Paying for Speed: Measuring Willingness to Pay in U.S. Broadband Markets

Richard Peterson*

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Abstract

This paper estimates willingness to pay for increased internet speeds using market data of consumer internet plans across 29 U.S. metropolitan areas. A two-stage approach is used to control for potential bias in the selection of product characteristics by internet service providers. I find that consumers are willing to pay $12.58 more for download speeds greater than 4 Mbps, and $47.65 for increases in speed above 25 Mbps. These estimates are of interest as the FCC has twice redefined broadband for consumer internet plans as at least 4 Mbps download speed then 25 Mbps download over the last decade. Additional findings are that increasing the number of firms in a market using DSL and cable technologies are associated with lower speeds and higher prices, and that the type of technology and whether television and telephone services are included in an internet plan are important to consumer's valuations.

JEL Classification: D12, D22, L11, L22, L96.

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*University of Colorado at Boulder.

1 Introduction

Policy makers face a number of important policy questions related to consumer's experience with private internet plans including regulation of internet traffic (Title II and the net neutrality debate), subsidies to low-income consumers (The FCC's Lifeline Program [1]), and antitrust cases (the mergers of AT&T and Time Warner, Wave Broadband and RCN Telecom Services, and others.) Evaluating these policies depends on accurate estimation of the costs and benefits to consumers and producers including the valuations for specific products and product characteristics by consumers. This study estimates the willingness to pay by consumers for additional internet speed measured Megabits per second (Mbps). Unique aspects of the broadband market including a small number of large internet service providers (ISPs), necessary investment in physical infrastructure, and multiple characteristics in the products sold make answering simple economic questions potentially difficult. I use a combination of detailed market data and a two-step control function empirical specification to overcome endogeneity issues and find estimates for consumers' benefits useful for policy makers, firms, and other research.

I use a large data set of over 25,000 consumer broadband plans including plan characteristics across the 29 largest broadband markets between January 2010 and November 2012. This market data provides variation in market structure and types of broadband plans allowing for estimation of willingness to pay controlling for two potential sources of endogeneity market power and selection bias. Ideally, a hedonic study would include consumer's choices in purchases, however this information is either costly to collect through survey methods or proprietary. Although I do not have access to consumer data the plan information includes detailed information on plan characteristics including download speed, type of technology (cable, DSL, or fiber connections), and characteristics of triple-play bundles, plans that include land-line telephone and cable television services which the majority of broadband

[1] United States Federal Communications Commission

consumers buy.

The period starting in 2010 is of particular interest because in March 2010 the Obama administration and the FCC released the National Broadband Plan a policy with the goal of expanding access to broadband to facilitate economic growth (FCC 2010). At this time the FCC redefined a broadband internet plan as one with download speeds of at least 4 Mbps and upload speeds of 1 Mbps from 768 kbps download and 200 kbps upload. In 2015 the FCC again increased the necessary speeds for an internet plan to qualify as broadband to 25 Mbps download and 3 Mbps upload. I find that consumers are willing to pay $12.58 more for a plan with download speeds of 4 Mbps - 10 Mbps than slow plans with speeds less than 4 Mbps. Consumers are willing to pay $47.65 more for speeds of 25 Mbps - 50 Mbps than slow plans, for plans that meet the 2015 minimum speeds that can be called broadband. The levels of these estimates suggest that policies encouraging higher speeds create additional consumer surplus, and when combined with cost estimates we have a fuller understanding of policies affecting the broadband market.

Previous studies of internet services address two important areas of endogeneity; competition and internet plan characteristics. Broadband markets are often characterized by a small number of firms and differentiated products that when excluded from a reduced form estimation could bias the estimate on any desired characteristics, like speed. For basic hedonic studies omitted variable bias can occur when product characteristics are not collected in data, when market characteristics (such as imperfect competition) affect observed characteristics, or even the unique tastes of individuals. Hedonic studies often rely on either detailed consumer choice data and estimate a random utility model with random coefficients to allow flexible estimates of consumer preferences (BLP 1995). However, these models rely on strict assumptions for usable instruments, may lead to unlikely results when the number of products is large, and are computationally burdensome (Bajari 2001). However, Rosen (1974) outlines a simple and effective framework for estimating the marginal values of product characteristics. To meet the basic assumptions under Rosen's method I use a two-step control function approach where I model firm's choices in broadband plan characteristic and include estimates from the first stage to control for endogeneity in a second-stage hedonic regression. I find evidence of endogeneity in the choice of plan characteristics suggesting that OLS estimation of the hedonic regression is biased and inconsistent without correction.

This study continues in section 2 with a brief review of the literature on internet valuation and market structure. Section 3 presents hedonic methods and the empirical strategy used in this study. Section 4 discusses the data set, and section 5 shows the results of estimation. Section 6 concludes.

2 Literature Review

Economists have a variety of questions about the internet as an avenue for market disrupting models of commerce, a potential driver of economic productivity, and as a consumer good omnipresent in people's lives. Studies on the applications of the internet are too great to discuss here so I limit the following discussion to research on valuation of the internet as a consumer product, as well as studies on the market structure of ISPs.

Broadband technology spread throughout the 1990s in the U.S. and provided researchers an opportunity to determine both supply side determinants of supply, and the opportunity to examine what types of consumers were most likely to adopt the technology. Downes & Greenstein find population, the size of a market, and existing infrastructure (from an existing telephone or cable firm) are predictors of early entry in the broadband market. Xiao and Orazem (2005) find that price competition is limited with more than three entrants into a market. Chen and Savage (2011) investigate whether internet service providers increase prices under differentiated consumer groups and when a different technology types (cable or DSL) exist in the same market and find that in both cases prices increase. Mallahan and Wallsten (2010) explore the effect of number of firms on downstream internet speed and prices and find that additional entrants (only looking in areas with up to three providers) is associated with both higher speeds and lower prices. Finally, Molnar and Savage (2017) look at the effect of wireline and wireless competition on internet speeds finding that the two technology types do not compete in quality, but that the number of firms within technology type is associated with increases in quality through the third or fourth firm.

Much of the focus on hedonic studies of internet prices has been focused on creating quality adjusted price indexes useful for including internet services in calculations of consumer price indexes. Studies from before 2000 mostly look at dial-up connections and observe that quality-adjusted price indexes decrease more when including quality variables such as hourly limits, speed, availability of technical support, and the number of e-mail addresses when compared to indexes that do not include quality controls (Stranger 2007, Yu & Prudhomme 2010). More recent hedonic studies with broadband technology have found similar results and make the case that government measures of CPI should include hedonic controls because of changes in quality variables such as speed (Williams 2008, Greenstein 2011).

Several studies look more specifically at the determinants of broadband demand and adoption between consumers by race (Prieger & Hu 2008) and experience with the internet and location (Savage & Waldman 2008). Carare, McGovern and Noriega (2015) survey broadband non-adopters and find that age, family structure, location and price are important in determining whether a household will adopt broadband. The gap between rural and urban broadband use is of particular interest in policy; Prieger (2013) discuss the differences in these groups in both value of the internet and the level of competition.

Studies closely related to this one estimate willingness to pay for characteristics in broadband plans. Rosston, Savage and Waldman use surveys and find that consumers are willing to pay $45 for an upgrade from dial-up speeds to "fast" speeds. Two recent papers provide useful comparisons to the estimates found in this paper. Nevo, Turner and Williams (2016) us high-frequency data from a U.S. ISP to estimate willingness to pay for several broadband characteristics and find that the average willingness to pay for an increase in download speed by one Mbps is $2. A study by Liu, Prince and Wallsten uses discrete choice surveys to understand consumers' valuations of download speed and latency; they find willingness to pay starting at $2.34 per Mbps for initial increases in speed and declining after.

This study builds on previous studies in several ways. First, I contribute to the literature on competition generally by further documenting a market where additional entry does not always lead to the expected changes in price and competition. Second, I use an empirical strategy that is effective in determining whether unseen endogeneity exists. Specifically, I incorporate a simple game in the choice of product characteristics and estimation of competition by technology type and the number of firms. And finally, I use market data instead of user data or survey data and find similar results to studies using detailed consumer choices suggesting that market data may be a useful substitute when more detailed data is either unavailable or costly to collect.

3 Hedonic Methods and Empirical Specification

In a competitive market, estimation of marginal valuation of product characteristics is possible by using hedonic analysis on observed market equilibria. My goal is to estimate the marginal value of additional download speed in consumer markets. However, due to the number of product characteristics in even basic broadband plans and the potential for endogeneity from unobserved market characteristics estimation may be biased.

Rosen (1974) provides the theoretical reasoning for using observed market prices to determine the marginal willingness to pay for a specific products attributes. Market equilibrium is determined by demand and supply functions that vary based on consumer tastes and preferences and cost determinants respectively. The consumer maximizes utility with respect to product characteristics z subject to a budget constraint. If there is variation in product characteristic available to consumers then it is theoretically possible to trace a willingness to pay function for each product characteristic and also the statistical determination of an average willingness to pay for that characteristic. However, the availability of characteristic z is made by producers who maximize profits with respect to the quantity of production and product characteristic z. If competition exists then the price of a good produced is driven to marginal cost and the marginal revenue of producing an additional unit is equal to the price offered at market equal to marginal cost. Prices observed in market data are then assumed to be equal to marginal cost equal to a function of the willingness to pay for product characteristics by consumers.

Equation (1) is a standard hedonic equation for the price of good i with coefficients representing the marginal valuation of a change in a product characteristic Z of good i.

$$price_i = \beta Z_i + \beta X_m + \beta N_m + u_i, \tag{1}$$

X_m are variables related to demand and cost of the good in market m, and u_i is a zero mean random error term for product i. In the case of a broadband plan the coefficient on the continuous variable download speed would represent the monetary value a consumer is willing to pay for a 1 Mbps increase in download speed[2].

Observed market prices are essential to identifying consumer's willingness to pay, but researchers are not often privy to the choices made by firms that influence a product's market price. In determining the valuation of speed the researcher must first ask what factors determine the firm's choice in providing a certain speed to consumers. Three potential determinants in a firm's choice include competition within a market, limitations of types of broadband technology, and regulatory definitions. Competition and the type of technology

[2] Download speeds are not provided continuously, and consumers do not necessarily value each additional increase in speed the same suggesting that a linear function like equation (1) is not appropriate.

employed by a firm are related as many markets will see both cable and DSL providers [3] (Chen & Savage, 2011), as well as wireless and wireline (Molnar & Savage, 2017) providers. The choice of technology can influence the potential speeds and costs of updating the physical infrastructure necessary to provide higher speeds; for example many of the copper wires used in providing DSL service are the same infrastructure used to provide fixed telephone services to homes [4]. Providing faster speeds through DSL services would require investment that incumbents may or may not find profitable. If DSL providers choice to provide slower speeds is determined by investment and upgrade decisions unseen to the researcher than hedonic methods may be provide biased estimates of marginal valuations. Specifically prices observed from market data may reflect costs and market power that bias prices away from marginal costs.

Regulatory definitions are also a source of potential endogeneity by influencing firm's decisions of plan characteristics and then market price. 2010 the FCC redefined "broadband internet" as an internet connection with download speeds of at least 4 Mbps and upload speed of 1 Mbps. This definition is important as it sets a floor in the speed characteristic of plans consumers may want to buy, assuming that consumers prefer a plan labelled as "broadband" and not just as internet access. For firms wanting to sell services with the "broadband" label they must maintain infrastructure to meet that minimum speed[5]. The effect of upgrading networks to meet minimum speed requirements necessary to offer plans labelled as broadband may bring about additional complementary infrastructure upgrades

[3]Fiber to the home (FTTH) technology which provides the highest maximum speeds is the newest type of technology and offers the greatest potential speeds. FTTH is similar to cable and DSL technology in that it appears consumers value it as a distinct service and markets may be open to having a cable, DSL, and fiber option. However, FTTH is still relatively unavailable; as of 2014 the FCC noted that 59 % of fixed broadband service subscriptions were through cable modem services, 29% through DSL and only 9% were FTTH. The remaining subscriptions were through satellite and fixed wireless which accounted for less than 3% overall (FCC 2016).

[4]See the FCC reports 2016 Broadband Progress Report and Measuring Fixed Broadband Report - 2016 for the FCCs discussion of service differences between different broadband technologies and providers

[5]The FCC updated the definition of broadband internet again in 2015 to include internet plans with download speeds of at least 25 Mbps and upload speeds of 3 Mbps. The data used in this paper is during 2010 through 2012 before this higher redefinition went into effect

affecting the plans offered by a firm. Determining whether such complementary upgrades occurred is beyond the scope of this study, but demonstrates the unseen firm choices and incentives in choosing product characteristics.

An OLS estimation of price on a broadband plans characteristics could provide a consistent and unbiased estimate of the willingness to pay for individual characteristics. However, unobserved variables that influence plan characteristics such as download speed and the price of the plan would bias OLS estimates. A standard approach to control for this type of bias is to find an instrument related to a firm's choice of product characteristics, but unrelated to the price of the good. Previous studies on the broadband market use variables related to the fixed costs of broadband infrastructure determined by geography[6]. However, a standard IV approach assumes a linear relationship to the dependent variable for identification. Internet service providers do not offer a continuous set of plan characteristics that allow us to examine prices at every possible speed. The grouping of offered speeds around certain amounts (such as around the minimum definition of broadband or other groups like 10 Mbps, 25 Mbps, and 50 Mbps) suggests that a standard IV is not appropriate.

The industrial organization literature often handles endogeneity from market structures using a two-stage process that follows from Heckman (1979) used in cases where sample selection on characteristics like market structure and unobserved firm decisions are possible. Studies in empirical IO (Bresnahan & Riess 1990, Mazzeo 2002, Manuszak & Moul 2008) have used this technique to incorporate a control for firm decision making in a firms entry decision given a simple structural framework. I use a similar procedure except the first stage is not a decision to enter a market, but to offer a higher level of speed in a broadband plan.

In deciding to offer a particular product characteristic a firm will first determine whether or not it is profitable to do so. The following game is played once by a homogeneous firm with

[6]For example the number of street intersections and housing density which are related to the costs of laying additional lines to reach neighbourhoods

perfect information across several markets. Each firm decides to offer a speed in one of six broadband download speed tiers for each market given the characteristic levels and numbers of competitors. There are many potential complications to this simple model including heterogeneous firms and dynamic multi-step decision making. Those complications require more data to identify the greater possible outcomes than what is present in the data set and are an opportunity for further research in this field. The short sampling period of the data and the fact that during the sampling period broadband had previously existed in all of the sample markets suggests that a one-time game is the most appropriate. Consider the following latent payoff function for a broadband plan with download speed j in market m:

$$\Pi_i(j, X_m, N_m, F_m; \theta) = \pi(j, X_m, N_m, F_m; \theta) + e_i. \tag{2}$$

Where j is the chosen characteristic (download speed), X_m are demand and supply shifters, N_m describe the market structure including the number of firms offering plans with similar speed, and e_i are any unobserved factors in the plan i. F_m are market specific characteristics that do not necessarily affect price, but are related to the profits of a plan such as investments costs related to upgrading physical broadband infrastructure. θ are the estimated parameters. Profit may or may not be increasing with speed conditional on the level of competition (N_m) and market characteristics(X_m). However, the speeds of a particular plan are constrained by the investments and type of technology employed by an ISP meaning that in order to provide a higher speed an isp must also pay some fixed cost in infrastructure spending. An ISP will offer a higher speed when it is profitable to do so given the fixed costs required to upgrade their network. The Nash equilibrium occurs at $j*$ and is characterized by the following payoff functions:

$$\begin{aligned} \pi_i(j*, X_m, N_m, F_m; \theta) + e_i > 0, \\ \pi_i(j*+1, X_m, N_m, F_m; \theta) + e_i < 0. \end{aligned} \tag{3}$$

Equation (3) shows that each ISP will choose speed $j*$, the equilibrium speed where payoffs are positive, but also the level where increasing speed does not provide positive profit. Firms will increase speed (and thus increase investment costs) until additional investment is too costly to earn a positive level of profit from providing higher speed products. This outcome represents a Nash equilibrium as no firm will have an incentive to offer a different level of speed conditional on the other firm's choices.

The parameters from equation (2) can be estimated using maximum likelihood estimation of an ordered probit which follows the sequential nature of the firm's decision making. The variation in the observable plan, market, and infrastructure variables is used to identify the cutoffs that relate to otherwise unobserved profits. Finally, I follow convention in the latent profit function and assume that error terms u and e are jointly normally distributed with mean vector zero and covariance matrix:

$$\begin{pmatrix} u_i \\ e_i \end{pmatrix} \sim N \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_u^2 & \\ \sigma_{ue} & 1 \end{pmatrix}$$

Using the estimates of the ordered probit model I calculate the inverse mills ratio:

$$\lambda = \frac{\phi(\pi_1(X_m, N_m, F_m)) - \phi(\pi_2(X_m, N_m, F_m))}{\Phi(\pi_2(X_m, N_m, F_m)) - \Phi(\pi_1(X_m, N_m, F_m))}, \tag{4}$$

where π_1 is the profit from a speed tier slower than π_2. In practice this variable is calculated using the estimated cuts from the ordered probit. λ is included in the price equation to control for any omitted variable bias due to the correlation between unobservables in the firm's speed decision and the pricing equation's error term u_i. Inserting this correction term in equation (1) we have the following pricing equation:

$$price_i = \beta Z_i + \beta X_m + \beta N_m + \sigma_{eu}\lambda + v_i \tag{5}$$

Estimating equation (5) provides an estimate of σ_{eu} the correlation of the error terms in equations (1) and (2). If $\sigma_{eu} = 0$ then endogeneity in characteristic choice is not present in the estimation and OLS provides a consistent and unbiased estimation; If $\sigma_{eu} \neq 0$ then there is concern of endogeneity and OLS estimation is biased and inconsistent.

A concern in identification of the first-stage is sufficient variation in identifying the λ term. If the explanatory variables are the same in equations (2) and (5), the model is only identified because λ is constructed as a nonlinear function, and there will be little additional variation by including λ. However, including additional explanatory variables in equation (2), similar to instruments used in an IV approach, can help to capture the unobserved characteristics proxied with λ (Verbeek 2008). I use a geographical determinant of fixed costs, a market's distance to an internet backbone node, discussed below.

4 Data

Data is collected by Telogical Systems a private information firm focused on the telecommunications field. The data set includes information on over 25,500 broadband and triple play (includes phone and television services) plans collected over 35 months from January 2010 to November 2012 in 29 of the top markets for broadband. Eighteen ISPs are included in the sample. Each observation is a single broadband plan and includes plan characteristics, including whether or not the plan is bundled with television and wireline phone services.

Although the data is collected over time the data is cross-sectional as plans are not linked over time be a single identifier. For example, a firm might offer several plans within one speed tier in a single month, the characteristics of the plans offered in the next month or the next year are not necessarily the same.

I separate six speed tiers based on definitions of plans that qualify as broadband and commonly used tiers by the FCC. The lowest speed tier is less than 4 Mbps which did not qualify as a consumer broadband plan after the FCC's reclassification in 2010. The FCC has since updated the definition of broadband to download speeds greater than 25 Mpbs, and another level 10 Mbps was considered at the time. I created one tier at each of these levels as they are most commonly used in regulation and are popular offerings[7]. Above 25 Mbps I followed the tiers used on the National Broadband Map which visualizes broadband data collected by the FCC from ISPs. In addition to using commonly used tiers there is a technological reason as well. One economic value in additional internet speed is the forgone time spent waiting for an internet application to load (Goolsbee, 2006). The time cost of speed depends heavily on the application, for example checking email without a perceivable wait time requires lower speeds than streaming high-quality video does for the same wait time. Additionally, the number of devices and applications using the same internet connection affects the potential slow down for a given plan. Meaning that an internet plan offering 4 Mbps download speeds has lower time costs for a household with one user compared to a household with two or more users who use the internet services at the same time. The FCC household broadband service guide suggests that the time cost for basic web browsing improves until 10 Mbps where additional speed is not noticeable[8]. A household with two users (or one user on two devices) is recommended to have 25 Mbps, with increased speed necessary for more people and devices. While higher level speeds may not be necessary at all times consumers may wish to purchase faster speeds depending on the size of their

[7]see Measuring Fixed Broadband Report 2016 from the FCC for sample tier offerings from many firms.

[8]https://www.fcc.gov/research-reports/guides/broadband-service-home-consumers-guide

household and the types of applications they use leading to demand for higher speed tiers beyond 25 Mbps.

Price is an observed monthly price for either a broadband plan or a triple play bundle including home telephone and television as well as broadband internet. Bundled plans are important to include in an estimate of willingness to pay as many consumers do not purchase broadband alone. Table 1 shows average number of plans, average speed, average price, and portion of the sample by technology for each speed tier for bundled and unbundled broadband plans. The majority of plans in the sample are unbundled plans (86%) and most of the unbundled plans are in the slowest speed tier (43% of the total sample). While a majority of plans in the sample use DSL technology few in the fastest speed tiers do. Conversely, fiber plans are rarely available in the slowest speed tiers while making up a larger part of the sample in higher speed tiers. The final row in each group is the percentage change in price from the slowest speed tier which illustrates the magnitude of price changes in the sample. For example, the average price for an unbundled plan in the speed tier with speeds greater than 100 Mbps is 406% greater than the plans in the slowest speed tier. On the other hand most bundled plans have similar prices with only a $20 difference between plans with the slowest speeds and fastest speeds.

Table 1: Summary Statistics by Speed Tier

	Broadband Only Plan						
Speed Tier	<4 Mbps	4≤x<10	10≤x<25	25≤x<50	50≤x<100	≤100	All Tiers
n	9580	3884	6001	1136	1107	414	22122
speed	1.91	6.38	15.17	29.72	51.52	132	12.64
dsl	0.65	0.72	0.43	0.15	0.03	0.00	0.53
cable	0.34	0.28	0.52	0.54	0.71	0.68	0.41
fiber	0.01	0.00	0.05	0.31	0.26	0.32	0.06
price	33.59	44.35	54.76	75.89	105.5	170.07	49.55
% change from <4		32%	63%	126%	214%	406%	
	Triple-Play Bundle						
Speed Tier	<4 Mbps	4≤x<10	10≤x<25	25≤x<50	50≤x<100	≤100	All Tiers
n	1442	880	1158	28	17	0	3525
speed	2.54	6.34	12.50	26.61	50		7.18
dsl	0.73	0.72	0.07	0.36	0		0.50
cable	0.27	0.28	0.67	0.46	1		0.41
fiber	<0.01	0	0.26	0.18	0		0.09
price	121.31	136.57	131.72	144.95	145.31		128.11
% change from <4		13%	9%	19%	20%		

A concern with this data set is that a few common plan characteristics, upload speeds, data limits, and latency are not included. Upload speed is often correlated with download speed, but consistently lower as many internet applications do not require fast return of large amounts of data. Exceptions include applications such as online gaming where individual's upload speeds can affect the overall experience. Not including upload speed in estimation of the price equation is likely to bias the estimate on the speed coefficients upward unless increased upload speed is a by product of increases in download speed in which case the bias is negligible. Data limits are caps on the amount of data that a consumer can download, often before additional fees are triggered. Data limits are more commonly seen in wireless internet plans, but exist for many wireline consumer plans as well. Finally, latency is a measure of delay consumers experience when using internet applications distinct from limits on download speeds, but related to how a consumers feels about speeds due to the internet "feeling slow" when latency is high. Latency is important in consumer's valuations, especially self-reported valuations like those found using survey data (Liu et al., 2017). However, latency is correlated with the type of technology used with cable and fiber technologies demonstrating less latency on average relative to DSL connections (FCC 2015). To the extent that consumers are able to choose a level of latency they likely due so relative to their experience of broadband technology and ISP which are included in the specifications used here.

Another concern of this data set is that advertised prices may not reflect the prices most commonly paid by consumers. Consumers will often pay additional fees such as a setup charge, or be eligible for discounts if they sign a one or two year contract. The setup charge is a fixed cost to consumers and should not affect consumers valuation of the service they receive month to month. Instead, a setup charge may act as a barrier to switching to a competing plan as a consumer may not want to pay another setup charge making it more likely that a consumer will pay the standard monthly price after any promotions have expired. Consumers also consider promotions that vary by plan. Promotions can include free installation, access to security software, free modems, reduced prices for upgrading plans including bundling of new services, and lowered monthly prices for a period of time anywhere from one month to a year. The variety of types of promotions make their inclusion in this study very difficult. However, a 2010 FCC Survey of U.S. internet users found that roughly 17% of users had switched ISPs in any year, including those who had moved residences and may have switched providers with their move (FCC 2010). This low level of switching suggests that most consumers end up paying listed monthly prices after a promotion has ended and do not continually chase promotions.

Demand variables are included to control for differences in price based on demographic characteristics. Table 2 shows summary statistics for population, the number of small firms (with under 50 employees), and median income. An increase in any of these variables should lead to a greater demand for broadband internet. Demand variables are collected for the Metropolitan Statistical for each market in the sample from the American Community Survey

5-year estimates except for the number of small businesses which is collected from the Small Business Administration. As this data is given annually there are only three unique values for each market for each variable.

Table 2: Demographic Summary Statistics

	Mean	Std. Dev.	Min	Max
Pop. (000s)	3939	3575	305	12862
small firms (000s)	103	109	6	493
median inc. (000s)	58	6	41	73
N	25647			

Table 3 shows the overall market structure by number of firms and type of broadband technology at the beginning and end of the sample. Each number in the table represents the number of markets in the sample with that market structure. For example in January 2010 two markets in the sample have four firms with cable technology, four firms with DSL technology and zero firms offering fiber. In November 2012 there are no markets with the same structure suggesting exit in the sample. The variation in market structure shown here is essential in identifying the effect of competition from the number of firms on product characteristics and price[9]. The average number of firms in each market falls from 5.17 to 3.45 over the sample, and the average number of plans offered within each market also falls from 28.1 to 23.8. It is unclear whether this decline is due purely to exit from the market altogether or because of the sampling methodology of Telogical Systems. As the sample includes 29 major metropolitan areas there are no markets in the sample with only one firm, this means that there is a minimum level of competition in every market. There are no firms that offer only fiber plans, meaning that some firms like Frontier and Verizon offer either DSL or Cable and Fiber plans and consumers have technology choices, but not from

[9]With a relatively small number of firms there is potential for implicit collusion allowing for mark-ups to exist. Wallsten and Mallahan (2010) find that advertised speeds are higher and advertised prices are lower in markets with two or three firms compared to those with only one firm suggesting that these competitive effects do exist. Xiao and Orazem (2011) however find evidence that markets with more than three broadband firms do not exhibit a greater amount of competition than those with only three firms

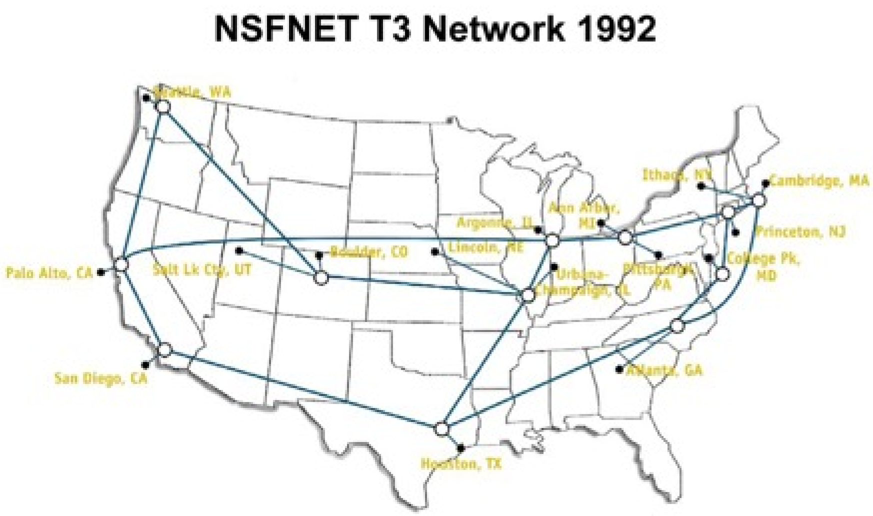
a distinct firm.

Table 3: Market Structure by Number of Firms and Technology

	January 2010									
no. of firms	No Fiber Firms					One Fiber Firm				
DSL\Cable	0	1	2	3	4	0	1	2	3	4
0										
1				1						
2		5	1	1			1	2	1	
3			3	2			1	2		1
4		1		1	2				1	1
5			1	1						
	November 2012									
no. of firms	No Fiber Firms					One Fiber Firm				
DSL\Cable	0	1	2	3	4	0	1	2	3	4
0			3							
1		4	2				1			
2	1	2	2	1			1	2	1	
3	1	2	2	1		1		1		
4								1		
5										

In order to identify the λ term in equation (3) I need additional variation from a variable that is correlated with offered speeds, but uncorrelated with price. I include the distance of market m from the nearest internet backbone node from the NSFNET T3 Network in 1992. The T3 network is the original infrastructure that connected a variety of academic research sites working to create the modern internet. The transition of control of the NSFNET backbone to private industry occurred in 1995, but the original network was maintained and built upon into the modern network. Individual firms invest in redundant backbone infrastructure that is available to use by other internet providers either for free or through a formal contract. The variable $distancefromnode$ is included in the first-stage estimation as a proxy for fixed costs where a greater distance to a node is reflective of higher fixed costs a firm would pay in building the physical infrastructure needed to provide different speeds.

I calculate distance from the nearest internet backbone connection documented in 1992 to each market in the sample and include this distance for each observation. Unfortunately, this variable does not change over time and is the same for all firms in a market so the additional variation only helps to identify differences in fixed costs between markets. The inclusion of this variable is still useful if building private networks occurs regionally and different ISPs choose to provide different speeds to markets based on initial infrastructure spending. The map below shows the initial backbone connections in 1992 directly before the conversion of the backbone to private ownership. The following table shows the distance in kilometers from each market in the sample to the closest backbone access point. Atlanta, San Diego, and Seattle all have a distance of zero as the access point was in those cities.



Distance From City in Sample to Nearest NSFNET T3 Node City

Market	Nearest Node	Distance (km)
Atlanta, GA	Atlanta, GA	0.00
Baltimore, MD	College Park, MD	43.66
Boston, MA	Cambridge, MA	4.44
Buffalo, NY	Ithaca, NY	200.44
Charlotte, NC	Atlanta, GA	364.06
Chicago, IL	Argonne,IL	34.44
Cincinnati, OH	Urbana-Champaign, IL	335.77
Cleveland, OH	Pittsburgh, PA	184.91
Dallas, TX	Houston, TX	361.77
Denver, CO	Boulder,CO	38.89
Detroit, MI	Ann Arbor, MI	57.62
GreenBay, WI	Argonne,IL	311.97
KansasCity, KS	Lincoln,NE	258.78
LosAngeles, CA	San Diego, CA	179.41
Miami, FL	Atlanta, GA	975.88
Minneapolis, MN	Lincoln,NE	539.10
NewOrleans, LA	Houston, TX	511.35
NewYork, NY	Princton, NJ	68.45
OklahomaCity, OK	Lincoln,NE	600.21
Philadelphia, PA	Princton, NJ	61.78
Phoenix, AZ	San Diego, CA	480.85
Portland, ME	Cambridge, MA	159.16
Raleigh, NC	College Park, MD	387.25
SanAntonio, TX	Houston, TX	304.34
SanDiego, CA	San Diego, CA	0.00
Seattle, WA	Seattle, WA	0.00
Shreveport, LA	Houston, TX	343.89
St.Louis, MO	Urbana-Champaign, IL	237.77
Washington, DC	College Park, MD	12.55

5 Empirical Strategy and Results

The following section presents estimates from the first and second stage of estimation. A discussion of the results follows.

5.1 First-Stage Estimates

The first-stage estimates the probability of a broadband package being in one of six speed tiers, with an ordered probit model. The linear form of the latent profit function for speed is:

$$speedtier_j = \beta_1 ndsl + \beta_2 ncable + \beta_3 nfiber + \beta_4 bundle + \beta_5 dsl + \beta_6 fiber$$
$$+ \beta_7 log(sfirms) + \beta_8 log(pop.) + \beta_9 log(medianinc.) + \beta_{10} distancefromnode+$$
$$\beta_{11} quarterdummy + \beta_{12} firmdummy + \beta_{13} marketdummy + e \quad (6)$$

where ndsl, ncable, and nfiber are the number of firms offering a broadband package in the same speed tier as the observation with the DSL, cable, and fiber technologies respectively. The variable bundle is a dummy equal to one when the broadband package is part of a triple play package, and zero otherwise. The variables cable and fiber are dummies equal to one when the broadband package uses either of those particular technologies. A dummy for a plan using DSL is excluded to avoid collinearity in the estimation process. The log of the number of small firms, population and median income are demand shifters that may be determinants of demanded speed. Finally, the distance from the node variable is standardized to be mean zero with a standard deviation of one for computational ease[10]. In case there are time specific shocks I include a quarter-year dummy variable. To control for market power from any specific firm I include a firm dummy variable. Finally, to control for location specific variation, such as local regulation, I include a market dummy variable.

[10]Distances variables are often log transformed, but some values for distance in the sample are zero.

Table 4: Latent Profit Estimation

VARIABLES	Estimated Coefficient	Standard Error
no. of DSL providers	-1.288***	0.013
no. of cable providers	-0.396***	0.011
no. of fiber providers	0.649***	0.033
bundle dummy	-0.158***	0.02
cable dummy	0.372***	0.058
fiber dummy	0.797***	0.05
log(no. small firms)	0.423**	0.199
log(population)	3.562*	2.058
log(median income)	13.326***	0.91
distance to node	-45.175**	20.746
α1	243.347***	49.656
α2	244.213***	49.656
α3	246.437***	49.656
α4	247.271***	49.656
α5	248.341***	49.656
Observations	25,647	
log-pseudolikelihood	-22433.36	

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Time, market, and firm dummies are not presented here.

Table 4 shows the estimates of the latent profits of speed using maximum likelihood estimation of the ordered probit model in equation (6). Although the estimated coefficients cannot be interpreted directly the sign of coefficients suggests the direction in the probability of being in the lowest or highest speed tier. For instance having additional firms providing DSL or cable plans means a plan is more likely to have speeds less than 4 Mbps. On the other hand, the existence of firms offering fiber plans suggests a plan is more likely to have speeds greater than 100 Mbps. These estimates can be used to calculate the marginal effects of changes in the explanatory variables for each speed tier. For example when all other variables are held at their mean the marginal effect of another DSL firm is an increase in the probability of a plan having speeds less than 4 Mbps by 44%, compare to a decrease in the probability of 45% of having speeds between 10 Mbps and 25 Mbps when another DSL firm is present[11]. Although we may expect to see improvements in the characteristics of a good (such as higher speeds) with additional firms this is not always the case. Firms may choose to keep speed levels the same and instead compete in price (Dorfman & Steiner 1954). The estimates shown here suggest that additional DSL and cable firms are not associated with competition in speed, but an additional fiber firm does encourage greater competition in speed.

Other plan characteristics such as whether or not the plan is bundled with television and telephone, and the type of technology are statistically significant. The dummy bundle variable is negative suggesting that the plans offered as part of a triple-play bundle are more likely to have the slowest speed tier. This may be because consumers who buy a bundle are less interested in any particular characteristic, but instead enjoy the overall bundle of goods. The cable and fiber dummy variables are both significant and positive suggesting that when compared to the average DSL plan cable and fiber plans are more likely to be faster. This is likely due to the technological constraints and investments by DSL firms, limiting available speeds relative to other technology types.

Median income, population, and the number of small firms are statistically significant. Median income is associated with faster speeds perhaps because higher income consumers have higher demand for more bandwidth intensive activities such as streaming video and increased capacity to pay for nonessential internet applications. Population is positively correlated with internet speed likely due to an increase in consumers who want different speed tiers at every level. The number of small firms is similarly related to the highest speed tiers.

The instrument, distance from the closest internet background node, is non zero and significant at the 95% level suggesting that it is a relevant instrument in determining the level of speed in a broadband plan. The negative sign on the distance variable suggests

[11] All marginal effects are available by request from the author.

that markets farther from internet backbone nodes are more likely to have slower speeds. The magnitude of the distance variable appears large, however, because it is standardized to mean zero and standard deviation one the marginal effect is measured in a change in one standard deviation, the change of 209 miles in distance from a backbone node[12].

5.2 Second-Stage Estimates

Second stage estimates are obtained by estimating the following equation using OLS:

$$\begin{aligned} log(price_i) = \beta_1 Speed_{4-10} + \beta_2 Speed_{10-25} + \beta_3 Speed_{25-50} + \beta_4 Speed_{50-100} + \\ \beta_5 Speed_{>100} + \beta_6 ndsl + \beta_7 ncable + \beta_8 nfiber + \beta_9 bundle + \beta_{10} dsl + \beta_{11} fiber + \beta_{12} log(sfirms) + \\ \beta_{13} log(pop.) + \beta_{14} log(medianinc.) + \beta_{15} quarterdummy + \beta_{16} firmdummy + \\ \beta_{17} marketdummy + \sigma_{eu}\lambda + v_i \end{aligned} \quad (7)$$

With the inclusion of the correction term $\sigma_{eu}\lambda$ OLS estimates should be unbiased and consistent. If σ_{eu} is zero or insignificant then the inclusion of the correction term is unnecessary for unbiased and consistent estimates. The variables of interest are the speed variables which are indicator variables equal to 1 when plan i is in that speed tier and 0 otherwise. The coefficient for each speed dummy are interpreted as the average willingness to pay above a broadband plan with less than 4 Mbps download speed[13].

[12]the magnitude of the estimated distance variable is sensitive to the chosen omitted market dummy. However, the effect remains consistent when comparing the sign of the effects that markets farther from the node are more likely to have slower speeds.

[13]The change from 0 to 1 of a dummy variable is not the same as a marginal increase in a continuous variable and must be transformed using the formula $\%Change = 100(e^{\beta} - 1)$ before it is interpreted.

Table 5: Price Regression

VARIABLES	Corrected		WTP($)	Uncorrected		WTP($)
	coef.	se		coef.	se	
4-10 Mbps	0.318***	0.013	12.58	0.269***	0.004	10.37
10-25 Mbps	0.533***	0.022	23.66	0.446***	0.004	18.88
25-50 Mbps	0.883***	0.032	47.65	0.755***	0.009	37.89
50-100 Mbps	1.127***	0.039	70.10	1.12***	0.009	69.38
>100 Mbps	1.8***	0.055	169.67	1.6***	0.016	132.82
no. of DSL providers	0.034***	0.009		0.0001	0.002	
no. of cable providers	0.002	0.004		-0.008***	0.002	
no. of fiber providers	-0.049***	0.007		-0.032***	0.006	
bundle dummy	1.133***	0.005	70.73	1.13***	0.004	70.41
cable dummy	0.151***	0.01	5.48	0.161***	0.009	5.87
fiber dummy	0.235***	0.012	8.90	0.255***	0.011	9.76
log(no. small firms)	-0.093***	0.036		-0.083***	0.036	
log(population)	0.422	0.33		0.507	0.348	
log(median income)	-0.467**	0.185		-0.1	0.156	
lambda	-0.03***	0.007				
Constant	3.057	5.838		-1.965	5.39	
Observations	25,647			25,647		
R-squared	0.8517			0.8516		

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Time, market, and firm dummies are not presented.

Table 5 shows the estimated coefficients for the price regression estimated using OLS. The corrected specification includes the λ term to control for endogeneity from the firm's choice in choosing plan characteristics[14]. Willingness to pay estimates are dollar amounts consumers would pay to reach a speed tier over the average price of an unbundled plan with a download speed of less than 4 Mbps, \$33.59[15]. The cutoffs, αs, are all statistically significant suggesting that the speed tiers chosen are distinct from one another.

The correction term is statistically significant at the 99% level which suggests that the choice of plan characteristics is correlated with market prices and excluding this term biases

[14]Standard errors in the corrected specification are bootstrapped with 100 replications. The second stage of this estimation procedure uses estimates of values from the first-stage introducing a new source of variation. Bootstrapping the second stage standard errors helps to correct for the issues from using estimated variables (Petrin and Train 2010). I also ran the bootstrap program with 1000 replications and beginning at different seeds with similar bootstrapped standard errors.

[15]These estimates are calculated as change in WTP = $(e^{\beta} - 1)\$33.59$.

estimates on willingness to pay. The negative sign on λ suggests that the omitted variable from the pricing equation is correlated with both the choice of internet speeds offered and market prices. Firms often compete in both price and quality such that either actual competition or the threat of competition will cause firms to increase the quality of a good or to decrease price. In the broadband market increasing quality can include providing higher speed plans and plans with more characteristics such as more television channels in a triple-play bundle. Product quality is positively correlated with competition in that we would expect to see greater quality and variety in markets with greater competition. Firms may also be constrained in how much they can vary quality, perhaps due to fixed costs needed to deploy new fiber lines, or because they are constrained in the physical limits of the technology they use such as DSL. In those cases we may expect to see more price competition where additional competition is correlated with decreases in price. Ignoring the effects of competition in a naive estimation would then provide estimates of consumer willingness to pay for increased speed that are downward biased. Comparisons of the r-squared in both the corrected and uncorrected specification suggests that including the correction term does not explain much additional unknown variation than the naive regression.

The estimate for the corrected specification for speeds from 4-10 Mbps is interpreted as a 37% increase in willingness to pay over a slow speed plan or \$12.58 more than the average plan offering speeds less than 4 Mbps. Consumers are willing to pay an additional 70% more for plans with speeds of 10 - 25 Mbps or \$23.66 more than the slow speed plan. OLS estimates are consistently lower than those from the corrected specification; for example consumer's willingness to pay for speeds from 4-10 Mbps are only \$18.88 above the price of a slow plan. Policy discussions and cost-benefit analysis that use the naive OLS estimates understate the the benefits consumer's have from higher broadband speeds.

The number of firms offering plans in the same speed tier has varying effects depending on the type of technologies the firms use. The number of DSL providers has a positive effect on price in the corrected specification suggesting that there is either a collusion effect where firms are willing to keep prices high and split consumers among themselves, or that many firms using DSL are wireline telephone providers and are able to leverage that access to consumers to keep prices high. The coefficient on the number of cable providers is similarly positive for the corrected specification, but the estimate is statistically insignificant. The number of fiber providers is statistically significant and correlated with lower prices which follows from standard economic theory that increased competition is associated with lower prices. Consumers at this time were only beginning to have access to fiber plans. Within the sample only ten markets had any fiber plans and only 5.9% of the plans in the sample overall are fiber technology. The faster speeds and decreased latency possible from fiber connections are clearer upgrade to the more homogeneous experiences offered by new DSL and cable firms. OLS estimates for the number of cable and fiber firms are significant at the 95% level and negative suggesting the traditional economic story, although the coefficient of the number of DSL firms is positive and insignificant. The difference in these estimates suggests naive estimates overstate the competitive value in additional firms that use cable and DSL technology.

The results in table 4 and table 5 suggest that on average adding an additional cable or DSL firm does not encourage either faster speeds or lower prices creating a puzzle for regulators wanting to encourage greater competition in broadband markets. The upside for regulators is that additional fiber firms do encourage the sort of competition that would lead to additional benefits to consumers and resources spent on additional fiber technology would have greater benefits than those supporting new DSL and cable entrants.

The bundle dummy is significant suggesting that consumers are willing to pay around $70 more for bundled wireline telephone and television services. Consumers are also willing to pay more for both plans using cable ($5.48) and fiber ($8.90) technologies relative to a slow DSL plan, likely due to those technologies being able to provide higher speeds and lower latency.

Table 6: Willingness to Pay Estimates per Additional Mbps

	Corrected	Uncorrected
4-10 Mbps	$2.10	$1.73
10-25 Mbps	$1.58	$1.26
25-50 Mbps	$1.91	$1.52
50-100 Mbps	$1.40	$1.39
>100 Mbps	$0.85	$0.66

Table 6 shows the willingness to pay for an additional Mbps of speed within each speed tier. The estimates here are similar to related valuations found in Nevo, Turner and Williams (2016) which find an average willingness to pay for an increase of one Mbps is $2, and in Liu, Prince and Wallsten (2017) which find willingness to pay starting at $2.34 per Mbps and declining after. Those studies use high-frequency user data and consumer surveys respectively to calculate their estimates. While those approaches have great strengths the similarity in the estimates suggests that market data is a complementary approach when more detailed data is difficult to attain. The per Mbps estimates in table 6 demonstrate that consumers have nonlinear valuations of internet speed and further research and policy should consider this issue in determining the potential benefits of policy. For instance by redefining broadband as plans with speeds greater than 25 Mbps the FCC has set a minimum level of benefits they expect from a consumer broadband plan. Specifically, a broadband plan is associated with a willingness to pay of $81.24 from the estimates in table 5. Increasing the definition of broadband to higher speeds is associated with lower benefits for each additional Mbps suggesting that further policy should carefully consider what level of speed is necessary for common internet applications and which are valuable to a subset of consumers.

An interesting result in table 6 is that the willingness to pay estimates do not appear to demonstrate purely decreasing marginal returns as expected from both economic theory and as found in other studies (Nevo et al 2016). There are two possible explanations for this phenomenon. The first is that broadband is an experiential good where consumers value greater speeds, and the activities those speeds allow, but only after they have experience with those speeds. For example Dutz et al. (2009) find that when comparing consumers with access to broadband and consumers with dial-up connections those with broadband connections have a higher stated willingness to pay for a broadband connection. The second explanation is that decreasing or constant marginal returns exist but consumer's experience large increases at discrete intervals. Over the interval 4 - 25 Mbps consumers have decreasing marginal returns in that they value initial increases to speed more than later ones. This range of speed is sufficient for web browsing, streaming high-definition video, and playing online games. At speeds greater than 25 Mbps consumers are able to use more devices running more applications with fewer noticeable declines in performance. These consumers have a higher willingness to pay for these speeds as additional speed is associated with either an increase in the number of devices and applications they can use at once or there is a noticeable decrease in the time it takes for them to do certain online activities. Tiers starting with 50 Mbps and greater also exhibit decreasing returns to scale in that an additional Mbps is less valuable than previous ones. These two explanations are not inconsistent with each other. In fact it appears that consumers who have experience with internet speeds above 25 Mbps have a greater value for broadband speeds than those who purchase slower plans and the question of valuation must be examined more to determine the relationship of minimum speeds necessary for particular applicationss and experience with various speed tiers with consumer valuation.

6 Robustness

6.1 Additional Fixed Cost Measures

A concern with the control-function specification is the identification of the λ term in equation (5) which requires additional regressors in the first-stage of estimation that satisfy the exclusion restriction. The model of characteristic choice outlined above suggests that variables associated with the fixed costs necessary to provide higher speeds are relevant to the choice of characteristic, but do not have an effect on market prices after controlling for endogeneity. The distance from the node variable included in the results above is statistically significant, however, it does not vary within a market meaning that multiple firms have the same distance from the node and variation in fixed cost comes only from comparing markets. As a check on the earlier estimates I estimate equations (6) and (7) again with two additional fixed cost measures: the number of houses a firm's physical infrastructure passes, and the population density of the area a firm provides access to[16]. The number of houses passed is a measure of infrastructure spending by firms where firms have to spend more on deploying physical cable, DSL, or fiber lines as the number of houses passed increases. However, for an area dense in population a firm spends less overall on infrastructure due to needing less physical amounts of the lines and can provide plans to more people.

Table 7: Summary Statistics - Fixed Cost Measures

	Mean	Std. Dev.	Min	Max
houses passed	1271655	1395758	2	7661848
pop. density	1600	2899	26	28312
N	22329			

I use data collected by the U.S. National Telecommunications & Information Administration as part of their National Broadband Map which records these measures beginning

[16]Measured by the number of people in a square mile

in December, 2012. While housing units passed and population density do not vary over time within the sample they provide additional variation within markets that help identify characteristic choice based on individual firm's fixed costs. Table 7 shows summary statistics for houses passed and population density, the number of observations is less than the full sample because not every firm was represented in each market in the FCC data. Both variables are logged before their inclusion in the latent profit estimation.

Table 8: Latent Profit Estimation

VARIABLES	Estimated Coefficient	Standard Error
no. of DSL providers	-1.287***	0.013
no. of cable providers	-0.355***	0.012
no. of fiber providers	0.626***	0.034
bundle dummy	-0.162***	0.02
cable dummy	0.205***	0.07
fiber dummy	0.791***	0.05
log(no. small firms)	0.681**	0.2
log(population)	4.344**	2.19
log(median income)	12.1***	0.943
distance to node	-50.79**	22.05
log(houses passed)	-0.035***	0.011
log(pop. density)	0.098***	0.021
α1	249.3***	52.83
α2	250.1***	52.83
α3	252.4***	52.83
α4	253.2***	52.83
α5	254.3***	52.83
Observations	22,329	
log-pseudolikelihood	-19846.586	

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Time, market, and firm dummies are not presented here.

Table 8 presents the estimates of the latent profit function for speed including the fixed cost variables houses passed and population density. The point estimates for the previously included variables are similar to the estimates in table 4. The estimated coefficient for housing units passed is statistically significant at the 99% level and negative which follows from theory; higher fixed costs discourage quality improvements and in this case the probability of being in the lowest speed tier is higher. The estimate for population density is statistically significant and positive suggesting that when fixed costs are low and less materials are used to build infrastructure firms are more likely to provide the highest speed tier. The magnitudes of the estimates for the new fixed cost measures are considerably smaller than the already included market and plan characteristics suggesting that while they may be statistically significant the economic effect may be small.

Table 9: Price Regression

VARIABLES	Corrected		WTP($)	Uncorrected		WTP($)
	coef.	se		coef.	se	
4-10 Mbps	0.318***	0.013	12.58	0.293***	0.004	11.44
10-25 Mbps	0.487***	0.021	21.08	0.442***	0.005	18.68
25-50 Mbps	0.810***	0.032	41.93	0.743***	0.009	37.04
50-100 Mbps	1.198***	0.039	77.73	1.117***	0.009	69.07
>100 Mbps	1.7***	0.049	150.32	1.596***	0.016	132.16
no. of DSL providers	0.017*	0.009		-0.001	0.002	
no. of cable providers	-0.007*	0.004		-0.012***	0.002	
no. of fiber providers	-0.044***	0.007		-0.036***	0.006	
bundle dummy	1.131***	0.005	70.52	1.129***	0.004	70.31
cable dummy	0.151***	0.01	5.48	0.156***	0.009	5.67
fiber dummy	0.256***	0.012	9.80	0.266***	0.011	10.24
log(no. small firms)	-0.117***	0.036		-0.108***	0.039	
log(population)	0.636	0.33		0.694*	0.384	
log(median income)	-0.147	0.185		0.026	0.165	
lambda	-0.016**	0.007				
Constant	-3.057	6.22		-5.887	5.917	
Observations	22,329			22,329		
R-squared	0.854			0.854		

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Time, market, and firm dummies are not presented.

Table 10: Willingness to Pay Estimates per Additional Mbps

	Corrected		Uncorrected	
	(a)	(b)	(a)	(b)
4-10 Mbps	$2.10	$2.10	$1.73	$1.91
10-25 Mbps	$1.58	$1.41	$1.26	$1.25
25-50 Mbps	$1.91	$1.68	$1.52	$1.48
50-100 Mbps	$1.40	$1.55	$1.39	$1.38
>100 Mbps	$0.85	$0.75	$0.66	$0.66

Most estimates from the price regression shown in table 9 are similar to those in table 5. In the corrected specification the coefficient on the number of cable providers is now significant and associated with a small decrease in price with each additional firm. The estimated coefficient of λ is statistically significant at the 95% level and has a smaller magnitude than the previous estimate with only one additional variable in the first-stage of estimation. Table 10 shows the willingness to pay per Mbps found using the estimates in table 9, specification (b), alongside the estimates from the earlier specification (a). The difference in the uncorrected estimates is due to the change in the sample and all but one estimate is within four cents of the original estimate. The estimates from the specification with three fixed cost measures are smaller than those with only one which is to be expected as the λ term suggests there is less concern of endogeneity when the latent profit function includes more variables excluded from the price regression.

7 Conclusion

This paper has investigated consumer willingness to pay for additional speed in broadband internet plans. The estimates found here contribute to our understanding of consumer valuation of the internet, and are useful in ongoing policy analysis and firm decision making. Specifically, I find that consumer's valuations of download speed increase as speeds increase, although consumers are willing to pay less for each additional Mbps. The empirical strategy used here provides a straight forward measure of endogeneity in market data such as unseen entry and exit or unobserved quality changes without requiring knowledge of what specific issues exist. The control function approach includes an additional variable constructed from a first-stage game where firm's choose the level of a product characteristic. Estimates from the corrected specification are around 25% greater at every speed tier than OLS estimates and the included correction term is statistically significant suggesting that OLS understates valuations of increased internet speed.

In 2010, the beginning of the sampled data included in this study, the FCC redefined broadband as plans with download speeds greater 4 Mbps, and then again in 2015 as plans with download speeds greater than 25 Mbps. The estimate presented here suggest consumers are willing to pay \$12.58 more for broadband plans under the 2010 definition and \$47.56 more for plans under the 2015 definition compared to download speeds under 4 Mbps. Uncorrected OLS estimates are lower (\$10.37 and \$37.89 respectively)and may be useful as a lower bound when measures of fixed costs are unavailable or do not provide much additional variation in the first stage of estimation. Adding additional fixed cost measures found estimates closer to the naive estimates suggesting that with sufficient variation in the number of markets, the number of firms and observations over time than OLS estimates are useful lower bounds of willingness to pay. Finally, The similarity of the estimates found here to recent studies using high frequency user data and survey data is encouraging evidence that market data is a valuable source of information to researchers and policy makers when more detailed data is unavailable.

There is continued interest in this topic as policy makers grapple with issues such as net-neutrality, local government's provision of internet services, and ongoing policy related to spectrum auctions and the consolidation of ISPs. Future research will expand on the work already done measuring willingness to pay for other broadband plan characteristics such as customer service, rental of firm owned modems and similar proprietary technologies. The results of this study suggest increased fiber deployment encourages the type of competition that increases quality and lowers prices. Further research can investigate the optimal policy instruments to spur new deployment and the distribution of benefits from existing subsidy programs.

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