Local Competition, Multimarket Contact, and Product Quality: Evidence From Internet Service Provision

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Abstract

I investigate the effect of competition on quality, examining both local competition within markets and repeated interaction among firms across markets. The internet service provision industry provides an ideal setting because its quality is objective and measurable. Moreover, in the United States, this industry is dominated by a small set of firms who overlap in many markets but who rarely price discriminate across markets. This provides a setting for multimarket contact to occur and to be channeled through the quality dimension.

I develop a stylized model of within-market competition, in which internet service providers strategically choose download speeds, and I use this model to predict the effect of competition on firms' choice of speed. I then use data from speedtest.net from 2010 to 2014 to test these predictions. I estimate a model of the effects of within-market competition and multimarket contact on realized consumer download speeds, instrumenting for local competition using firms' presence in nearby markets. I find that increased multimarket contact leads to decreased download speeds, consistent with the mutual forbearance hypothesis. I also find that competitive markets are associated with faster speeds than monopolies, but that the effect of increased local competition is not monotonic, which is consistent with the predictions of my theoretical model.

JEL-Classification: L13, L15, L96

Keywords: multimarket contact, telecommunications, internet, broadband, product quality

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1 Introduction

"Competition is good in these local markets, and as providers have to compete, they lower their rates on traditional Internet speed and also improve their service offerings," (New York Times, 2014) Julian Castro, former mayor of San Antonio. Castro's statement came on the heels of Google's announcement identifying San Antonio as one as one of nine potential sites for its gigabit fiber network, and his statement reflects a sentiment expressed by many: when firms face greater competition, they will respond by offering lower prices and better quality products. While countless studies have analyzed the effects of competition on price, its effects on product quality are far less well-understood. This paper aims to investigate the effects of competition on quality, focusing on firm interactions both within and across markets.

In particular, I focus on the provision of internet access. In a recent resolution, the United Nations (2012) formally recognized the global and open nature of the internet as a driving force behind development, and encouraged nations to promote and facilitate access to the internet. According to the United States Census Bureau (2012), 74.8% of all households in the United States have internet access at home, evidence that the Internet is an important tool used by the majority of the U.S. population. However, in addition to simply having access to the internet, sufficient speed is necessary in order to take full advantage of its capabilities. The United States lags behind other countries in this area, ranked 34th in the world in internet download speed according to Ookla's speedtest.net (2014). Understanding the determinants of the speeds offered by internet service providers is therefore of great importance. Therefore, in this paper, I analyze the effect of competition among internet service providers (ISPs) on the download speeds they offer.

In this industry, competition takes place at both the local and national levels. At the local level, when ISPs make quality decisions, they must account for the other options available to consumers within the market. To analyze this, I develop a stylized model of intra-market competition, allowing firms within a market to choose the price and speed that maximize their profits, given the choices of their competitors. I use this model to investigate how firms' optimal choice of speed varies with the number of local competitors, and find a non-monotonic effect of local competition on internet speed. I then estimate a reduced-form model which allows the effect of competition to vary with the number of providers in the market, using fixed effects to control for unobserved heterogeneity in ISPs, markets, and time, and find that the prediction of my theoretical model is supported by the data. Given the endogenous formation of market structure, I instrument for local competition using the number of ISPs present in a nearby city. ISPs typically locate in many cities within a region, making the number of ISPs in a nearby city a good predictor of the number of ISPs in a given market. At the same time, unobserved shocks that affect one city are not likely to affect other cities that are far enough away. After instrumenting, my results are qualitatively similar to my OLS estimates, while the estimated effects increase in magnitude.

At the national level, many ISPs repeatedly interact across markets. The mutual forbearance hypothesis contends that when firms compete against one another in multiple markets, they "may hesitate to fight local wars vigorously because the prospects of local gain are not worth the risk of general warfare. (Edwards, as quoted in Scherer 1980)". Bernheim and Whinston (1990) formalize this intuition and develop a framework in which they show that when considering a market in isolation, cooperation between firms may not be possible, as a firm may stand to gain from deviating and competing more aggressively by lowering its price; but, if these firms interact in many markets, rivals can punish a firm for deviating by lowering prices in all markets in which they jointly compete, thereby pooling the incentive constraints across markets. This argument translates naturally to the quality dimension of competition: if firms face the threat of punishment in many of their markets nationwide, they may be less likely to compete aggressively by increasing the speeds they offer.

The literature on the effects of competition on product quality is relatively sparse, largely because product quality is often difficult to define and measure. For most products, quality is multi-dimensional, as consumers value many aspects of a product; and, these valuations often vary across consumers, with no clear objective measure of quality. Mazzeo (2003) estimates the impact of competition on airlines' on-time performance, showing that increased competition is correlated with fewer delays. In a related work, Matsa (2011) analyzes the effect of competition on the quality of the retail experience provided by supermarkets, using product availability as a proxy measure. The internet service industry is ideal for a study of product quality, as quality is approximately one-dimensional: consumers care about the download speed they receive above all else. As evidence of this, virtually all major ISPs in the United States advertise their plans using only their price and download speed. Moreover, the actual speeds that consumers enjoy are observable and measurable. Local competition in this market has been studied recently by Wallsten and Mallahan (2013) and Molnar and Savage (2017), who indeed find that speeds are faster in more competitive markets. This paper complements these works by disentangling the local competition effect from the national multimarket contact effect.

The existing literature on the effect of multimarket contact has primarily focused on firms' pricing decisions. Evans and Kessides (1994) provide some of the first empirical evidence in support of the existence of the mutual forbearance hypothesis. They find that airlines that experience high levels of multimarket contact follow the "golden rule." That is, they do not initiate aggressive pricing actions on a given route for fear of facing backlash from competitors on other jointly contested routes. Ciliberto and Williams (2014) confirm this finding in the airline industry, and go further to show that the effect of multimarket contact depends on the cross-price elasticities between airlines. Jans and Rosenbaum (1996) find that multimarket contact increases prices in the U.S. cement industry; Parker and Roller (1997) and Fernandez and Marin (1998) find similar results in the mobile phone and hotel industries. Prince and Simon (2009) offer what is, to my knowledge, the only study which analyzes the effect of multimarket contact on product quality, again within the context of the airline industry. They show that higher contact is associated with increased delays. In this paper, I build upon this result, documenting evidence of the effects of multimarket contact on product quality in the broadband industry. This industry is ideal for analysis of this phenomenon, as it is dominated by a small set of firms who overlap in many markets, but who rarely price discriminate across markets, thus providing a setting for multimarket contact to occur and for its effects to be channeled through the quality dimension. Moreover, due to the regional nature of ISPs' territories and the existence of smaller local providers, there is significant variation in the degree of multimarket contact both across markets, and across firms within markets. In the empirical analysis, I find that higher levels of multimarket contact are associated with lower speeds offered.

The remainder of the paper proceeds as follows. Section two develops a simple model of within-market competition among internet service providers, which is used to make predictions about how ISPs will respond to changes in competition. Section three describes the data used in the empirical analysis. Section four develops the empirical model of within-market competition and multimarket contact, and details the construction of an instrumental variable. Section five describes the results of estimation, and section six concludes.

2 A Simple Model of Within-market Competition

In this section, I develop a simple model in which internet service providers compete in differentiated products competition. The model is highly stylized, assuming a particular functional form for consumer demand, but it captures the essential elements of demand for internet service. I use this model to generate predictions about how firms will respond to increased competition within a market, and use these predictions to motivate the empirical analysis that follows.

I consider a model in which market demand for an ISP's service depends on its own choices of price and speed, as well as the choices of its competitors. Specifically, I assume that a firm's market demand takes the following form:

$$q_i = d(p_i, p_{-i}, s_i, s_{-i}) = \alpha - \beta \frac{p_i}{s_i} + \sum_{j \neq i} \gamma \frac{p_j}{s_j} \tag{1}$$

where $\beta > \gamma > 0$. ISPs choose to offer a price, p_i, and a speed, s_i, that (along with competitors' actions) determine the number of customers who will purchase internet service from provider i. $\beta > \gamma$ says that a change in an ISP's own price or speed will affect its demand more than an equal change in one of its competitor's price or speed. This functional form assumes that, in aggregate, consumers value dollars spent per megabit-per-second (Mbps). This is likely a good approximation to market demand, as there are a number of indexes that track this figure, including one compiled by the OECD. The implications of this modeling choice are that consumers are willing to spend more money to receive faster speeds, and that the number of customers willing to purchase service from provider i does not change when its price and speed increase at the same rate.

I assume that each firm faces a constant marginal cost of providing internet service, which I then normalize to zero. In addition, I assume that each ISP must pay a fixed cost, F_i, which depends on its choice of s_i, so that $F_i = f(s_i)$, where $f(\cdot)$ is increasing and strictly convex.

Finally, the ISP chooses a price-speed pair, (p_i, s_i), to maximize its profits:

$$\pi_i = p_i(\alpha - \beta\frac{p_i}{s_i} + \sum_{j\neq i}\gamma\frac{p_j}{s_j}) - f(s_i) \tag{2}$$

The first order necessary conditions are:

$$\frac{\partial \pi_i}{\partial p_i} = \alpha - 2\beta\frac{p_i}{s_i} + \gamma\sum_{j\neq i}\frac{p_j}{s_j} = 0 \tag{3}$$

$$\frac{\partial \pi_i}{\partial s_i} = \beta(\frac{p_i}{s_i})^2 - f'(s_i) = 0 \tag{4}$$

For simplicity, in what follows, I focus on the symmetric Nash equilibrium. Since each ISP chooses its price and speed from an analogous set of first order conditions, I have that $p_i = p\ \forall i$ and $s_i = s\ \forall i$.

Combining the two first order conditions yields:

$$f'(s) = \frac{\alpha^2\beta}{[2\beta - \gamma(n-1)]^2} \tag{5}$$

Applying the implicit function theorem, I can write:

$$\frac{\partial s(n)}{\partial n} = \frac{2\alpha^2\beta\gamma}{f''(s)[2\beta - \gamma(n-1)]^3} \tag{6}$$

This simple comparative static provides some information about how ISPs should optimally respond to the number of competitors in a market.

Proposition 1. *If $n = 1$, then $\frac{\partial s(n)}{\partial n} > 0$*

Proof. Suppose that $n = 1$.
Then $\frac{\partial s(n)}{\partial n} = \frac{\alpha^2\beta\gamma}{f''(s)[2\beta]^3} > 0$, since $\beta > 0, \gamma > 0, f''(s) > 0$. □

Note that the proof of Proposition 1 does not rely on the assumption that $\beta > \gamma$, only that $\beta > 0$ and $\gamma > 0$. Proposition 1 shows that a monopolist's optimal response to an increase in its number of competitors is to increase the speed it offers.

Proposition 2. *If $n = 2$ or $n = 3$, then $\frac{\partial s(n)}{\partial n} > 0$*

Proof. Suppose that $n = 2$.
Then $\frac{\partial s(n)}{\partial n} = \frac{\alpha^2\beta\gamma}{f''(s)[2\beta-\gamma]^3} > 0$, since $\beta > 0$, $\gamma > 0$, $f''(s) > 0$, and $\beta > \gamma$, which implies that $2\beta - \gamma > 0$.
Suppose that $n = 3$.
Then $\frac{\partial s(n)}{\partial n} = \frac{\alpha^2\beta\gamma}{f''(s)[2\beta-2\gamma]^3} > 0$, since $\beta > 0$, $\gamma > 0$, $f''(s) > 0$, and $\beta > \gamma$. □

Proposition 2 shows that when there are three or fewer firms in a market, firms' optimal response to an increase in local competition is to increase the speeds they offer, under the assumption that a change in a firm's own price or speed will affect its demand more than an equal change in the price or speed of one of its competitors.

Proposition 3. *$\exists \hat{n}$ such that $\forall n > \hat{n}$, $\frac{\partial s(n)}{\partial n} < 0$.*

Proof. Since $\beta > 0$, $\gamma > 0$ and $f''(s) > 0$, we know that
$\frac{\partial s(n)}{\partial n} < 0 \iff 2\beta - \gamma(n-1) < 0 \iff \frac{2\beta+\gamma}{\gamma} < n$

Now, let $\hat{n} = \frac{2\beta+\gamma}{\gamma}$

Then $\forall n > \hat{n}$, $2\beta - \gamma(n-1) < 2\beta - \gamma(\hat{n}-1) < 0$,

which implies that $\frac{\partial s(n)}{\partial n} < 0 \ \forall n > \hat{n}$ □

Proposition 3 shows that when the number of firms in a market is sufficiently large, ISPs' optimal response to an increase in competition is to offer lower speeds.

The intuition underlying these results is that there are two countervailing effects of increased competition. The first is that customers are attracted to higher quality. Therefore, when more firms are present in the market, any individual firm has an incentive to further increase its own quality in order to attract more customers. However, the second effect is that when more firms are present, any individual firm must settle for a smaller fraction of the customer base. This makes the increased fixed cost of offering a higher quality more difficult to rationalize. When there are few firms in the market, the former effect dominates, while when there are many firms in the market, the latter effect dominates.

The predictions generated by this model are testable. I can observe in the data when increased local competition is associated with increases in speeds, and when it is not. In the empirical analysis that follows, I will evaluate the predictions of this theoretical model to see how well they align with reality.

3 Data

The primary source of data for this research is the Net Index source data, provided by Ookla. Ookla owns and operates speedtest.net, a website where users can check the internet speeds they are receiving by downloading and uploading a file to a nearby server. Ookla records these tests and makes the data available to the public. They provide the daily average download and upload speeds for each ISP in 958 U.S. cities from January 01, 2008 to the present, though the sample used in this paper contains data only through February 08, 2014. The unit of observation in this sample is an ISP within a market on a given day. I define a market to be at the city level. In this industry, a market is limited to the consumers that live or work within the geographic area served by an ISP. This facilitates the task of segmenting the country into mutually exclusive markets. City boundaries are an appropriate choice for this, since there are often substantial distances between cities. It is possible that firms may consider markets on an even finer scale than at the city level, but anecdotal evidence from advertisements and news reports suggests that ISPs typically roll out upgraded speed packages to their entire customer base within a city. The measure of quality that I use is download speed, measured in Mbps. The majority of typical internet usage relies on download speed (as opposed to upload speed), including accessing web pages and email, and streaming music and video. I then use the Net Index data to calculate the number of firms present in each market, and to calculate a measure of multimarket contact between ISPs in each market at any given time.

In addition, I pair this dataset with demographic data from the 2010 U.S. Census in order to compare the sample of cities in my data to the average U.S. city. Finally, I use geolocation data from MaxMind, a private company specializing in IP geolocation and advertisement targeting, to construct an instrument for within-market competition.

A consequence of utilizing user-contributed data is that its reliability depends on the number of users. Ookla boasts that they perform over 50 million tests every month. However, Speedtest.net has experienced rapid growth in usage over the years. This point is illustrated in figure 1. The number of tests conducted increases approximately linearly until May 2010. [1] Following this, the number of tests conducted increases at a slower rate and with increased variation. Given this pattern, it seems likely that prior to May 2010, speedtest.net experienced a learning period, where more and more people found out about the website. Therefore, I worry that in the early dates of the sample, when I observe the "entry" of an ISP in a market, it may simply be because users in that area were not conducting speed tests prior to that date. For this reason, in the analysis that follows, I restrict attention to dates between July 01, 2010 and February 08, 2014.

A critical feature of the data is that when ISPs make upgrades to their infrastructure

[1] The total number of tests conducted in May and June 2010 is dramatically lower than all surrounding points because the data was inexplicably missing observations from all cities except Seattle for half of May and all of June.

Figure 1: Total Tests Over Time

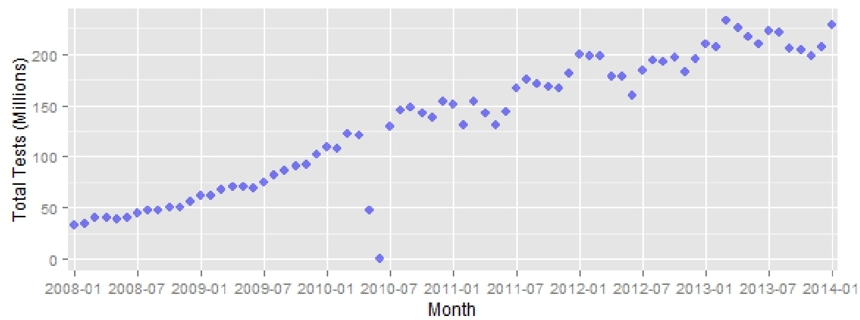
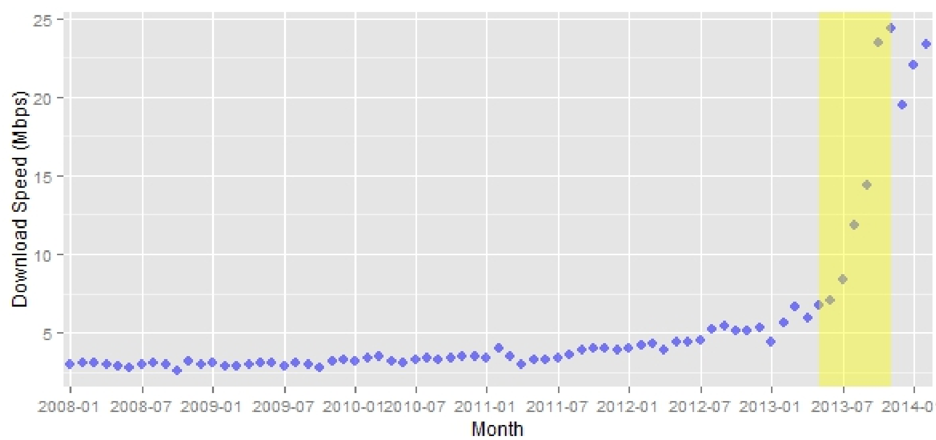


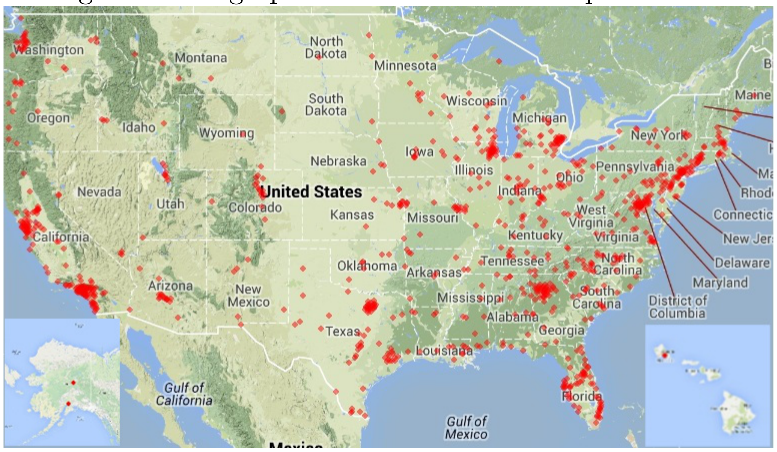
Figure 2: CenturyLink Investment in Omaha, NE



and thus change the speeds they offer, this is actually represented in the observed average speeds; it isn't somehow "lost in the noise". I will provide some simple evidence of this. A press release from CenturyLink dated October 09, 2013 states the following: "CenturyLink launched its first 1 Gbps fiber network in Omaha, Neb. in May 2013. The company expects to have the targeted homes and business (sic) in Omaha connected with its fiber-to-the premises (FTTP) technology by the end of October." Figure 2 illustrates the impact of this investment on average download speeds quite clearly. The plot shows the months prior to the upgrade (including time while CenturyLink was operating as Qwest Communications), and shows the months during the rollout of the fiber network in the shaded area. Note that between May and October 2013, average download speed for CenturyLink customers increased by 247%.

This observation highlights a potential shortcoming of this data. Despite the fact that

Figure 3: Geographic Distribution of Sample Markets



CenturyLink offers 1 Gbps [2] download speed, their average speed only reaches 23.46 Mbps. This is because not all customers choose to purchase this speed of service. In general, this data cannot distinguish between customers who purchase different tiers of service from an ISP. Only the average speed among all customers of an ISP is reported. For this reason, all results in this paper reflect changes in the average download speed among all customers, which may or may not be representative of the speed received by most consumers. With that said, any net improvement in the speed provided by an ISP will be reflected in their average speed.

3.1 Descriptive Statistics

This sample of cities represents the cities of the United States reasonably well. Figure 3 shows the geographic distribution of the cities in the sample. The sample is quite geographically diverse, containing cities located in 49 of the 50 states [3] and the District of Colombia.

In addition, table 1 compares the cities in the sample to the U.S. average for several key demographic characteristics. Since my sample contains cites with a large number of internet users, it is unsurprising that the average city in my sample has statistically significantly higher population, household income, education levels, and a lower percentage of seniors than the

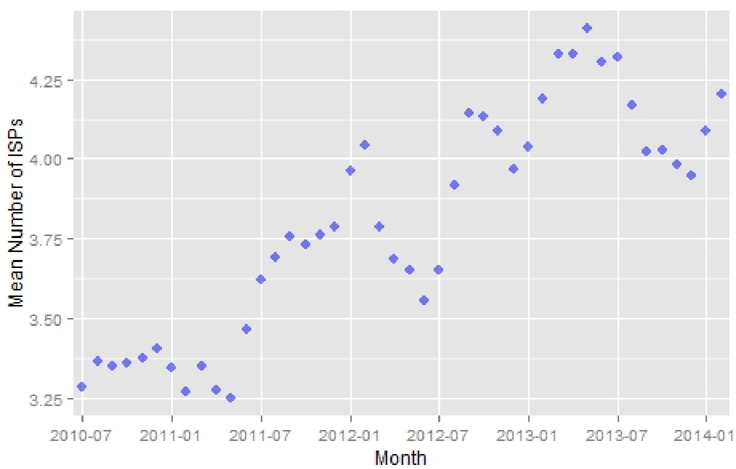
[2] 1 Gbps = 1000 Mbps
[3] There are no cities in Vermont in the data

Table 1: Mean Demographic Characteristics of Sample

	Sample	National Average	Difference in Means
Population	123,906.60	15,951.70	107,954.90
			(10,993.64)***
Household Income	57,064.51	53,046.00	4,018.51
			(698.72)***
High School	86.69	85.70	0.99
			(0.24)***
Bachelors	32.40	28.50	3.90
			(0.47)***
% Over Age 65	12.25	13.70	-1.45
			(.15)***

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

Figure 4: Number of ISPs in each Market over Time

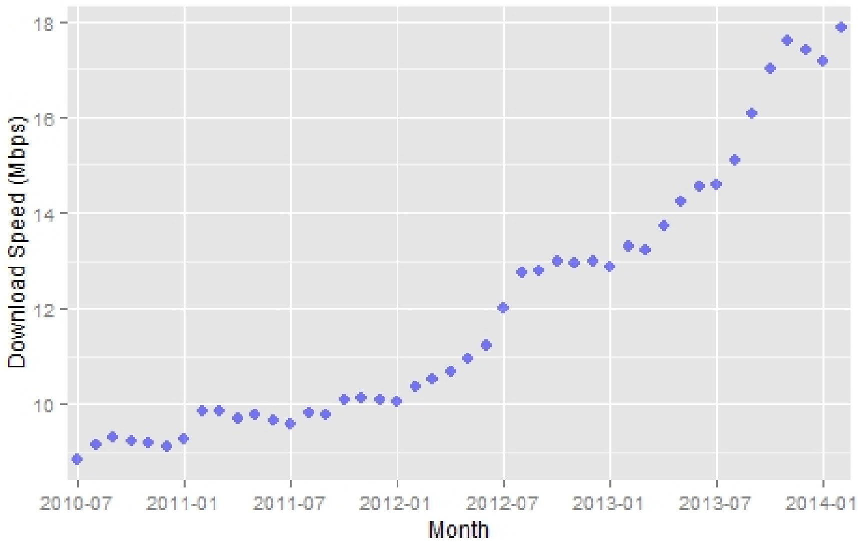


average U.S. city.

Over the time period represented in my sample, there is a systematic shift away from monopolies towards greater levels of competition within markets. This point is illustrated in figure 4, which shows the evolution of the average number of ISPs per market over time. At the start of 2010, the average market had about 3.3 providers, while by early 2014, the average had about 4.2 providers, a 28% increase.

While this systematic shift toward greater numbers of ISPs in markets was ongoing, there was also an overall upward trend in the download speeds offered by ISPs. Figure 5 plots the average download speeds recorded over time, aggregated across firms and markets. Average

Figure 5: Download Speed Over Time



download speed doubled from 8.8 Mbps in July 2010 to 17.9 Mbps in February 2014.

In the following empirical analysis, I aim to connect these changes in the number of ISPs operating within markets to changes in the average download speeds recorded. In doing so, I estimate the impact on average download speed of adding an additional ISP to a market.

3.2 Measures of Multimarket Contact

Considering only competition within markets, however, paints an incomplete picture of how firms make decisions. Internet service providers, especially large, national firms are unlikely to consider individual markets in isolation. Instead, when contemplating increasing the speed they offer in one market, they should consider the effect it would have on total nationwide profits, which requires them to think about how the competitors they face in this market will respond in other markets. Following the theoretical analysis of Bernheim and Whinston (1990), Evans and Kessides (1994) operationalize this idea, defining multimarket contact at the market level as follows:

$$AVGContact_m = \frac{1}{J_m(J_m-1)/2} \sum_{j \in J_m} \sum_{k \neq j \in J_m} \sum_{n \in M} \mathbb{1}\{j \text{ operates in } n\}\mathbb{1}\{k \text{ operates in } n\} \tag{7}$$

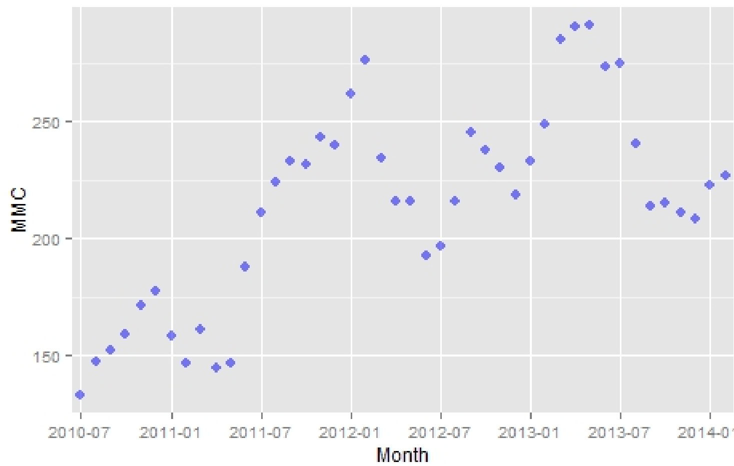
where j and k index firms, J_m denotes both the set of firms operating within market m and the number of firms operating in market m, n indexes markets, and M indicates the total number of markets. This measure calculates the number of other markets in which the firms of market m interact, then averages across all firms within a market. In this paper, I use a measure similar to that of Prince and Simon (2009), defining

$$MMC_{jm} = \sum_{k \neq j \in J_m} \sum_{n \in M} \mathbb{1}\{j \text{ operates in } n\}\mathbb{1}\{k \text{ operates in } n\} \tag{8}$$

where j and k index firms, J_m is the set of all firms located in market m, n indexes markets, and M is the set of all markets. For this setting, this measure offers a few advantages. Since it is defined at the firm-market level, it allows multimarket contact to vary across firms within the same market. This is important, as not all internet service providers within a market experience the same degree of multimarket contact. Smaller ISPs who compete in few markets are not likely to consider multimarket contact in the same way as national firms. For example, there should be no direct effect of multimarket contact on an ISP that serves only one market, as they do not fear punishment for their actions in other markets.[4] Second, in the market-level measure, the presence of smaller ISPs will pull the market average towards zero. This is not desirable in this setting, as two major ISPs should anticipate retaliation from one another in their shared markets regardless of whether a small ISP is present in a given market. Finally, this modified measure is not averaged over the number of firms in the market, as the opportunities for multimarket contact to occur should increase with the

[4]With that said, there could be a second order effect, whereby local ISPs know that their national competitors face widespread punishment, and respond appropriately to this information. Whether they respond by increasing quality or not remains ambiguous. In this paper, I focus on the direct multimarket effect, as described above.

Figure 6: Multimarket Contact Over Time



number of firms present in the market.

Figure 6 illustrates the trend in multimarket contact over time by plotting the average multimarket contact measure per month, aggregated over markets and firms. Note that the scale of this measure does not have inherent meaning. Its interpretation will be discussed in greater detail in the results section. The overall trend in multimarket contact is very similar to the overall trend in the number of local market competitors. This is to be expected, since, by definition, multimarket contact increases when more firms enter new markets. However, the effect of these two variables on quality can be separately identified. This is because although they are highly correlated in aggregate, they move separately at the firm-market level. For example, suppose firms A and B compete in market 1 and that A has a monopoly in market 2. Then, suppose that B enters market 2. This causes the number of ISPs to rise in only market B, and causes AT&T's multimarket contact to rise in market A and market B.

4 Empirical Model

To estimate the effect of both local competition and multimarket contact on download speeds, I first estimate the following specification:

$$s_{jmt} = \beta_1 + \beta_2 ln(\#ISP_{mt}) + \beta_3 MMC_{jmt} + \beta_4 Distance_{jmt} + \beta_5 Distance^2_{jmt} + \alpha_j + \eta_m + \gamma_t + \varepsilon_{jmt} \tag{9}$$

s_{jmt} represents the average download speed recorded for customers of ISP j in market m on day t, $\#ISP_{mt}$ indicates the number of internet service providers competing in market m on day t, MMC_{jmt} indicates the degree of multimarket contact faced by ISP j in market m on day t, and $Distance_{jmt}$ is the average distance of customers of ISP_j in market m on day t from the server used to test their speed. $Distance_{jmt}$ is included in order to reduce the noise in the recorded download speeds, and $Distance^2_{jmt}$ is included to allow this effect to vary over distance. I also include ISP, market, and day fixed effects to account for unobserved heterogeneity that is invariant for an ISP over markets and time, for a market over ISPs and time, and for a given time over markets and ISPs. By including these fixed effects, the variation in s_{jmt} that is being used to identify the β coefficients is variation in download speeds for a given ISP that deviates from both the national average and a given market's average download speed.

I estimate the equation using the natural log of the number of ISPs to allow the absolute effect (the change in download Mbps in response to a unit increase in the number of ISPs) to vary across different levels of competition. It is reasonable to expect the effect of increasing competition to be larger when moving from a monopoly to a duopoly, than when moving from four ISPs to five ISPs, for example. In fact, Xiao and Orazem (2011) find that once a local broadband market has between one and three firms, the fourth entrant has little effect on competitive conduct.

The disadvantage of the above specification, however, is that it still imposes a specific functional form for the way in which the effect varies over levels of competition. To address this issue, in the next specification I include dummy variables for different levels of local competition, which allows me to flexibly estimate the effect of adding each additional ISP. This takes the following form:

$$s_{jmt} = \beta_1 + \sum_{i=2}^{6} \beta_i \mathbb{1}\{\#ISP_{mt} = i\} + \beta_7 \mathbb{1}\{\#ISP_{mt} \geq 7\} + \beta_8 MMC_{jmt} + \tag{10}$$

$$+ \beta_9 Distance_{jmt} + \beta_{10} Distance^2_{jmt} + \alpha_j + \eta_m + \gamma_t + \varepsilon_{jmt}$$

In equation (**??**), $\beta_2, ..., \beta_7$ can be interpreted as the average change in speeds due to a particular level of competition, relative to a monopolized market.

4.1 Endogeneity

The identifying assumption in the previous specifications is there there is no correlation between the error term, ε_{jmt}, and either $\#ISP_{mt}$ or MMC_{jmt}. The former is likely to be violated, because market structure is determined endogenously. The number of ISPs that locate within a given city is determined by the underlying profitability of operation, which is determined by some combination of characteristics of the city itself. As a result, there are likely determinants of market structure that also help to determine the download speeds that ISPs provide. Endogeneity of MMC_{jmt} is of less concern. Conditional on ISP_j being located in market m at time t, its degree of multimarket contact is largely determined by the presence of other ISPs in other markets, neither of which are influenced by ε_{jmt}.

Market and ISP fixed effects alleviate many concerns about endogeneity of $\#ISP_{mt}$. For instance, if the fixed costs of providing service in a particular city are very high, this may both deter entry and induce entrants to offer slow speeds. But, to the extent that this is constant over time, it is accounted for by the market fixed effects. The remaining potential for endogeneity is primarily through correlation between market-time-specific shocks and the number of ISPs in a city at a given point in time. For instance, cities experienced different unemployment rates following the recession in 2008, which likely deterrred ISPs from entering these markets. At the same time, ISPs already present in those markets may have chosen not to upgrade their speeds if customers were unable to afford a price increase.

To address this issue, I propose an instrument for $\#ISP_{mt}$. ISPs often locate in many cities within the same region. As a result, if an ISP is located in city m, it is likely to be located in nearby city l. This suggests that the number of ISPs in city l may be a good predictor of the number of ISPs in city m, potentially providing me with a viable instrument.

In addition to predictive power, I also need the following to hold: the number of ISPs in city l must be uncorrelated with any unobservable time trend that is specific to city m. Since the number of ISPs in city l is likely to be correlated with its own unobservable city-specific time trend, this implies that the unobservable time trend that is specific to city l must be uncorrelated with the unobservable time trend that is specific to city m.

One would expect, however, that cities that are in close proximity to one another would experience shocks over time that are very similar. For this reason, I instrument for the number of ISPs in market m using the number of ISPs that are in the city nearest city m that is at least 20 miles away and within the same state.[5] [6] This city should be near enough that it provides predictive power, but far enough that the unobservable time trends of the two cities are uncorrelated. Evidence of the former claim can be seen in the strength of the first stage regression results in table 5. Though the latter cannot be shown explicitly, I provide some simple evidence to support this claim. Table 2 shows the correlations between a city's own demographic characteristics and its 20-mile neighbor. These correlations are quite weak, with the possible exception of household income. While this evidence cannot prove that the cities' unobservable time trends are uncorrelated, the fact that the cities are quite different along observable dimensions lends credibility to the idea. Finally, the reason I only consider cities within the same state is that an ISP's presence in one city may not be a good predictor of that ISP's presence in a nearby city if that city is across a state border because regulatory environments differ between states. [7]

This instrument is in the same vein as as a "Hausman instrument." In their estimation of a multilevel demand system for beer, Hausman et. al. (1994) instrument for price using

[5] Distance is calculated "as the crow flies."

[6] I also use a radius of 10 miles and 30 miles in section 5.1.

[7] As a result, an additional reason for choosing a 20 mile "bubble" is that a larger distance would not allow me to effectively instrument in small states such as Delaware, because all of Delaware's cities in the sample are so close together.

Table 2: Correlation of Demographic Characteristics of Neighboring Cities

	Population	Density	Household Income	High School %	Bachelors %	% Over 65
Correlation	0.015	0.262	0.423	0.138	.059	0.318

prices in nearby cities. Both their instrument and my own rely on spatial correlation of the independent variable, but no correlation of the error. The use of a "bubble" around each market was used by Bloom et. al (2011), who instrument for the number of hospitals in an area with the political marginality of surrounding districts, as they estimate the effect of competition among hospitals on the quality of management practices. Demonstrating low correlation between observable characteristics of neighboring cities to provide credibility for the instrument is used by Fan (2013), who instruments for newspaper characteristics by using the demographics of a newspaper's secondary market, as she estimates the effect of ownership consolidation in newspaper markets.

5 Results

The results of estimating equation (9) are reported in table 3. Column 1 uses no fixed effects, column 2 uses only ISP fixed effects, column 3 uses ISP and market fixed effects, and column 4 uses ISP, market, and day fixed effects. The R^2 values of the columns suggest that the driving factor behind differences in observed speeds is actually systematic differences across ISPs, that ISPs consistently offer similar speeds across markets. The inclusion of market and time fixed effects explain relatively little of the variation in download speeds.

The negative coefficient on $ln(\#ISP_{mt})$ in column 1 is likely due to the fact that when a city has only one or two ISPs, these providers are most often national firms such as Comcast and Verizon, who systematically offer fast speeds, relative to other ISPs. This is supported by the fact that as soon as I include ISP fixed effects in column 2, the coefficient of $ln(\#ISP)$ becomes positive. This is because we are now looking at a within-estimation, where the coefficient is identified by differences in the speeds that a given ISP offers when it faces different levels of within-market competition. The inclusion of market fixed effects in column 3 provides a higher estimated coefficient on $ln(\#ISP)$, which suggests that failing to account for individual market characteristics, such as demographics, underestimates the true effect of intra-market competition. Finally, after including time fixed effects in column 4, the estimated effect of intra-market competition shrinks dramatically. This is likely because during the time period studied, there was a dramatic increase in download speeds, as shown in figure 4, accompanied by a significant increase in the number of ISPs operating within the average market. However, the speed increase was likely not only driven by increased within-market competition, but also improvements in technology available to ISPs and increased demand for faster download speeds, following the advent of services such as Netflix and Skype. Given this discussion, it is my belief that the results in column 4 most faithfully represent the changes in download speeds that are actually due to changes in local competition. The effect of this competition is therefore estimated to be such that a 100% increase in the number of ISPs operating within a market is associated with an increase of .131 Mbps. For example, this means that transitioning from a monopoly to a duopoly is associated with an increase of .131 Mbps, while the shift from two firms to three is associated with an increase of only .065 Mbps. As a benchmark, the average download speed among all U.S. users in the data in February 2014 was is 17.9 Mbps. This evidence suggests that the effect of within-market competition on the download speeds that internet service providers offer is economically quite small.

The estimated effect of multimarket contact on download speeds varies in magnitude across specifications as well. For the reasons discussed above, the true effect of multimarket contact is best estimated by the specification in column 4. The inclusion of ISP fixed effects identifies the effect of multimarket contact on download speeds by comparing the speed offered by the same ISP when it faces different levels of contact. It is also important to include market and time fixed effects to account for differences across markets and national trends over time that influence the speeds that are provided. The OLS estimated coefficient on multimarket contact is therefore -.002, suggesting that increased contact among firms decreases the download speeds they provide. This number is not easily interpreted, however, because the scale at which contact is measured is largely arbitrary. To get a sense of the the

Table 3: OLS Estimates with $ln(\#ISP)$ Independent Variable

	(1)	(2)	(3)	(4)
$ln(\#ISP_{mt})$	-1.085	.814	1.857	.131
	(.009)***	(.007)***	(.013)***	(.013)***
MMC_{jmt}	-.001	-.00006	-.0003	-.0007
	(.00003)***	(.00003)**	(.00003)***	(.00003)***
$Distance_{jmt}$	-.078	-.029	-.029	-.002
	(.0004)***	(.0002)***	(.0003)***	(.0003)***
$Distance^2_{jmt}$	.0002	.00006	.00006	9.77e-06
	(1.90e-06)***	(1.10e-06)***	(1.38e-06)***	(1.33e-06)***
$Constant$	17.384	11.193	9.127	5.029
	(.020)***	(.151)***	(.172)***	(.191)***
N	4782612	4782612	4782612	4782612
R^2	.024	.701	.728	.752
ISP F.E.	*N*	*Y*	*Y*	*Y*
Market F.E.	*N*	*N*	*Y*	*Y*
Time F.E.	*N*	*N*	*N*	*Y*

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

magnitude of this effect, I note that a one standard deviation[8] shift in multimarket contact is associated with a .40 Mbps decrease in download speed. Again, this effect is quite small, especially when compared with the speed that the average consumer receives.

As one would expect, the coefficient on $Distance_{jmt}$ is negative, giving evidence that users who are further away from the test server record slower speeds. The positive coefficient on $Distance^2_{jmt}$ suggests that this distance matters less for users who are far away from a test server than those who are close. These estimated coefficients provide some reassurance that including $Distance_{jmt}$ and $Distance^2_{jmt}$ help to reduce noise in the data, but they are not critically important beyond this.

In table 4, I repeat the specifications shown in table 3, but this time estimating equation (**??**), which allows the effect of competition to vary flexibly with the number of firms in a market. The difference across the columns in table 4 is consistent with the patterns seen in table 3. For the same reasons, it is my belief that column 4 best represents the true effect of competition. This specification is an improvement over column 4 of table 3, as it does not impose a functional form for how the effect of within-market competition changes with the

[8]The standard deviation of MMC_{jmt} is 198.20

number of firms in a market. This allows me to better capture the effect of changes in market structure at each level of local competition. The interpretation of each of the # ISP dummy variable coefficients is the change in speed associated with that number of ISPs present in the market, relative to a monopoly. First of all, positive coefficients on all # ISP dummy variables shows that any level of competition is associated with faster download speeds than a monopoly. However, the estimated coefficients suggest a non-monotonic relationship between the number of providers in a market and the speeds they offer. Download speed increases when transitioning from a monopoly to a duopoly or when the number of firms increases beyond four, but download speed decreases when increasing from two providers to three, or from three providers to four. Generally, the estimated effect of within-market competition under this specification is similar in magnitude to the effect estimated in column 4 of table 3.

Under the specification in column 4 of table 4, increased multimarket contact is again estimated to have a negative effect on download speeds. Here, a one standard deviation increase in multimarket contact associated with a decrease in download speed of .12 Mbps. This effect is smaller in magnitude than the estimate in table 3, though the difference between them is very small when compared with the average download speed that consumers receive.

Due to the endogeneity concerns discussed in section 4.1, I instrument for the level of local competition using the number of internet service providers in a nearby city that is at least 20 miles away. I use this instrument to estimate equation (**??**). In order to implement this instrument, I use the first stage regression to predict the number of ISPs that will be located within each market. Now, however, these predictions are not integer-valued. Therefore, to estimate equation (**??**), I modify the construction of the # ISP dummy variables. For example, $\mathbb{1}\{\#ISP_{mt} = 2\}$ is replaced by $\mathbb{1}\{-1.5 \leq \#\hat{ISP}_{mt} < 2.5\}$. I then run the second stage regression on these new dummy variables. The results of the first stage of the instrumental variables estimation are reported in table 5. A positive, statistically significant coefficient on the number of ISPs in a city's 20-mile neighbor, coupled with a high R^2 and F statistic, suggest that this instrument does quite well in predicting the number of ISPs

Table 4: OLS Estimates with $\#ISP$ Dummy Independent Variables

	(1)	(2)	(3)	(4)
$2\ ISP_{mt}$	-2.036	.682	.694	.152
	(.055)***	(.031)***	(.035)***	(.034)***
$3\ ISP_{mt}$	-3.309	1.092	1.172	.091
	(.054)***	(.031)***	(.036)***	(.034)***
$4\ ISP_{mt}$	-3.970	1.231	1.584	.077
	(.055)***	(.031)***	(.037)***	(.035)**
$5\ ISP_{mt}$	-4.211	1.389	1.982	.120
	(.055)***	(.032)***	(.038)***	(.036)***
$6\ ISP_{mt}$	-4.384	1.516	2.319	.122
	(.056)***	(.032)***	(.039)***	(.037)***
$7^{+}\ ISP_{mt}$	-4.419	1.800	2.805	.129
	(.055)***	(.032)***	(.040)***	(.039)***
MMC_{jmt}	-.0004	.0003	.0001	-.0006
	(.00003)***	(.00003)***	(.00003)***	(.00003)***
$Distance_{jmt}$	-.077	-.030	-.030	-.002
	(.0004)***	(.0002)***	(.0003)***	(.0003)***
$Distance^2_{jmt}$	.0002	.00006	.00006	9.95e-06
	(1.90e-06)***	(1.10e-06)***	(1.38e-06)***	(1.33e-06)***
$Constant$	19.277	11.260	10.268	5.125
	(.055)***	(.153)***	(.175)***	(.193)***
N	4782612	4782612	4782612	4782612
R^2	.026	.701	.727	.752
ISP F.E.	*N*	*Y*	*Y*	*Y*
Market F.E.	*N*	*N*	*Y*	*Y*
Time F.E.	*N*	*N*	*N*	*Y*

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

Table 5: Instrumental Variables First Stage

	(1)
$\#ISP_{l_{20}t}$	.131
	(.0006)***
$Constant$	2.655
	(.026)***
N	4782612
R^2	.92
F	24278.36

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

Table 6: Instrumental Variables Second Stage

	(1)
$2\ ISP_{mt}$	.673
	(.073)***
$3\ ISP_{mt}$	.616
	(.079)***
$4\ ISP_{mt}$	.444
	(.087)***
$5\ ISP_{mt}$	.256
	(.097)***
$6\ ISP_{mt}$	.177
	(.110)
$7^{+}\ ISP_{mt}$	-.071
	(.126)
MMC_{jmt}	-.0005
	(.00006)***
$Distance_{jmt}$	-.002
	(.0007)***
$Distance^2_{jmt}$	.00001
	(.000003)***
N	4782612
R^2	.752
ISP F.E.	*Y*
Market F.E.	*Y*
Time F.E.	*Y*

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

located in a given market. The second stage results are reported in table 6. The coefficient on multimarket contact is nearly identical to the estimated OLS coefficient. This coefficient suggests that a one standard deviation increase in multimarket contact is associated with a .10 Mbps decrease in download speed. This finding is consistent with the theory of mutual forbearance, which predicts that firms will compete less aggressively when they face high potential punishment in their other markets. Furthermore, it is consistent with existing empirical literature, which has shown that airlines do not lower prices on routes they share with competitors with whom they repeatedly interact. The translation of the mutual forbearance hypothesis to quality competition is very natural, and this finding provides some of the first empirical evidence thereof.

The estimated effect of within-market competition is somewhat different after instrumenting. The estimated coefficients on the 2 ISP through the 5 ISP dummies are statistically significant at the 1% level, while the estimated coefficients for 6 ISP and 7 ISP are not statistically different from zero. These estimates again suggest that any level of non-monopoly local competition will lead to faster download speeds than those that would occur in a monopolized market. As before, this competitive effect is non-monotonic. The fastest speeds are associated with markets with two competitors, while further increases in the number of ISPs decrease the speed that is offered. When compared to a monopoly, the within-market competitive effects estimated by instrumental variables are much larger. For example, shifting from a monopoly to a duopoly is estimated to increase download speed by .673 Mbps. This is more than four times as large as the effect estimated by OLS. This suggests the presence of a downward endogeneity bias in the OLS estimates. Eliminating this endogeneity allows me to give the estimated coefficients in table 6 a causal interpretation. For example, adding an additional ISP to a monopolized market will, on average, increase download speed by .673 Mbps. These results generally support the predictions of the theoretical model developed earlier in the paper. In a monopolized market, the model predicts that firms will respond to an increase in local competition by increasing speeds, and there is evidence of this behavior in the data. The model also predicts that beyond a certain number of ISPs, adding any additional competitors will decrease the speeds provided. The data suggest that this begins to happen as soon as there are more than two providers in a market. The model, however, predicts that speeds will continue to increase in response to higher local competition when there are two or three firms in a market. This prediction is not supported by the data.

5.1 Robustness

In this section, I demonstrate that my results are robust to using different "bubble" sizes in my instrumental variables estimation. I estimate equation (**??**) once again, using a 10-mile "bubble" and a 30-mile "bubble." The first stage results from using each instrument are reported in table 7. In both cases, the coefficient on $\#ISP_{lt}$ is positive and statistically significant, the R^2 values and F statistics are quite high. This again demonstrates the

Table 7: Instrumental Variables First Stage

	10 Mile Instrument	30 Mile Instrument
$\#ISP_{lt}$	.132	.126
	(.0005)***	(.0006)***
$Constant$	2.658	2.659
	(.026)***	(.026)***
N	4782612	4782612
R^2	.921	.92
F	24327.55	24222.52

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

strength of the instrument. The second stage results reported in table 8 are nearly identical to the results generated by the 20-mile instrument. This shows that the choice of "bubble" size has very little effect on the results, which lends the instrument additional credibility.

6 Conclusion

There is a wide held belief that when facing greater competition within markets, firms will respond not only by lowering prices, but also by offering better quality products and services. The internet service provision industry provides an ideal setting to investigate this idea, both because quality is easily defined and measured, and because of the important role of internet access in modern society. I develop a stylized theoretical model of intra-market competition between ISPs, and show that transitioning away from monopolies increases the speed offered by providers, but that quality does not increase monotonically with the number of firms in the market. In the empirical analysis, I find that adding one additional ISP to a monopolized market, on average, increases download speeds by .673 Mbps. Markets with more than two providers, however, are likely to have slower speeds.

Any discussion of competition among internet service providers, however, should consider national-scale competition along with market-level competition. The hypothesis of mutual forbearance predicts that firms that repeatedly interact across markets are unlikely to compete aggressively with one another, thus dampening the level of competition. The translation of this idea from pricing competition to quality competition is very natural, and this paper

Table 8: Instrumental Variables Second Stage

	10 Mile Instrument	30 Mile Instrument
2 ISP_{mt}	.685 (.073)***	.692 (.072)***
3 ISP_{mt}	.619 (.079)***	.618 (.078)***
4 ISP_{mt}	.433 (.087)***	.430 (.087)***
5 ISP_{mt}	.251 (.097)***	.221 (.097)**
6 ISP_{mt}	.130 (.110)***	.135 (.110)***
7^+ ISP_{mt}	-.112 (.125)***	-.182 (.127)***
MMC_{jmt}	-.0005 (.00006)***	-.0005 (.00006)***
$Distance_{jmt}$	-.002 (.0006)***	-.002 (.0006)***
$Distance^2_{jmt}$	.00001 (.000003)***	1.00e-05 (.000003)***
$Constant$	4.660 (.465)***	4.659 (.192)***
N	4782612	4782612
R^2	.752	.752
ISP F.E.	*Y*	*Y*
Market F.E.	*Y*	*Y*
Time F.E.	*Y*	*Y*

Note: *, **, and *** indicate statistical significance at the 10% level, 5% level, and 1% level, respectively.

provides some of the first empirical evidence thereof. This industry is ideal for studying the effect of multimarket competition because of the substantial variation in contact between national internet service providers and local and regional providers. I estimate that a one standard deviation increase in multimarket contact decreases download speeds by .10 Mbps, a small but statistically significant amount.

This research demonstrates that firms who interact repeatedly across markets are unlikely to compete aggressively by increasing the quality of their product. In addition, it confirms a common belief that competitive markets lead to the provision of higher quality than monopolized markets, but perhaps goes against conventional wisdom in finding that increasing the number of local competitors does not necessarily increase quality.

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