.14 (0.07)***	0.11 (0.05)**
	DSL * Income	0.01 (.05)	0.01 (0.06)	0.01 (0.05)
	Fiber * Income	0.32 (.05)***	0.49 (0.06)***	0.46 (0.08)***
	Cable * Household Size	-0.72 (.03)**	-0.78 (0.34)**	-0.84 (0.13)***
	DSL * Household Size	-0.03 (.03)	-0.09 (0.34)	-0.11 (0.15)
	Fiber * Household Size	-0.56 (.28)**	0.21 (0.34)	0.14 (0.29)
ψ	Price	0.03 (.01)***	0.03 (0.01)***	0.03 (.02)*
η	Download Speed	0.05 (.01)***	0.03 (0.01)***	0.03 (.01)**
	Accounts for technology availability	N	Y	Y
	Accounts for submarket demographic heterogeneity	N	N	Y
	# Markets	98	98	98

Standard errors in parentheses

, **, and * denote statistical significance at the 10% , 5%, and 1% levels*

Figure 5: Technology Preferences by Demographics

size,

$$g_j(Y) = \hat{\alpha}_j + Y\hat{\gamma}_j - \hat{\psi}\bar{p}_j + \hat{\eta}\bar{D}_j \quad (6)$$

where Y is any pair of values for income and household size, $\hat{\alpha}_j$, $\hat{\gamma}_j$, $\hat{\psi}$, and $\hat{\eta}$ are estimated coefficients from the demand model, and $\bar{p}_j$ and $\bar{D}_j$ are the average price and speed of product j across all markets. Therefore, on average, a household prefers product j to product j' whenever

$$g_j(Y) \geq g_{j'}(Y) \quad (7)$$

Figure 5 illustrates the combinations of income and household size for which this inequality holds for each technology. This shows that preference for FTTH (over cable and DSL) increases rapidly with both income and household size, while preference for cable (over DSL) increases with income but decreases with household size. These results are well-explained by the technological advantages and limitations of each product. Households of different income levels are likely to use the internet for different purposes. For example, bandwidth-intensive activities such as video and music streaming,

Table 5: Own Elasticities

	Cable	DSL	FTTP
Price	-0.71	-0.68	-0.85
Download Speed	0.68	0.12	0.42
Income	0.25	0.04	2.28
Household Size	-0.86	-0.23	0.31

videoconferencing, and online gaming are more common in households with higher incomes, leading them to prefer the faster speeds that can be offered by cable and especially FTTP. Similarly, larger households will utilize greater total bandwidth, leading them to prefer FTTP over cable or DSL. And, since cable subscribers share bandwidth with all of their neighbors, those who live in areas with large households will prefer DSL.

In order to better understand the magnitudes of the estimated coefficients, I report elasticities in table 5. As expected, price elasticity is negative and download speed elasticity is positive. Price elasticity is inelastic for all three technologies, reflecting the near necessity of access to broadband internet. Consumers are also inelastic in response to changes in download speed, especially so for DSL. This is unsurprising, as DSL’s download speeds are considerably slower than those of cable or FTTP. The most striking result is that consumers are very responsive to income in their decision to choose FTTP.

4 Supply

In the following section, I develop a dynamic model of public and private firms’ entry and technology adoption. The model imposes that private firms value only profits, but flexibly allows municipalities to place some (as yet) unknown weight on consumer surplus. The dynamic nature of the model allows players to form expectations about rivals’ future actions and best-respond in the present, which is necessary to capture private firms preemptive motives. I then use data from the National Broadband Map to estimate the weight that municipalities place on consumer surplus, as well as the costs of entering, exiting, and adopting FTTP.

After estimating the model, I simulate private and public firms’ decisions in a setting with and without a ban on municipal provision of internet access. I compare private firms’ actions under both regimes in order to measure the effect of public competition on private investment. Finally,

I decompose this effect on private firms in order to learn the degree of crowding out of private investment and the extent to which the threat of public investment induces private firms to invest preemptively.

4.1 Model

4.1.1 Players and States

Each market has exactly three players. Their types (τ) are a cable firm, a DSL firm, and a public firm. The cable and DSL firm are both privately owned. At every point in time, each player's *status* is either a potential entrant, a cable/DSL provider¹⁸, or a FTTP provider. The current *state* ($\$$) of the market includes the status of each type. The state space is therefore the entire range of possible market structures.

4.1.2 Actions and Costs

In each period, each player chooses an action (a). The actions available to a given player are determined by the player's status. A potential entrant can choose to stay out of the market (and retain the option value to act in the future), enter as a cable/DSL provider, or enter as a FTTP provider; a cable/DSL provider can exit, remain a cable/DSL provider, or upgrade to FTTP; a FTTP provider can exit or remain a FTTP provider.

Each of these actions is accompanied by a corresponding sunk cost. On average, entering as a cable/DSL provider, entering as a FTTP or upgrading to FTTP, and exiting, cost

$$\mu_{cd}^{\tau} = \kappa_{cd} + \rho_{cd} \mathbb{1}\{\tau = public\} \quad (8)$$

$$\mu_f^{\tau} = \kappa_f + \rho_f \mathbb{1}\{\tau = public\} \quad (9)$$

$$\mu_x \quad (10)$$

The κ represent the upfront costs of entering a market or upgrading technology, both explicit and implicit. The ρ represent the additional costs of those actions when undertaken by a public firm. Public firms typically cannot take advantage of economies of scale, and more importantly,

¹⁸When in this status, a cable firm provides cable service, a DSL firm provides DSL service, and a public firm provides cable service.

face significant political costs of convincing constituents to approve the endeavor and overcoming opposition from private firms. Both κ and ρ are common knowledge to all players.

In addition, in each period, each player receives an idiosyncratic shock (ν) to the cost of each of its actions. These shocks represents deviations from average costs and are private information to each firm. These shocks are assumed to be independently and identically distributed, drawn from a type 1 extreme value distribution.

4.1.3 Utility

In each period, each player earns utility according to the current state of the market and its type. Specifically, utility takes the form

$$u_m^\tau(\$) = \begin{cases} \pi_m^\tau(\$) & \text{if } \tau \in \{cable, DSL\} \\ \pi_m^\tau(\$) + \lambda \Delta CS_m(\$) & \text{if } \tau = public \end{cases} \quad (11)$$

where m indexes markets, $\pi_m^\tau(\$)$ represents profits earned by type τ in market m in state $\$$, $\Delta CS_m(\$)$ represents the change in consumer surplus resulting from the availability of FTTP in market m in state $\$$, and λ is the weight placed by municipalities on consumer surplus. If $\lambda = 0$, public entities operate as pure profit-maximizing firms; if $\lambda = 1$, public entities operate as social welfare-maximizing agents.

Profits take the form

$$\pi_m^\tau(\$) = \begin{cases} MarketShare_m^\tau(\$) * \#Housholds_m * Price_m^\tau(\$) & \text{if } \tau \text{ incumbent in } \$ \\ 0 & \text{otherwise} \end{cases} \quad (12)$$

Price and number of households are taken directly from the data. Market share is calculated using the estimates from the demand model and observed product and demographic characteristics. Specifically,

$$MarketShare_m^\tau(\$) = \frac{\exp[\hat{\delta}_m^\tau(\$)]}{1 + \sum_{j \in \{cable, DSL, fiber\}} I_j(\$) * \exp(\hat{\delta}_{mj})} \quad (13)$$

where $\hat{\delta}_{mj}$ is the estimated mean utility of technology j in market m , and $I_j(\$)$ is an indicator

representing whether technology j is available in state $\$$. $\hat{\delta}_m^\tau(\$)$ corresponds to the $\hat{\delta}_{mj}$ indicated by the player's type and status. Market shares are calculated from the demand estimates rather than taken directly from the data because for each market, it is necessary to predict what market shares would be realized under all possible market structures, most of which are never observed for any particular market.

Consumer surplus takes the form

$$\Delta CS_m(\$) = \log\left[\frac{1 + \sum_{j \in \{Cable, DSL, FTTP\}} I_j(\$) * \exp(\hat{\delta}_{mj})}{1 + \sum_{j \in \{Cable, DSL\}} I_j(\$) * \exp(\hat{\delta}_{mj})}\right] * \frac{\#households_m}{\hat{\psi}} \quad (14)$$

The log of the numerator in the first term is an individual household's expected consumer surplus, given the products available in state $\$$ in market m ¹⁹. The log of the denominator in the first term is a household's expected consumer surplus if FTTP is removed from the set of available product. Their difference (or equivalently, the log of their ratio) is the gain in a household's expected consumer surplus resulting from the availability of FTTP. This consumer surplus gain is then multiplied by the number of households in market m to create a market-level measure of consumer surplus and divided by $\hat{\psi}$, the estimated price coefficient from the demand model, to convert the measure to dollars.

4.1.4 Timing

Time is discrete and the horizon is infinite. Players discount the future at a common rate, β ²⁰. Within each time period, events unfold in the following order:

1. Players observe their current state and private information shocks
2. Players receive utility according to the current state
3. Players choose their actions and pay any associated costs
4. The state evolves according to players' decisions

¹⁹This functional form arises because the consumer surplus of a household is its expected maximum utility, given its available products. With a type 1 extreme value error term, this takes the form of the log of the sum of the exponentials of the products' mean utilities, plus some unknown constant.

²⁰In the estimation, I choose a value of 0.9 for β .

4.1.5 Value Functions

The value functions for a player of type τ in market m with a status of potential entrant, cable/DSL provider, and FTTP provider are given by

$$\begin{aligned} V_m^{\tau,pe}(\mathbb{S}; \theta, \nu) &= u_m^\tau(\mathbb{S}; \lambda) + \max\{ \nu_o + \beta \mathbb{E}_{\mathbb{S}'}[\mathbb{E}_{\nu'}[V_m^{\tau,pe}(\mathbb{S}')|\mathbb{S}, a], \\ &\quad -\mu_{cd}^\tau + \nu_{cd} + \beta \mathbb{E}_{\mathbb{S}'}[\mathbb{E}_{\nu'}[V_m^{\tau,cd}(\mathbb{S}')|\mathbb{S}, a], \\ &\quad -\mu_f^\tau + \nu_f + \beta \mathbb{E}_{\mathbb{S}'}[\mathbb{E}_{\nu'}[V_m^{\tau,f}(\mathbb{S}')|\mathbb{S}, a]] \} \end{aligned} \quad (15)$$

$$\begin{aligned} V_m^{\tau,cd}(\mathbb{S}; \theta, \nu) &= u_m^\tau(\mathbb{S}; \lambda) + \max\{ -\mu_x + \nu_x, \\ &\quad \nu_{cd} + \beta \mathbb{E}_{\mathbb{S}'}[\mathbb{E}_{\nu'}[V_m^{\tau,cd}(\mathbb{S}')|\mathbb{S}, a], \\ &\quad -\mu_f^\tau + \nu_f + \beta \mathbb{E}_{\mathbb{S}'}[\mathbb{E}_{\nu'}[V_m^{\tau,f}(\mathbb{S}')|\mathbb{S}, a]] \} \end{aligned} \quad (16)$$

$$\begin{aligned} V_m^{\tau,f}(\mathbb{S}; \theta, \nu) &= u_m^\tau(\mathbb{S}; \lambda) + \max\{ -\mu_x + \nu_x, \\ &\quad \nu_f + \beta \mathbb{E}_{\mathbb{S}'}[\mathbb{E}_{\nu'}[V_m^{\tau,f}(\mathbb{S}')|\mathbb{S}, a]] \} \end{aligned} \quad (17)$$

where $\theta \equiv (\kappa_{cd}, \kappa_f, \rho_{cd}, \rho_f, \mu_x, \lambda)$. In each value function, the player receives utility according to the current state of the market. Additionally, the player selects an action and receives the corresponding value from within the max operator. Within each max operator, the inner expectation over ν represents the players' uncertainty over future values of the idiosyncratic shocks to their costs, while the outer expectation is taken over possible future values of the state. This outer expectation is then conditional on the current state as well as the action chosen by the player.

The value functions in equations (15), (16), and (17) are conditional on the players observing ν . However, ν is not observable to the econometrician and therefore these equations cannot be used directly in estimation. Instead, the players' ex-ante expected value functions are used. Prior to observing ν , the expected value functions are given by

$$\begin{aligned}
\mathbb{E}_\nu[V_m^{\tau,pe}(\mathbb{S};\theta)] &= u_m^\tau(\mathbb{S};\lambda) + \log[\exp\{\beta\mathbb{E}_{\mathbb{S}'}[\mathbb{E}_\nu[V_m^{\tau,pe}(\mathbb{S}')|\mathbb{S},a]\} + \\
&\exp\{-\mu_{cd}^\tau + \beta\mathbb{E}_{\mathbb{S}'}[\mathbb{E}_\nu[V_m^{\tau,cd}(\mathbb{S}')|\mathbb{S},a]\} + \\
&\exp\{-\mu_f^\tau + \beta\mathbb{E}_{\mathbb{S}'}[\mathbb{E}_\nu[V_m^{\tau,f}(\mathbb{S}')|\mathbb{S},a]\}]
\end{aligned} \tag{18}$$

$$\begin{aligned}
\mathbb{E}_\nu[V_m^{\tau,cd}(\mathbb{S};\theta)] &= u_m^\tau(\mathbb{S};\lambda) + \log[\exp\{-\mu_x\} + \\
&\exp\{\beta\mathbb{E}_{\mathbb{S}'}[\mathbb{E}_\nu[V_m^{\tau,cd}(\mathbb{S}')|\mathbb{S},a]\} + \\
&\exp\{-\mu_f^\tau + \beta\mathbb{E}_{\mathbb{S}'}[\mathbb{E}_\nu[V_m^{\tau,f}(\mathbb{S}')|\mathbb{S},a]\}]
\end{aligned} \tag{19}$$

$$\begin{aligned}
\mathbb{E}_\nu[V_m^{\tau,f}(\mathbb{S};\theta)] &= u_m^\tau(\mathbb{S};\lambda) + \log[\exp\{-\mu_x\} + \\
&\exp\{\beta\mathbb{E}_{\mathbb{S}'}[\mathbb{E}_\nu[V_m^{\tau,f}(\mathbb{S}')|\mathbb{S},a]\}]
\end{aligned} \tag{20}$$

4.2 Estimation and Identification

For estimation, I define a market to be a zip code. This is the geographic level that best approximates the area considered by firms when making decisions. Smaller areas, such as census blocks or census tracts, contain too few households for firms consider them separately. On the other hand, larger areas, such as MSAs or counties are too large, as firms will typically only serve a subset of these areas.

I estimate the model using a nested fixed point maximum likelihood algorithm. Under this approach, conditional on a particular value of θ , I solve for the value functions in equations (18), (19), and (20)²¹. These value functions then generate probabilities that players take each action²². Finally, I use these probabilities to form a likelihood function. Then, I perform a non-linear search over parameter vectors in order to maximize a likelihood function, given by

$$L(\theta; W) = \sum_{t=1}^T \sum_{m \in M} \sum_{\tau \in \{cable, DSL, public\}} \sum_{a \in A_\tau(\mathbb{S})} \log[Pr_m^\tau(a; \mathbb{S})] * I_{mt}^\tau(a) \tag{21}$$

²¹The procedure for this is to begin with a guess for $\mathbb{E}[V_m^{\tau,pe}(\mathbb{S};\theta)]$, $\mathbb{E}[V_m^{\tau,cd}(\mathbb{S};\theta)]$, and $\mathbb{E}[V_m^{\tau,f}(\mathbb{S};\theta)]$ and iteratively apply equations (18), (19), and (20) until a fixed point is reached. This algorithm was developed by Pakes and McGuire (1994).

²²These probabilities take on the usual logit form, given the actions available to the player

Table 6: Supply Model Parameter Estimates

κ_{cd}	Cable/DSL cost	\$2,385,885 (42,262)
κ_f	FTTP cost	\$5,798,481 (33,631)
ρ_{cd}	Additional public cable cost	\$20,078,985 (85,811)
ρ_f	Additional public FTTP cost	\$5,630,219 (47,229)
μ_x	Exit cost	\$3,868,241 (26,769)
λ	Public consumer surplus weight	0.23 (0.01)

where W is data on players' actions, t indexes time, $A_\tau(\$)$ is the set of actions available to a player of type τ in state $\$$, $Pr_m^\tau(a; \$)$ is the model-generated probability that a player of type τ in market m in state $\$$ chooses action a , and $I_m^\tau(a)$ is an indicator representing whether the player of type τ in market m in period t took action a in the data.

The cost parameters in the model are identified by variation in entry, upgrade, and exit decisions across markets with varying profitability. Players undertake these actions if and only if the gain in expected discounted utility exceeds the cost of doing so. The estimated cost parameter is the threshold value of utility, above which players take an action and below which they do not. λ , public providers' weight placed on consumer surplus, is identified by differences in private and public firms' entry decisions and technology choices. In particular, λ is identified by variation in public providers' decisions across markets with varying consumer surplus, holding all else constant.

4.3 Results

Results from estimating the model of entry and technology adoption described in this section are reported in table 6. I estimate that it costs a private firm about \$2.4 million to enter a market using cable or DSL technology, and about \$5.8 million to enter a market using FTTP or to upgrade from cable or DSL to FTTP. These appear to be well in line with industry estimates. Brouse (2010), the network director for Charter Communications estimates that for the median market in my data, it would cost about \$1.9 million to enter a market using cable technology and about \$3.1 million to install FTTP. Additionally, I find that it costs public providers an additional \$5.6

million to provide FTTP and an additional \$20.1 million to provide cable technology. These costs likely represent the substantial burden of convincing constituents to undertake such an endeavor. In particular, it is likely monumentally difficult to convince constituents to install a cable network when a next-generation FTTP network is a viable option. In fact, since these are not explicit costs, it is more accurate to state that public entities behave as though it is significantly more costly for them to provide internet service than for a private firm.

Finally, I estimate that municipalities place a weight of 0.23 on consumer surplus, suggesting that they value each dollar its constituents receive in consumer surplus at \$0.23. I can safely reject the hypotheses that $\lambda = 0$ and that $\lambda = 1$. The evidence shows that municipalities do value consumer welfare and therefore make decisions quite differently from firms. But, at the same time, municipalities do not approach making decisions as a social planner either. It is perhaps unsurprising that municipalities appear to value profits much more than consumer welfare. Convincing constituents that the local government should take on the task of providing internet service is not easily accomplished. Arguing that such a network would be profitable, or at least nearly so, is likely a necessary first step.

4.4 Goodness of Fit

In order to get a sense of how well the model fits the data, I simulate the actions chosen by the players over the time periods spanned by the data. I start each market in the state in which it appears in the data in June 2010 and then let each market evolve according to the simulated actions for four years. The results from this exercise are reported in table 7. As a whole, the model appears to fit the data quite well. In particular, the model predicts DSL and public FTTP entry extraordinarily well. The model under-predicts cable exits and over-predicts DSL exits, suggesting that their exit costs are heterogeneous.

5 Counterfactuals

In order to measure the effect of public competition, I simulate the actions undertaken by public and private firms both with and without a ban on municipal provision of internet access over a period of twenty years. I implement the ban such that any municipalities providing internet service prior

Table 7: Model Fit: Actual and Simulated Actions from 2010 through 2014

	Actual	Baseline Simulation
Cable (Cable) Entry	1439	1636
Cable (FTTP) Entry	94	30
Cable Upgrade	115	320
Cable Exit	1432	586
DSL (DSL) Entry	622	573
DSL (FTTP) Entry	26	25
DSL Upgrade	697	886
DSL Exit	144	1092
Public (Cable) Entry	96	135
Public (FTTP) Entry	223	222
Public Upgrade	55	1
Public Exit	112	25

Table 8: Policy Simulation: 20 Year Ban on Public Provision

	Baseline	Public Ban	Δ
Fraction of Markets with FTTP	0.26	0.25	-0.01
Expected # of Years with FTTP	4.83	4.52	-0.31
Private Profits	\$121.11B	\$123.91B	\$2.80B
Public Profits	\$10.92B	\$1.42B	-\$9.50B
Consumer Surplus	\$194.68B	\$193.57B	-\$1.11B
Total	\$326.71B	318.90	-\$7.81B

to 2010 may continue doing so, but place a ban on any future entry. Table 8 reports a comparison of market outcomes under these two scenarios.

I find that placing a ban on municipal provision decreases the fraction of markets which gain access to FTTP by the end of the 20 year period by 1%. This statistic, however, does not take into account the timing of FTTP installation. I calculate the expected length of time (out of 20 years) that a market will have access to FTTP, and find that it falls by about 4 months under a ban on municipal provision.

Next, I calculate welfare both with and without a ban on municipal provision. I find that a ban increases private firms' profits by \$2.8 billion, decreases municipalities' profits by \$9.5 billion, and decreases consumer surplus by \$1.1 billion. In net, a ban on municipal provision decreases welfare by \$7.8 billion.

In order to measure the effects of public competition on private investment, I tabulate the

Table 9: Effects of Banning Public Provision on FTTH Probability

	Δ Public	Δ Private	Δ Total
Direct Ban Effect	-1.43%	0%	-1.43%
Crowding Out Effect	0%	0.76%	0.76%
Preemption Effect	0%	-0.10%	0.10%
Net Effect	-1.43%	0.66%	-0.77%

fraction of markets with access to FTTP through a private firm both with and without a ban on public provision of internet access. I find that with a ban in place, the probability of private FTTP provision rises by 0.66 percentage points. This change, however, represents the net effect of gaining private provision from firms who were crowded out by municipalities and losing private provision from firms who were induced into investing preemptively by the threat of municipal provision. In order to decompose this net effect into its component parts, I simulate an artificial intermediate scenario, one in which private firms *believe* that municipalities may enter the market in the future but in which they never actually do. I define any private firm who provides FTTP in this scenario or in the absence of any ban, but not under a true ban on municipal provision, to have preemptively invested in FTTP. I define any private firm who does not provide FTTP in the absence of a ban, but does provide FTTP when municipalities cannot enter, to have been crowded out. The results of this decomposition are reported in table 9.

I find that under a ban on municipal provision, the probability of private provision of FTTP increases by 0.76 percentage points due to the absence of the crowding effect, and decreases by 0.10 percentage points due to the absence of the preemption effect. In net, the probability of private provision of FTTP increases by 0.66 percentage points. However, the probability of public provision of FTTP decreases by 1.43 percentage points, so the increase in private provision is only enough to offset about half of this loss. In total, the probability that a market gains access to FTTP over 20 years falls by 0.77 percentage points.

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