Competition and Dynamic Bargaining
in the Broadband Industry*

Daniel Goetz †

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Abstract

This paper measures the effect of horizontal mergers in the broadband industry when content providers can invest in product quality. I estimate a structural model of dynamic multilateral bargaining between U.S. broadband internet service providers (ISPs) and Netflix over how to split the surplus from investments Netflix makes to improve the quality of its streaming video. The dynamic bargaining model recovers the value and split of the investment surplus when the econometrician observes only bargaining durations and consumer responses to lowered stream quality. I find that ISP scale— independently of ISP market power—matters for how much surplus ISPs extract, which is a novel source of bargaining power in the empirical literature. Using the model, I find that allowing the two largest U.S. cable internet providers to merge would have increased the magnitude of aggregate consumer welfare loss by 4.3% due to a longer period of degraded Netflix quality, and reduced the probability of Netflix making the quality investments by between 0% and 5.1%.

Keywords: Mergers, Broadband Internet, Bargaining

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1 Introduction

Two-sided markets, where intermediaries provide consumers access to content supplied by third parties, are increasingly common.1 Recent empirical work including Dafny, Ho and Lee (2016) and

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†Correspondence: Department of Economics, Princeton University, Princeton, NJ 08544. Tel.: (609) 349 1043. Email: dtgoetz@princeton.edu. Web: http://scholar.princeton.edu/dgoetz

1Older industries with two-sided characteristics such as cable television, medical insurance, and broadband internet have recently been joined by online platforms providing access to vacation homes, ride sharing services, and contract
Gowrinsankaran, Nevo and Town (2015) has sought to understand how market power in two-sided markets affects consumer welfare. In this literature, the quality of available content is taken as given; as a result, greater intermediary market power against the content side of the market can only help consumers, as larger intermediaries negotiate better terms with content providers and then pass those efficiencies on to consumers (as in Crawford and Yurukoglu (2012)) without any reduction in content quality.

This paper evaluates the consequences of market structure in the market for broadband internet when the quality of content is not fixed. In this market, content streaming quality—for instance, how quickly and at what resolution online videos load—is an important component of internet users’ experience. Motivated by data on bargaining between U.S. internet service providers (ISPs) and Netflix—the leading provider of streaming video content—over the terms of interconnection, I build a structural model where streaming quality can be degraded in two ways. First, bargaining frictions between ISPs and Netflix will imply that negotiations take time, and Netflix streaming quality is degraded at an ISP until negotiations resolve. Second, bargaining is over how to split the surplus from a Netflix capacity investment that will maintain streaming quality; if too much of Netflix’s surplus from the investment is extracted by ISPs then Netflix may choose not to invest. I structurally estimate the model and simulate the effects of counterfactual policies, including a merger and a prohibition on quality reductions during bargaining, on both bargaining durations and on Netflix’s incentive to invest.

There are two novel empirical findings from the paper, as well as a methodological contribution. The first empirical finding is that both ISP size and ISP market power matter for how much surplus ISPs extract from Netflix’s ISP-specific investments. An ISP with more market power—whose subscribers cannot switch to another provider when Netflix quality is degraded during bargaining—extracts more surplus; however, an ISP that is present in many markets—even if its consumers have multiple internet options in all the markets the ISP is present in—will also extract relatively more surplus. The intuition behind the result that ISP size matters independently from market power is that Netflix has economies of scale in its surplus which weakens its bargaining position against ISPs that serve more subscribers. The second empirical finding is that in this two-sided market with quality investment, the ISPs find it optimal to extract Netflix’s investment surplus even though doing so disincentivizes Netflix from making the investment. This result need not be true in theory, as in a two-sided market the intermediary may find it optimal to incentivize investment in content quality to charge a higher markup to consumers who value quality. Finally, the paper makes a methodological contribution with a model of dynamic bargaining that takes data on bargaining durations and consumer substitution in response to reduced quality and recovers information about the magnitude and split of Netflix’s investment surplus.

The empirical core of the paper is a cross-section of bargaining durations between U.S. ISPs work.
and Netflix over how to split the surpluses from Netflix’s ISP-specific capacity investments. In reduced form regressions, an ISPs’ market footprint is positively and significantly associated with bargaining length, while the number of competitors an ISP faces in the markets it serves has a negative but insignificant effect. This cross-sectional correlation forms the basis for the insight that ISP scale, in addition to market power, matters for bargaining. Panel data regressions of ISP subscriber numbers on Netflix quality—which is reduced during bargaining—show that a small but significant number of subscribers value Netflix enough to leave the affected ISPs, suggesting a welfare cost to longer bargaining, as well as a cost to ISPs.

The supply model is a structural joint durations model that rationalizes the delays in bargaining between Netflix and the ISPs, and which maps delays and subscriber substitution into the split of Netflix’s investment surplus. As in the data, in the model Netflix can make ISP-specific investments that generate surplus in two ways: an investment improves transmission of Netflix content to its subscribers at an ISP, which is a quality improvement whose value to consumers I identify from demand data, and an investment also saves Netflix money on transmission costs, the value of which only Netflix knows. I assume that ISPs do not know the exact value of the surplus they face, but they do know its distribution, and that they make take-it-or-leave-it offers of interconnection fees in each bargaining period. Netflix will reject a high fee offer to signal that its investment surplus with that ISP is low, leading to positive probabilities of delay. As in the data, in the model Netflix streaming quality remains degraded at an ISP until the capacity investment is made.

The model maps bargaining durations to surplus splits by assuming that longer periods of bargaining reflect strategic choices by the ISPs to screen Netflix’s surplus more finely. ISPs’ strategic tradeoff in the model is between making a low initial fee offer to Netflix, in which case the offer will be accepted quickly and the ISP will have avoided losing subscribers but will not extract much surplus from Netflix, versus making high initial offers that slowly decrease, which may cost the ISP subscribers during periods of quality degradation but which will extract more of Netflix’s surplus in expectation. Consumers’ willingness and ability to substitute away from ISPs with degraded Netflix quality is a measure of ISP market power, and lower market power will make a finer screening strategy less profitable. Consumer substitution also generates interactions between ISPs’ screening strategies: by offering a low fee to Netflix that is likely to be accepted an ISP can poach subscribers from rivals whose quality remains degraded. How the distribution of surplus an ISP faces varies with ISP characteristics captures whether Netflix experiences economies of scale in its cost-savings.

The model is estimated in a two-step procedure: I first recover the demand for internet access as a function of Netflix quality degradation and plan features; I then assume ISPs take the demand curve as given and estimate the unobserved surplus distributions—and associated optimal screening strategies—that maximize the model’s probability of matching the bargaining delays in the data.

I estimate consumer preferences for internet access and for Netflix streaming quality using in-
individual level data on internet plan choices, combined with nationwide ISP subscriber numbers and data on Netflix-ISP pairwise quality of service degradation. While ISPs charge higher monthly subscription fees for plans with more features, this pricing and feature schedule varies little nationwide, making it difficult to estimate how consumers value internet service with market share data alone. I use fine geographic variation in the set of available ISPs and plans to identify the distribution of preferences for price, download speed, access technology, and Netflix quality of service in a mixed-logit framework with random choice sets.

I assume that the observed data on bargaining durations is a perfect Bayesian equilibrium of the multilateral dynamic screening model. Given parameters, I solve for ISPs’ optimal state-contingent fee offers, which imply a joint distribution of bargaining durations for all ISPs with which I can perform MLE. Intuitively, if ISPs with certain characteristics—i.e., larger networks—take longer to bargain on average, then conditional on subscriber loss they must be facing surplus distributions with higher means to make the finer screening strategy worthwhile.

From the demand curve results, I estimate that during periods of disagreement, ISP market shares decrease by about 0.5 percent on average with substantial heterogeneity across ISPs. For instance, Comcast is predicted to lose more, and higher-margin, subscribers than AT&T during bargaining, which will help match the fact that Comcast agrees more quickly in the data. The median price elasticity among all ISP-plan-quarter combinations is 2.667, substantially higher than the 0.7 estimated in Dutz, Orszag and Willig (2012).

In the bargaining game, I estimate that there are increasing returns to scale in Netflix’s cost-saving infrastructure investment; that is, the mean and variance of the distribution of surplus are convex in the number of housing units ISPs are connected to. These estimates are driven by a key reduced form fact in the data: network size is strongly positively associated with bargaining durations even after controlling for measures of ISP market power. The surplus distribution mean being convex in size makes sense of this correlation by showing Netflix brings relatively more surplus to a larger ISP, so that ISP finds it worthwhile to trade off greater expected lost subscriber revenue in order to screen Netflix’s surplus more finely. That returns to scale in investment can be a source of bargaining power in two-sided markets is a key insight of the paper. I find that Netflix retains only 29% of the surplus against the four largest ISPs, but 34% against the smaller ISPs, implying that ISP size worsens a hold-up problem in Netflix’s quality investment.

With the estimates in hand, I examine two regulatory interventions: a merger between Comcast and TimeWarner Cable—the two largest providers of cable internet in 2013 in the U.S.—that was blocked by the FCC in 2015, and a policy that prohibits content quality degradation during bargaining.

My main counterfactual allows Comcast and TimeWarner to merge before the bargaining event begins. The model predicts that the magnitude of the aggregate consumer welfare loss due to degraded quality during bargaining increases by 4.3 percentage points after the merger, and Netflix’s
share of the upstream surplus from its investment decreases by 9.4 percentage points. Since I assume that Netflix must pay an upfront cost to make the investment, Netflix faces a holdup problem that is exacerbated by the merger. I find that Netflix’s probability of making the investment in interconnection infrastructure that precipitated bargaining would be reduced by 5.1 percentage points. Intuitively, the merged firm has more to gain from screening than Comcast or TimeWarner combined due to economies of scale in Netflix’s interconnection surplus, but the merged firm’s marginal loss in subscribers from disagreement increases only linearly. The tradeoff between losing subscribers and extracting investment surplus tips towards extracting surplus, giving the merged firm the incentive to prolong negotiations. Moreover, in the estimated model the marginal gain in subscribers to an ISP from concluding bargaining is larger when rival ISPs have not yet agreed; thus, the merged firm’s finer screening induces slightly more aggressive offers on average by competing ISPs, decreasing disagreement lengths and improving welfare for consumers at those ISPs.

In my second counterfactual, I prohibit the degradation of Netflix quality during bargaining. This policy is related to recent Federal Communication Commission rules on network neutrality that ban ISPs from selectively degrading content providers’ connection quality to the end consumer; my policy is slightly more general, in that it bans both content providers and ISPs from degrading the connection quality. I find consumer welfare increases, with the largest increases at large ISPs like AT&T and Comcast whose bargaining took the longest to resolve. However, bargaining times actually increase and Netflix’s surplus share decreases, making Netflix 8.7 percentage points less likely to invest in interconnection infrastructure. This follows from the fact that in the data, marginal consumers are more willing to ISPs than cancel Netflix, so prohibiting quality degradation actually removes Netflix’s advantage in bargaining granted by the relative inelasticity of their subscriber base.

1.1 Related literature

This paper contributes to several literatures within industrial organization. To begin, I add to a growing literature that analyzes bargaining between firms along the supply chain. Starting with Grennan (2013), recent industry analyses have endogenized firm costs by posing a model of upstream bargaining over inputs. Papers that allow for substitution by downstream consumers in response to upstream bargaining include Crawford and Yurukoglu (2012), Gowriensankaran, Nevo and Town (2015) and Dafny, Ho and Lee (2016). Consumer substitution is a key source of upstream bargaining incentives, and I extend these papers’ insights to a dynamic setting.

A literature including Evans (2003), Evans (2010) and Evans and Schmalensee (2013) has recognized that two-sided markets, like the market for internet service, face a unique set of antitrust issues, since market power may only be exerted against the content side of the market. Empirical work including Argentesi and Filistrucchi (2007) and Chandra and Collard-Wexler (2009) focuses
on the consequences of intermediary market power on content-side prices, and on exit and entry of content providers. I contribute to these analyses by allowing content providers to negotiate with intermediaries, and by allowing the margin of adjustment on the content side to be investment by an existing content provider, as opposed to entry and exit of content.

There is a small but growing set of tools to empirically analyze dynamic bargaining. A complete information framework for multilateral dynamic bargaining is developed in Merlo and Wilson (1995) and Merlo and Tang (2012), where delays arise if the value of surplus to be split is stochastic and may rise over time. My model complements their analysis by allowing for delay even with constant surplus and introducing downstream competition among bargaining parties. Ambrus, Chaney and Salitsky (2016) have structurally estimated a dynamic bargaining game with incomplete information, and I extend their framework to the multilateral setting. Bargaining durations resemble joint optimal stopping problems, notable examples of which include Berry and Tamer (2006), Honoré and de Paula (2010) and Björkegren (2015). I draw on insights from this literature, especially with regards to how payoff interactions affect the set of equilibria.

Finally, the paper contributes to a theory literature on whether allowing content quality degradation is welfare improving. Lee and Wu (2009), Becker, Carlton and Sider (2010), Economides and Hermalin (2012) Gans (2015), and Peitz and Schuett (2016) have analyzed whether a policy of network neutrality—that is, prohibiting ISPs from selectively reducing content quality—is welfare improving, and what types of distributional impacts different neutrality policies will have. I add to this discussion the idea that temporary violations of neutrality may actually be to the benefit of content providers if consumers are willing to substitute ISPs to improve content quality.

2 The Broadband Industry

2.1 Structure of the Internet

The internet is a two-sided market. On one side are consumers, who purchase access to the internet in order to consume online services and content such as email and streaming video. On the other side are the providers of services and content, such as Google and Netflix, who charge consumers either indirectly, via advertisements, or directly, via subscription fees, for using services and viewing content. In the middle are layers of firms that intermediate the relationship between consumers and content providers. In what is to follow I refer to the service/content side of the market as content providers.

Consumers and small businesses interact with ”last-mile” or ”edge” internet service providers like Comcast and Verizon. A consumer’s choice set for wired internet service depends on which ISPs have infrastructure connected to her house, since last-mile ISPs have the exclusive right to sell service on infrastructure they own. Service is differentiated by infrastructure technology (cable,
fiber optic, etc.) across providers, and by tiered menus of plans varying by monthly price and download speed in megabits per second (MB/s) within providers.\(^2\) By 2013, 70% of households had access to two or more wired providers offering maximum download speeds greater than 10MB/s. However, the industry is concentrated: for 91% of those consumers, at least one alternative was provided by the four largest last-mile ISPs: AT&T, Comcast, Time Warner, and Verizon.

Netflix and other large content providers seek to connect to last-mile ISPs, and have several options to do so. The largest, like Google or Microsoft, incur a large fixed cost to install infrastructure that allows them to connect directly with last-mile ISPs at low variable cost. Others buy access from "transit" ISPs like Level3 and Cogent, who connect with last-mile providers to transmit content to consumers. Using third parties to transmit content comes with a higher variable cost, and content providers must ensure they purchase sufficient access to meet consumer demand. To avoid purchasing enough transit access to meet demand at peak times, content companies can also pay to upload content to so-called "content delivery networks" (CDNs)—caches of servers distributed around the country that ensure no consumer is far from a content source.

### 2.2 Netflix Bargaining Event

Starting in mid-2012, Netflix developed a strategy to transition from using mainly third parties to disseminate content, to using its own infrastructure. They developed a custom CDN, called Open Connect, and in so doing incurred a large fixed development and deployment cost.\(^3\) Open Connect would save Netflix money in two ways. First, it would allow them to save on the variable cost of using third party CDNs. As the largest online video distributor, Netflix not only paid transit ISPs for connections and the CDNs for servers, but also pursued a policy of paying the fees that last-mile ISPs charged CDNs and transit ISPs carrying Netflix content.\(^4\) Second, by locating the servers inside last-mile ISPs’ own networks, Netflix would no longer need to ensure that it paid for sufficient bandwidth from transit ISPs to accommodate demand at peak times. With Open Connect servers located in, for instance, Comcast’s network, Netflix could update the servers slowly and during off-peak times when Comcast consumers were not streaming, and therefore save on transit costs.\(^5\) Open Connect would allow Netflix to deliver service reliably and at lower cost.

By mid-2013, Netflix had not installed Open Connect in the vast majority of last-mile ISP networks, and had begun to report degraded quality of service to a number of U.S. ISPs. I emphasize

\(^{2}\)Upload speed in MB/s, caps on how much content can be consumed in a month, and contract length are also plan features, but these are much less important: 92.5% of respondents in the 2013 Current Population Survey Internet Supplement list price, download speed, or reliability as the most important feature of service, from a list of choices that also includes upload speed, data usage caps, mobility, and bundling options.

\(^{3}\)Netflix Petition to Deny, pg. 49, paragraph 1. Fixed investment in R&D and deployment on the order of $100 000 000.

\(^{4}\)Paragraph 12, Statement of Ken Florance, Vice President of Content Delivery at Netflix since 2012.

\(^{5}\)Netflix petition to deny, pg. 49, paragraph 2. "Open Connect...uses a 'proactive caching' method to conduct daily content updates during periods when networks are least used, such as early in the morning, to avoid congesting the network."
the quality degradation for the largest two U.S. ISPs by subscriber count, AT&T and Comcast, who in 2013 collectively accounted for 43% of all U.S. broadband subscribers, in Figure 1. Starting in mid-2013, the average transmission rate of Netflix data to subscribers at these ISPs dips far below trend, and is restored after varying amounts of time. ISPs including TimeWarner (13% of subscribers) and Verizon (10.5%) also experience degradation, while Cox (5.5%) and Cablevision (3.3%) do not.

I argue that these slowdowns and their resolutions correspond to periods of bargaining disagreement over the negotiated fees for installation of Open Connect. In Figure 1 Comcast service quality is fully restored during the first quarter of 2014, which corresponds to Netflix FCC filings indicating that by January, 2014, Netflix and Comcast had reached a deal on interconnection fees. AT&T service quality is only restored later: in Netflix’s April 2014 Q-10 filing, they state that AT&T still has not agreed to Open Connect interconnection, but data from the Center for Applied Internet Data Analysis (CAIDA) indicates that AT&T began interconnecting with Netflix in August 2014—around the time AT&T service quality is restored. When describing the event in FCC filings at the end of 2014, Netflix notes that "none of the U.S.’s four major ISPs [had] agreed to partner with Open Connect without payment", implying that the parties were indeed negotiating over explicit transfers from Netflix to the ISPs.

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6 Petition to Deny, pg. 57, paragraph 2 — pg. 58 paragraph 2.
7 Netflix 2014Q1 letter to investors, pg. 5 paragraph 3.
8 Petition to deny, pg. 49, paragraph 2.
3 Data

3.1 Demand Data

Demand data is collected from several sources. An overview of the time trends between in market shares, choice sets, and plan characteristics between 2010 and 2014 is presented in Figure 2.

**Market shares:** Data on market shares are gathered from ISPs’ quarterly and yearly earnings reports (10-Q and 10-K) which are available for all publicly traded companies in the U.S. Total internet subscriber numbers are given every quarter; combined with auxiliary data on market sizes detailed below, these numbers imply nationwide market shares. The reports also contain ancillary data on mergers, which provide a source of variation in available plans. Some ISPs are privately held—e.g. Cox and RCN—in which case I use estimates of the subscription base from Leichtman Research Group. Market share movements are dominated by trends and mergers.

**Plan characteristics:** The menu of prices and download speeds each ISP offers are gathered primarily from the FCC Urban Rate Survey and Open Connectivity Database. Where prices are missing, I collect them by hand from stored ISP frontpages on the Internet Archive Project. When the Internet Archive is unable to recover the prices—for instance, due to prices being hidden behind a localization layer—I comb ISP-specific consumer reviews on DSLreports.com. ISPs add or drop plans from their menu across different regions, but conditional on offering a plan it is advertised at the same price everywhere during the sample period. The price per megabit averaged across offered plans drops by 58% over the sample period.

**Choice sets:** Most consumers have access to only one or two wired internet options. Data on what choices are available to consumers comes from the National Broadband Map (NBBM), a government initiative with data available from 2010 through 2014 which collects information at half-yearly intervals on ISP connections at the census block level. For each census block, ISPs report whether they provide service to that block and their maximum advertised speed. The maximum advertised speed truncates ISP plan offerings in that block, generating geographic variation in menus. Combined with census data on exact counts of households within each block, this data gives the weight of households across choice sets for any level of geographic aggregation. I assume that all consumers have access to satellite internet as part of their choice set. The share of consumers with access to two or more high speed (≥ 25 Mb/s) providers increases from below 20% to almost 70% during the sample.

**Plan microdata:** I construct a time series of within-ISP plan shares using data from the FCC’s Measuring Broadband America (MBBA) program. The program consists of high frequency testing data for an unbalanced panel of roughly 10 000 households from 2012 through 2014. I observe a household’s ISP and their tested download speeds, which I use to back out which plan within an ISP’s menu each household subscribes to in each quarter. The distribution of customers

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9No relationship with Netflix’s Open Connect CDN.
across plans changes over time, but substantial upgrading only occurs later in 2014.

**Demographic microdata:** The 2013 and 2014 waves of the American Community Survey (ACS) link household choices of access technology to their demographics within over 2000 Public Use Microdata Areas (PUMAs). The 2011, 2013 and 2015 waves Current Population Survey (CPS) link demographics to a variety of questions about internet usage, including use of streaming video and ISP switching behaviour.

**Netflix data:** I recover Netflix’s quarterly subscribers, as well as the share of paid subscribers, from their Q-10 and K-10 filings. Netflix prices do not change over this time period. Whether and to what degree Netflix streaming quality is degraded is linked to bargaining disagreement durations, which I describe in Section 3.2 below.

### 3.2 Supply Data

**Bargaining Delays:** I gather data on the Netflix quality degradation event from several sources, including the Netflix data in Figure 1, data from an independent measurement company MLab, and CAIDA. In addition I draw extensively from business filings; the full data construction description, as well as the list of ISPs and associated bargaining times, is provided in Appendix C. Bargaining begins simultaneously for all U.S. ISPs in the third quarter of 2013, and lasts for between 0 and 4 quarters. I present the histogram of disagreement lengths in Section 3.2. Disagreement between an ISP and Netflix affects that ISP’s customers nationwide.

### 4 Patterns of Consumer Substitution and Agreement Timing

In this section, I document two key reduced form facts in the data that will inform the results in the structural model.

The first fact is that ISPs with more households in their network take longer to bargain than smaller ISPs. This fact is surprising because network size is not necessarily an indication of market power: an ISP with many households in its network may face many competitors at the households its serves, while a smaller ISP may be a monopolist to the houses it serves. Why larger ISPs find it worthwhile to take longer and extract more surplus from Netflix at the cost of subscriber revenues is a key question for the model.

The second fact is that marginal consumers substitute away from ISPs that take longer to bargain. Robustly demonstrating this relationship is key to the identification of the surplus distribution, which relies on the intuition that bargaining ISPs expect to extract at least as much surplus from a screening strategy as subscribers they expect to lose. Moreover, that marginal subscribers substitute implies that delaying agreement over how to split the surplus from the capacity investment has welfare costs for consumers.
Figure 2: Time Variation in Internet Data

Large ISP Market Shares

Large ISP Average Price per Mb/s

Households with 2 Highspeed (≥ 25Mb/s) Wired Options

Plan Choices (quantiles)

The quantile graph shows the 20, 40, 60 and 80% quantiles for a balanced subpanel of 1913 MBBA participants. The unbalanced panel has substantial attrition, and large additions that change the distribution.
4.1 Agreement timing patterns

To document how disagreement timings vary across ISPs, I first run simple cross-sectional regressions of disagreement durations on features of an ISP’s network:

$$\text{duration}_f = \beta X_f + \epsilon_f.$$ 

The dependent variable is how long bargaining lasts in quarters. $X_f$ contains a measure of ISP size, as well as other covariates including what technology the ISP uses to serve consumers (cable, DSL or fiber), the degree of geographic connectedness of an ISP’s network, and measures of the intensity of competition the ISP faces.\footnote{An ISP whose network is geographically contiguous will have a high degree of connectedness. Taking each census block as a vertex and whether that block is physically adjacent to another block as an edge, for each ISP I sum the total number of edges and divide it by the product of the number of vertices for that ISP and the average number of edges per vertex in the network given by all census blocks in the continental United States.}

Results from several specifications are presented in Table 4. The two measures of size, footprint—which measures how many housing units are in the ISP’s network—and its national market share, are included separately. A one standard deviation increase in size is associated with between a 0.5 and 0.8 standard deviation increase in disagreement duration; other covariates are insignificant.

Note that size is not equivalent to market power since regardless of geographic scale, most ISPs are duopolists to the households they serve. However, if Netflix has relatively more to gain from making its capacity investment in a larger ISP compared to a smaller ISP, then larger ISPs have a relatively stronger bargaining position and can extract a greater share of Netflix’s surplus.

If ISPs tend to agree quickly after their competitors it may be an indication that market power matters for bargaining. I estimate the following specification using the panel of ISPs that were present at the beginning of bargaining in mid-2013:

$$\text{agree}_{ft} = \sum_{k=0}^{1} \gamma_k \text{comp_agree}_{f,t-k} + \beta X_{ft} + \alpha_f + \alpha_t + \epsilon_{ft},$$
where \( agree_{ft} \) takes a value of 1 if ISP \( f \) concludes bargaining at time \( t \), and \( comp.agree_{ft} \) takes a value of 1 if the ISP with the greatest share of overlap in \( f \)'s markets concludes negotiations with Netflix at time \( t \). An ISP exits the panel the period after it concludes negotiations.

Results presented in Table 5 indicate a positive relationship between when an ISP agrees and when its primary competitor agrees; that is, agreement timings are correlated. However, this relationship is insignificant after time fixed effects are included. The data cannot distinguish between whether ISP interaction or correlated shocks are driving the agreement timing patterns. In my structural model I will allow both mechanisms to operate in a restricted way.

### 4.2 Consumers switch ISPs

In this section I show that there exist marginal consumers who leave ISPs that do not reach an agreement with Netflix quickly, implying that degraded Netflix quality is costly for consumers. I further show that ISPs that take time to negotiate with Netflix experience reductions in the rate of subscriber growth during negotiations, implying that lengthy negotiations are also costly for ISPs.

Using the individual level panel of individual ISP and speed choices from the MBBA, I estimate the following equation:

\[
P_{it}(f' | f) = \gamma_{\text{disagree}_{ft}} + \beta \Delta \log p_{ft} + \alpha_i + \alpha_t,
\]

where \( P_{it}(f' | f) \) is the probability that consumer \( i \) leaves ISP \( f \) for any other \( f' \) at time \( t \), including the outside option, \( disagree_{ft} \) is a dummy indicating whether ISP \( f \) is still negotiating, and \( p_{ft} \) is the price of \( f \)'s entry level plan. Results are presented in Table 6 and indicate a robust correlation between the probability of exiting an ISP and whether that ISP is currently experiencing degraded Netflix quality.

Suggestive evidence that Netflix users drive the increased switching during the periods of degraded streaming quality comes from cross-sectional data from the mid-2013 CPS Internet Use Supplement. 18.8% of households in the CPS report having switched ISPs in the past 3 years, and households with a TV-based internet streaming device were 36% more likely to switch than households without such a device. This may be due to a difference in switching costs: streaming video users were 4.7% less likely to bundle internet with cable. It may also be an extreme manifestation of a prevalent preference for reliability: 36.7% of respondents list reliability as most important feature of a plan, greater than price (30.5%) or download speed (25.3%).
presents median residual ISP growth rates for two groups of ISPs: those that experienced a delay in negotiation with Netflix, and those that did not. The first vertical line indicates the beginning of bargaining, the dashed vertical line indicates the conclusion of the first wave of bargaining, and the final line indicates when the last ISPs agreed. The median ISP that did not experience disagreement and a quality degradation grows 0.5% faster during the slowdown than ISPs that did. To construct these series I purge ISP specific time trends, time dummies, and control for mergers and price movements.

To formalize the relationship in the graph, I run the following regression:

$$\Delta \log \text{subscribers}_{ft} = \gamma \text{disagree}_{ft} + \beta \Delta \log p_{ft} + \bar{\alpha}_f + \bar{\alpha}_t + \epsilon_{ft},$$

where the dependent variable is the log change in ISP f’s reported number of internet subscribers, \(\text{disagree}_{ft}\) is a dummy variable indicating whether an ISP is currently in disagreement with Netflix, and \(p_{ft}\) is the price of the ISP’s entry tier plan.

Results are reported in Table 7. The estimated reduction in subscriber growth for ISPs that delay the resolution of negotiations is between 0.4 and 0.8 percent during periods of delay. The negative relationship is robust across specifications that include ISP and time fixed effects and that control for price changes and mergers. Price also has the expected negative coefficient, although it is not significant, potentially due to endogeneity with unobserved demand shocks.

The results suggest an economically significant role for subscriber substitution between ISPs in response to Netflix quality degradation. That is, I find that marginal consumers do substitute away from ISPs that are in a state of disagreement with Netflix. This suggests that not only do these consumers value Netflix streaming quality, they value it enough (and are informed enough)
to leave ISPs (or at least, not sign up with ISPs) whose streaming quality is degraded.

4.3 Netflix Demand is Inelastic

I argue that Netflix demand during 2013-2014 is inelastic. Since I lack microdata on switching behaviour of individual Netflix subscribers and Netflix does not provide a measure of churn, I analyze the residual growth rates in Netflix aggregates from Q-10 and K-10 filings.

Figure 5 gives the residual growth rate in Netflix streaming subscribers after controlling for a time trend and seasonality. The series begins in 2012, since prior to this date Netflix aggregated its DVD rental and streaming customers. Even with controls for quarter, the growth rate exhibits periodicity; however, the pattern of subscription growth around 2014 looks very similar to that in 2013.

One possible explanation for why subscriber growth does not drop is that Netflix made more free trial memberships available during the slowdown. That is, while Netflix does not change the sticker price of its service during this time, they may be reacting to the (endogenous) negative demand shock by offering more free trials. Figure 6 gives the residual growth rate in the fraction of streaming customers that pay for service. In 2014 the growth rate in paid subscribers is lowest during the bargaining event, unlike in 2013 and 2015 when the low point happens midway through the year. The series is very noisy, and only weakly suggests that relatively more of the growth in Netflix’s subscriber base were free trial offers during the slowdown.

The evidence for substitution away from Netflix is weak. This agrees with the results in the previous section in that it points to a high consumer valuation for Netflix. Speculatively, the inelastic demand may come from the lack of similarly priced alternatives for on-demand TV and movies,\textsuperscript{12} as well as strong consumer sentiment that ISPs such as Comcast are solely responsible for network slowdowns.\textsuperscript{13} In my base model specification, I will assume that demand for Netflix is completely inelastic, but that slowdowns affect consumer valuations for ISPs. I relax this condition in the online appendix.

5 Model

There are three types of agents in the model: consumers, internet service providers, and Netflix. I assume that time is discrete, with each time period \( t \) representing three months (one quarter).

Consumers demand internet access and purchase it from the ISPs, according to their heterogeneous valuations of plan characteristics. This feature of the model predicts ISP plan shares in each

\textsuperscript{12} By the beginning of 2013, DISH—the purchasers of Blockbuster—had shut down 1100 of 1500 stores, and shuttered 1450 of 1500 by 2015. A monthly Netflix subscription granting unlimited streaming was $7.99 per month in 2013, while pay-per-view movies were anywhere from $2.99 to $5.99 for a one week rental.\textsuperscript{F}

\textsuperscript{13} Consumer Reports
period as a function of parameters, whether Netflix quality has been restored, and data on household and plan characteristics. I do not model households’ choice of whether to purchase Netflix or not, but allow disutility for reductions in ISP-specific Netflix throughput.

ISPs earn profits from selling subscriptions, and may lose subscriber profits from a quality reduction in Netflix. Using estimates of the demand curve and assumptions on ISP competition and price setting, the model will predict profit as a function of the complete vector of which ISPs have restored Netflix quality of service.

On the bargaining side, Netflix and ISPs bargain multilaterally. The model predicts agreement time and fee offer probabilities as a function of supply parameters and the estimated profit elasticities. That is, the model endogenizes agreement timings, and allows for strategic interaction between ISPs in their offers as they trade off higher fee offers against potentially losing subscribers to a rival.

I begin by describing the dynamic bargaining framework, taking the ISP subscriber profit function as given. I then describe the model of price setting and consumer demand that will serve as an input to the bargaining model.

5.1 Upstream Bargaining

Upstream bargaining is a dynamic game played between all downstream internet service providers indexed by \( f = 1, \ldots, F \), and the upstream content provider Netflix, indexed by \( N \).

Time is discrete and runs from \( t_0 \) to a terminal period \( T \).\(^{14}\) Bargaining is exogenously and simultaneously initiated with all ISPs by Netflix at time \( t_0 \). At \( t_0 \), \( N \) draws conditionally independent,\(^{14}\)

---

\(^{14}\)I postpone a discussion for why I assume a terminal period to the estimation and identification section.
ISP-specific types $\mu_f$ from a distribution $F(\mu_f | w_f, \theta_s)$ where $w_f$ are observables.$^{15}$

Netflix’s vector of draws $(\mu_1, \ldots, \mu_F)$ is its private information. In this setting, these draws correspond to Netflix’s ISP-specific marginal increase in surplus from installing their CDN servers in that ISP’s network. $w_f$ includes functions of observable ISP network characteristics such as their total footprint and technology, which are plausibly informative about Netflix’s benefit. The eventual goal will be to estimate the parameters $\theta_s$ and use them as primitives in counterfactuals.

**Actions and Timing**

Starting from $t_0$, within each period $t$:

1. Any ISP whose prior offers have not been accepted observes the history of past agreement timings, its own private information about the vector $(\mu_f)$, and information on ISP demand shifters, and proposes a lump sum interconnection fee $\tau_{ft} \in \mathbb{R}$

2. Netflix accepts or rejects each $f$’s offer, $a_t = (a_{1t}, \ldots, a_{Ft})$ where $a_{ft} \in \{0,1\}$. If $N$ accepts $f$’s offer, $N$ pays $f \tau_{ft}$ and realizes surplus $\mu_f$.

3. ISPs observe the vector of acceptance/rejections $a_t$ and compete for consumers. ISPs receive flow payoffs and ISPs whose offer is accepted exit the bargaining game.

At the beginning of each period, all remaining ISPs make offers simultaneously. That is, ISPs experience both incomplete information vis-à-vis Netflix’s marginal valuation, and imperfect information regarding each others’ actions. Moreover, I assume that in addition to the draws $(\mu_f)$ which neither the econometrician nor $f$ observes, there is a vector of demand shocks $(\xi_{ft})$ which the firms observe but which the econometrician and Netflix do not.

**Netflix’s problem**

After exogeneously initiating bargaining at $t_0$, Netflix chooses its strategy of acceptances and rejections in each period to maximize its profits. Netflix period profits are

$$\tilde{\pi}_{Nt}(a_t, \tau_t) = \tilde{\pi}_{Nt} + \sum_f (\mu_f - \tau_{ft})a_{ft}. $$

$\tilde{\pi}_{Nt}$ is profit from subscriptions. In my base model I assume Netflix demand is perfectly inelastic during this time period, so $\tilde{\pi}_{Nt}$ does not depend on the vector of disagreements.

If Netflix is dynamic, their problem is to choose a vector of acceptances in each period as a function of ISP offers, the observable history of acceptances and rejections, and whatever they

$^{15}$Note that the vector $\mu_f$ does not depend on the number of subscribers at the ISP. Therefore, if consumers substitute between ISPs in response to slowdowns, it does not change the size of the ISP-specific investment surplus to be split.
can infer about ISPs’ information sets given histories and ISP strategies. For a history \( h_t = \{a_0, \ldots, a_{t-1}\} \), Netflix’s continuation value is:

\[
V(h_t, \tau_t) = \max_{a_t, \ldots, a_T} E_{\xi_t, \ldots} \left[ \sum_{t' \geq t} \beta^{t' - t} \pi_N(a_t) \big| h_t, \tau_t \right]
\]

Netflix’s problem is difficult for informational and computational reasons. To know whether they should accept \( f \)'s offer in a given period, Netflix must be able to forecast the next period’s offer, which requires understanding how a rejection will affect the evolution of \( f \)'s beliefs about the distribution of \( \mu_f \). This issue is made complicated by the demand shock \( \xi \), since the unobserved shock will affect \( f \)'s learning in each period in a way that is difficult for Netflix to infer. Computationally, Netflix must optimally choose a vector of actions \( a \) from an action space of size \( 2^{23} \) each period (although this space shrinks as firms exit.)

To manage this complexity, in my base model I assume that Netflix is myopic with \( \beta = 0 \). Combined with the assumption on inelastic demand, this implies that \( N \)'s optimal strategy is separable in offers:

\[
a_{ft}(b, \tau) = a_{ft}(\tau_f) = \begin{cases} 1 & \text{if } \mu_f \geq \tau_f \\ 0 & \text{else.} \end{cases}
\]

Before receiving offers, a myopic \( N \) would like to adopt a more sophisticated strategy, but after receiving offers they can do no better than the above.

Assuming Netflix is myopic and that demand is inelastic simplifies Netflix’s strategy greatly. It also makes it trivial to invert their strategy as a function of their unobserved type, which is important for the ISPs—who will be dynamic—to be able to learn from rejected offers. Because I assume Netflix and the ISPs are bargaining over a lump sum transfer paid in the same period, there is no sense in which I am forcing Netflix to irrationally accept high offers by making them ignore a future stream of payments to ISPs. I show how to allow for elastic Netflix demand in robustness exercises in an online appendix.

**ISPs’ problem**

At the end of time \( t \), after \( f \) has observed the vector of demand shocks \( \xi \), made offers, and Netflix has accepted or rejected each offer, firm \( f \) flow profits are written as follows:

\[
\pi_{ft}(a_t, \tau_{ft}) = \tilde{\pi}_{ft}(a_t) + a_{ft}\tau_{ft}
\]

where \( \tilde{\pi}_{ft}(a_t) \) is the profit earned from \( f \) subscribers at time \( t \), which depends on \( a_t \) as marginal consumers may substitute between ISPs in response to slowdowns. \( \tilde{\pi}_{ft} \) will be recovered from
optimal prices and the demand curve, estimated in the next section. The second component of profits \( \alpha_{ft} \) is equal to the lump sum transfer \( f \) stands to receive if its offer is accepted.

Each ISP \( f \) seeks to maximize expected profits by choosing a best response sequence of offers. Expectations are taken over the probability of each realization of the agreement vector in each period induced by Netflix and \( -f \)'s strategies. \( f \) is best responding both to other ISPs' offers, as well as Netflix's optimal strategy of accepting/rejecting offers:

\[
V(h_t, \xi) = \max_{\tau_{ft}, \ldots, \tau_{fT}} \mathbb{E}_{a_t} \ldots \left[ \sum_{\tau \geq t} \beta^{\tau-t} \pi_{ft}(a_t, \tau_{ft}) \left| h_t, \xi \right. \right]
\]

where \( \xi \) is the complete vector of demand shock realizations for all firms.

To formulate the ISPs’ problem recursively, I show that given Netflix’s optimal strategies and a set of ISP strategies, each ISP’s information set will be a vector of (Bayesian) beliefs about the upper bound on the distributions every ISP faces. That is, \( f \)'s information will be a vector of real numbers \((b_1, \ldots, b_F)\) such that \( f \) knows \( \mu_f' < b_f' \) for every \( f' \).

First, given a set of ISP strategies, if any ISPs remain in the bargaining game at time \( t \) it must mean that their lowest offer in prior periods was rejected; given Netflix’s strategy vis-à-vis \( f \) to accept any offer less than or equal to \( \mu_f \), \( \mu_f \) must therefore be lower than that lowest offer. Second, notice that given ISP strategies and histories, it is possible for each ISP to construct the full information set since ISPs have no unobserved heterogeneity with respect to each other. I restrict ISPs to strategies such that if two histories of acceptance and rejection timings lead to the same information set, the optimal strategies going forward from that information set are identical. This restriction implies equivalence between histories and the information state, so that ISP optimal strategies can be solved as functions of the information state alone.

I formulate ISP \( f \)'s problem recursively as a function of the complete information state:\footnote{Either the full information state, or the complete history of agreement times is necessary. The current vector of commonly observed agreement plus a firm’s own information about \( \mu_f \) is not a sufficient state when there are more than two ISPs. For instance, with three firms, suppose the state is such that one firm has agreed but the other two have not. Without knowing how long ago the first firm agreed, the second and third firms cannot infer each others’ current strategies, which are necessary to determine the transition probabilities to next period’s agreement vector. At any given time, if the first firm agreed very early, then the rate of screening by the other two firms would have been different than if the first firm agreed only recently. Each firm must be able to accurately infer what the other knows about its distribution to predict the probability of agreement in this period.}

\[
V_{ft}(b_f, b_{-f}) = \max_{\tau} \mathbb{E}_{a, \tau} \left[ \pi_{ft}(a, \tau) + \beta V_{ft+1}(\tau, \tau_{-f}) \left| \mu_f < b_f, \mu_{-f} < b_{-f} \right. \right]
\]

I assume all demand shocks \( \xi_{ft} \) are perfectly forecasted, and therefore do not include it as a state variable since value functions are indexed by \( ft \).\footnote{In literature using mixed logit demand systems, firms are either presumed to know each others’ demand shocks as in Berry, Levinsohn and Pakes (1995), or demand shocks are assumed away as in Bajari, Benkard and Levin (2007).} Moreover, I index the value functions by \( f \) and \( t \), so that each named ISP will have its own value function to solve. Since ISPs are highly
heterogeneous in their cross sectional plan offerings, market coverage, and demand shocks, as well
as in the evolution of those characteristics over time, I index value functions to avoid introducing
a high dimensional state space of characteristics.

The goal in the estimation section will be to solve each ISP’s optimal policies to recover proba-
bilities of agreement timings, then use MLE to estimate the parameters of the surplus distribution, \( \theta_s \).

Alternate Sources of Asymmetric Information

To induce delay in agreement, one can introduce (1) asymmetric information as in Fudenberg and
Tirole (1983), (2) irrational optimism as in Yildiz (2004), or (3) stochastic payoffs as in Merlo and
Wilson (1995). I rule out optimism to keep agents rational in this first attempt at using dynamic
bargaining in an industry setting. I rule out the stochastic payoff model as it requires that payoffs
might increase if there is delay, which is difficult to square with this environment where quality
degradation persists, and possibly grows worse, as long as there is disagreement.

An alternative to an unknown additive supply-side surplus might be unknown consumer elas-
ticities. If ISPs and/or Netflix do not know how the marginal subscriber will substitute in response
to a slowdown and they are bargaining over subscriber surplus, a delay might arise. However, if
the purpose of the bargaining delay was for market participants to learn about their own sub-
scriber elasticities, it begs the question of why ISPs and Netflix chose to learn through a costly,
multi-month long quality degradation as opposed to smaller, cheaper experiments.

5.2 ISP Plan Pricing and Profits

In this section I discuss how I recover \( \tilde{\pi}_{ft}(a_t) \) as a function of the demand curve. I assume that
ISPs take the menus of their offerings and the period’s vector of agreements \( a_t \) as given.

If the price elasticities from the demand curve are not greater than one, then I assume a marginal
cost of zero and calculate profits as revenues from the demand curve. If the price elasticities are
greater than one, then \( f \) chooses a vector of prices for its plans to maximize profits, conditional on
the best response pricing of other firms. That is, \( f \) solves

\[
\tilde{\pi}_{ft}(a_t) = \max_{\{p_{jft}\}} M_t \sum_{j \in J_{ft}} s_{jft}(p_t(a_t), a_t)(p_{jft}(a_t) - mc_{jft}),
\]

where \( j \) is an ISP plan (price-download speed combination), \( M_t \) is the size of the market at time \( t \),
and \( J_{ft} \) is the set of plans offered by \( f \) at \( t \). \( s_{jft} \) is the nationwide demand for plan \( j \) offered by \( f \)
at time \( t \).

Taking first order conditions and inverting the system of equations to solve for marginal costs
yields the standard equation:

\[ m_c t = p_t + \Delta_t^{-1} s_t, \]

I assume a plan has the same price nationwide. This restriction is in keeping with the data, where plan prices do not vary across geographic markets. Moreover, since I lack share data at the market level, it is impossible to recover market specific unobservable shocks which would be necessary for taking the derivative of the market specific demand curve.

5.3 Demand

This section of the model predicts demand curves as a function of parameters, Netflix quality degradation, and other data to feed into \( \tilde{\pi}_{ft} \).

Flow utility

The ISPs available to a household vary broadly by geographic market \( m \) and by time \( t \). A consumer in market \( m \) will have an individual specific choice set, reflecting the fact that not all ISPs in that market \( m \) may have infrastructure connected to that individual’s dwelling. Markets are relevant to the consumer as the same ISP operating in two markets may offer different plans.

An individual \( i \) in market \( m \) at time \( t \) chooses among internet service providers \( f \) that belong to that individual’s choice set, \( \mathcal{F}_{mt} \). Each available firm \( f \) offers a menu of vertically differentiated plans \( j \in \mathcal{J}_{fmt} \) which vary by market. Conditional on choosing a firm, a consumer chooses among the available \( j \) offered by \( f \) in \( m \) at time \( t \). The indirect utility to \( i \) from choosing firm \( f \in \mathcal{F}_{imt} \) is

\[ u_{ifmt} = \delta_{ft} + \lambda_{ifmt} + \epsilon_{ifmt}, \]

where \( \delta_{ft} \) is the mean utility each consumer derives from consuming \( f \) at time \( t \). Mean utility depends on ISP fixed effects, time, whether the ISP has reached agreement with Netflix or not, and an unobserved firm specific shock \( \xi_{ft} \):

\[ \delta_{ft} = \tilde{\gamma}(1 - a_{ft}) + \tilde{\alpha}_{ISP_f} + \tilde{\alpha}_{ISP_f \times t} + \xi_{ft}, \]

where \( a_{ft} \) is a dummy indicating whether Netflix and ISP \( f \) have reached agreement and restored quality of service. Based on the reduced form analysis, I expect that \( \tilde{\gamma} < 0 \). Each ISP \( f \) has an

\[ ^{18} \text{I assume that switching costs between vertically differentiated products within a provider, as well as switching costs between providers or to the outside option, are all zero. Prohibiting switching costs between ISPs is done to reduce the computational burden in the supply model, since otherwise ISPs would need to keep track of consumer states.} \]
unobserved dimension of heterogeneity, $\xi_{ft}$. As in similar papers on demand for telecommunications services, this time-varying heterogeneity may reflect quality of customer service and the quality of bundled services—for example, whether a cable internet provider adds or drops channels from its TV service.

Firms are not uniquely identified with a price or download speed, so these variables do not enter $\delta_{ft}$. Individuals choose among $f$’s menu of offered plans, and the effect on indirect utility is captured by $\lambda_{ifmt}$:

$$\lambda_{ifmt} = \max_{j \in J_{fmt}} \{\alpha_{ip} p_{jft} + \alpha_{iq} q_{jft}\} + \alpha_{if} + \gamma_i (1 - a_{ft}).$$

$p_{jfmt}$ and $q_{jfmt}$ are the price and download speed associated with each plan $j$ in the set of plans offered by $f$ in $m$ at time $t$, $J_{fmt}$. $(\alpha_{ip}, \alpha_{iq}, \alpha_{if}, \gamma_i)$ are individual specific coefficients on price, download speed, firm technology, and whether or not there is a slowdown, respectively.

I model consumer heterogeneity $(\alpha_{ip}, \alpha_{iq}, \alpha_{if}, \gamma_i)$ as being comprised of observed and unobserved characteristics. In particular,

$$\begin{align*}
\alpha_{ip} &= -\exp \left( - \left( x_i' \alpha_o^p + \sigma_p \nu_{ip} \right) \right) \\
\alpha_{iq} &= x_i' \alpha_o^q + \sigma_q \nu_{iq} \\
\alpha_{if} &= x_i' \alpha_o^g + \sigma_g \nu_{ig} \\
\gamma_i &= x_i' \gamma_o + \sigma_s \nu_{is}
\end{align*}$$

(2)

where $x_i$ denotes a vector of consumer characteristics including functions of income, household size, etc. and $\{\nu_{ip}, \nu_{iq}, \nu_{ig}, \nu_{is}\}$ denote unobserved (by the econometrician) consumer tastes. Define the complete vector of characteristics for a household as $\omega_i \equiv (x_i, \nu_i)$, and the complete vector of demand heterogeneity parameters $\theta^h_d \equiv (\alpha, \sigma)$. The full vector of demand parameters $\theta_d$ also includes the mean effect of Netflix quality degradation and ISP fixed effects, $\theta_d \equiv (\bar{\gamma}, \bar{\alpha}, \theta^h_d)$.

I assume that the unobserved tastes are distributed independent standard normal across and within consumers. As usual, $\epsilon_{iflt}$ is assumed to be distributed according to the type I extreme value distribution. I borrow the functional form for the heterogeneous price coefficient from Berry, Levinsohn and Pakes (2004).

Consumers have an outside option regardless of their choice set, which reflects either non-purchase or purchase from a dialup internet provider. Indirect utility from the outside option is

$$u_{i0mt} = x_i' \alpha_o^o + \epsilon_{i0mt},$$

where $\xi_{0t}$ is normalized to zero to fix relative utility levels, which are otherwise unidentified.
Market shares

As usual, the conditional choice probabilities for a given consumer $i$ in market $m$ at time $t$ have an analytic form due to the assumption of the type I extreme value error. Given a choice set $F_{mt}$, $i$’s probability of choosing $f$ is:

$$\Pr(f_{imt} = f | F_{mt}, \omega_i) = \frac{\exp(\delta_{ft} + \lambda_{ifmt})}{\sum_{f' \in F_{mt}} \exp(\delta_{f't} + \lambda_{if'mt})},$$

where $\delta_{ft}$ incorporates the mean utility from choosing $f$ in market $m$ at time $t$, and $\lambda_{ifmt}$ incorporates individual and market specific deviations from the mean. I assume the outside option is contained in every choice set.

Within a market $m$, households have a vector of probabilities of being assigned to each choice set in the market. For intuition, a market will be a geographic area defined by the census (a Public Use Microdata Area) while choice sets are observed combinations of ISPs operating in the market. The assignment probabilities potentially depend on households’ observable characteristics, the moments of the distribution of observable characteristics for individuals in each choice set, and the fraction of households each choice set covers within the market. Define $i$’s probability of being assigned to $F_{mt}$ as $\phi_{mt}(F_{mt}|x_i)$, where indexing $\phi$ by $mt$ incorporates the potential for the probability to depend on the distribution of observed characteristics and household weights across choice sets within a market.

To construct market shares at the national level, I aggregate across choice sets for a given $i$, then across $i$ within a market, and finally across markets using potentially time-varying market weights $w_{mt}$:

$$s_{ft} = \sum_m w_{mt} \int \left( \sum_{F_{mt}} \Pr(f_{imt} = f | F_{mt}, \omega_i) \phi_{mt}(F_{mt}|x_i) \right) dG(\omega_i|\theta_d). \tag{3}$$

The equation Equation (3) is the model’s prediction of the distribution of ISP market shares in a given $t$ given the distribution of consumer characteristics, plan characteristics, choice sets and a vector of parameters $\theta_d$. Matching these predicted shares to the observed shares from quarterly filings will form the basis of my estimation strategy as in Berry, Levinsohn and Pakes (2004).

The model also generates the distribution of consumer plan purchases within each firm for given parameter values. In this model, consumer heterogeneity in the valuation of prices and download speeds ($\alpha_{ip}, \alpha_{iq}$) is the only reason why within-firm plan shares are non-degenerate. Matching conditional purchase moments from the MBBA with the model’s predictions will be informative about these consumer heterogeneity parameters. Because the heterogeneity parameters govern the disutility of price, these moments are essential to identify the price elasticity of demand. The share of individuals purchasing plan $j$ from firm $f$ at time $t$ is given by:
\[
    s_{jft} = \sum_{m|f \in m} \tilde{w}_{mt} \frac{\int \left( \sum_{\mathcal{F}_{mt}} 1 \left[ j = \arg \max_{j' \in \mathcal{J}_{mt}} \{ \alpha_{ipjft} + \alpha_{iqjft} \} \right] \Pr(f|\mathcal{F}_{mt}, \omega_i) \phi_{mt}(\mathcal{F}_{mt}|x_i) dG(\omega_i) \right)}{\int \left( \sum_{\mathcal{F}_{mt}} \Pr(f|\mathcal{F}_{mt}, \omega_i) \phi_{mt}(\mathcal{F}_{mt}|x_i) dG(\omega_i) \right)},
\]

where \( \tilde{w}_{mt} = w_{mt}/\left(\sum_{m'|f \in m'} w_{m't}\right) \).

6 Estimation and Identification

6.1 Demand

I use the Berry, Levinsohn and Pakes (1995) approach to estimate demand parameters, with the addition of micro moments as in Berry, Levinsohn and Pakes (2004) to help identify heterogeneity in parameters across the population and provision for choice sets that vary across individuals as in Goeree (2008). I first recover estimates of the unobserved firm (and time) specific utility \( \delta_{ft} \) as a function of demand heterogeneity parameters \( \theta_{hd} \). Next, for choice of instruments \( Z_{fmt} \) I form a GMM objective function using micro moments only to identify the heterogeneity parameters. At the \( \theta_{hd} \) that minimizes the GMM criterion, I recover \( \delta_{ft}(\theta_{hd}) \), and use it to estimate the mean effect of Netflix quality degradation and ISP fixed effects under various assumptions on the joint distribution of the exogenous component of \( \delta_{ft}(\theta_{hd}) \) and \( \xi_{ft}(\theta_{hd}) \).

From Equation (2), the demand parameters \( \theta_d \) to estimate are:

- Mean shifters: \( \{ \bar{\gamma}, \bar{\alpha} \} \)
- Observed heterogeneity: \( \{ \alpha_p^o, \alpha_q^o, \alpha_g^o, \gamma^o \} \)
- Unobserved heterogeneity: \( \{ \sigma_p, \sigma_q, \sigma_g, \sigma_s \} \).

To estimate these parameters, I match three sets of predicted moments to their sample analogues: (1) the covariance between unobserved firm-level heterogeneity and a set of instruments that shift firm markups; (2) the covariances of the observed technology type with observed consumer characteristics; and (3) the covariance of the set of instruments with the difference between the predicted conditional plan shares and observed conditional plan shares.

The first set of moments are useful for identifying the mean consumer valuation for each ISP and for the mean response to the Netflix quality degradation. Given parameter guesses, \( \xi_{ft} \) will allow the model to exactly fit the observed market shares by shifting the mean utility for each firm at each date. Depending on the joint distribution of the ISP dummies, \( a_{ft} \) and \( \xi_{ft} \), I can recover the coefficients \( (\bar{\gamma}, \bar{\alpha}) \) by OLS, FE or IV. In my base specification, interacting these \( \xi_{ft} \) with a set of
contemporaneous and lagged instruments will help identify the mean shifters even in the presence of latent switching costs (see Scherbakov (2015)).

The second set of moments match observed consumer attributes from the 2013 and 2014 waves of the ACS to each consumer’s chosen technology within a geographic market. These moments will be particularly useful in identifying the observed heterogeneity parameters $\alpha$. If, for instance, large households choose the cable option relatively more in a market where cable download speeds are higher compared to large households in a region with poor cable options, the estimation will attribute a positive coefficient to the interaction of download speed with household size. There is substantial variation in the set of plans and technologies available across markets, mostly due to plausibly exogenous geographic variation in ISP service areas. Cross sectional and time series variation in the sets of ISPs that are still negotiating with Netflix in 2013 and 2014 identifies heterogeneous consumer valuations to the slowdown.

The final set of moments will help identify unobserved heterogeneity in the valuation of price and download speed, $(\sigma_p, \sigma_q)$. I match the model’s prediction for the vector of nationwide conditional plan shares for each ISP observed in the MBBA data with the observed conditional shares.\footnote{I drop the highest plan for each provider to have an excluded category, since otherwise the moment will be flat in the parameter value.} Variation in the menus of available plans over time and across ISPs will provide the identifying power for these parameters.

**Recovering $\delta$**

I recover the $\delta_{ft}$ that rationalize the observed nationwide ISP shares according to the standard BLP algorithm. That is, given a guess for $\theta_d$ and an initial guess of the vector of $\delta^0 \equiv (\delta^0_{ft})$, I iterate the following equation until it converges for each $t$:

$$
\delta^{(a+1)}_t(\theta^h_d) = \log(s_t) - \log(\hat{s}_t(\theta^h_d, \delta^{(a)}(\theta^h_d))) + \delta^{(a)}_t(\theta^h_d),
$$

(5)

where $s_t$ is the vector of data on national market shares at time $t$ and $\hat{s}_t(\theta^h_d, \delta)$ is the model’s prediction of shares. Denote the recovered parameters by $\hat{\delta}_{ft}$, where dependence on $\theta_d$ is implicit.

To predict $\hat{s}_t(\theta, \delta)$ requires integrating individual conditional choice probabilities across consumers and choice sets within markets. I integrate by simulation. In each $m$, I sample $r = 1, \ldots, R$ households (with replacement) from the empirical distribution of consumer (and characteristics $x$) in that market, using census provided weights as sampling weights. I draw unobserved heterogeneity $\nu$ from a multivariate standard normal.

Individuals must still be assigned choice sets to construct the integral. In my baseline case, I take $\phi_{mt}(F_{mt})$ to be the empirical share of households in PUMA $m$ who are in choice set $F_{mt}$ from the National Broadband Map. For each sampled household $r$, I assign them a single choice...
set, with probabilities of each choice set dictated by \( \phi_{mt}(\mathcal{F}_{mt}) \). That is, if PUMA \( m \) has 40\% of households in a Comcast-Verizon choice set, I will assign sampled households \( r \) to that choice set with 40\% probability regardless of household characteristics. Denote \( r \) in market \( m \) at time \( t \)'s choice set as \( \hat{\mathcal{F}}_{rmt} \).

The simulated market shares for firm \( f \) at time \( t \):

\[
\hat{s}_{ft}(\theta_d^h, \delta) = \sum_m w_{mt} \frac{1}{R} \sum_r \Pr(f|\hat{\mathcal{F}}_{rmt}, \omega_r, \theta_d^h, \delta_t)
\]

The simulated conditional share for plan \( j \) offered by \( f \) at time \( t \):

\[
\hat{s}_{jft}(\theta_d^h, \delta) = \sum_{m|f \in m} \tilde{w}_{mt} \frac{\sum_r 1 \left[ j = \text{argmax}_{j' \in \mathcal{J}_{fmt}} \{\alpha_{ip} p_{jft} + \alpha_{iq} q_{jft}\} \right] \Pr(f|\hat{\mathcal{F}}_{rmt}, \omega_r, \theta_d^h, \delta_t)}{\sum_r \Pr(f|\hat{\mathcal{F}}_{rmt}, \omega_r, \theta_d^h, \delta_t)}.
\]

where \( \tilde{w}_{mt} = w_{mt} / \left( \sum_{m'|f \in m'} w_{m't} \right) \).

**Estimating the Heterogeneity Parameters**

Having recovered \( \delta \), I estimate the heterogeneity parameters using the second and third sets of moments. The second moment requires that within a market, interacting instruments with the difference in the mean characteristics of households predicted by the model to choose technology \( g \) and the mean observed characteristics of consumers who actually choose \( g \) is minimized:

\[
G^2_R(\theta_d^h, \delta) = \frac{1}{NM_t} \sum_m Z_{gmt} \left[ \frac{1}{n_{gmt}} \sum_{i_{gmt}=1}^{n_{gmt}} x_{i_{gmt}} - E[x|g(f_{int})] = g, \theta_d^h, \delta] \right],
\]

where \( n_{gmt} \) is the number of ACS respondents reporting they use technology \( g \) in market \( m \), and \( NM_t \) is the number of markets at time \( t \). \( g(f_{int}) \) is a function that returns the technology of firm \( f \) in market \( m \) at time \( t \).\(^{20}\)

The conditional mean term in the square brackets is the model’s prediction of the mean characteristics of an individual choosing technology \( g \). I estimate it using the simulated individuals:

\[
E[x|g(f_{int}) = g, \theta_d^h, \delta] \approx \frac{\sum_r x_r \Pr(g(f_{rmt}) = g|x_r, \nu_r, \theta_d^h, \delta)}{\sum_r \Pr(g(f_{rmt}) = g|x_r, \nu_r, \theta_d^h, \delta)}
\]

The third set of moments use data from the MBBA testing program. These moments are similar in spirit to the second set of moments, interacting the difference between actual and predicted

\[^{20}\text{A firm’s technology may vary, e.g. Verizon serves markets using both DSL and fiber optic cable.}\]
conditional shares with an instrument. The moments are:

$$G^3_{ht}(\theta^h, \delta) = \frac{1}{\tilde{F}_t} \sum_f \frac{1}{|\tilde{J}_{ft}|} \sum_{j \in \tilde{J}_{ft}} Z_{ft} \left[ \frac{n_{j|ft}}{n_{ft}} - \hat{s}_{j|ft}(\theta^h, \delta) \right],$$

(7)

where \(\tilde{F}_t\) is the number of firms present in the MBBA data at time \(t\) (with \(\tilde{F}_t \leq F_t\)), \(n_{j|ft}\) is the number of individuals in the data who choose \(j\) as their plan—given that they choose \(f\) at time \(t\)—and \(n_{mt}\) is the number of individuals who choose firm \(f\) at time \(t\). \(\tilde{J}_{ft}\) is the set of plans offered by \(f\) at \(t\) dropping the top plan, and \(|\tilde{J}_{ft}|\) is the total number of plans offered by \(f\) at \(t\).

Potential instruments \(Z_{ft}\) and \(Z_{fmt}\) include a firm’s own prices, technology dummies, and functions of the menu of download speeds, as well as the equivalent quantities for a firm’s competitors. The main concern is that price is endogenous to the unobserved demand shock \(\xi_{ft}\).

Since demand shocks are firm wide, they correspond intuitively to changes in the quality of (non-Netflix related) bundled services, system-wide disruptions in reliability, or the quality of customer service. Since the shocks are observed by \(f\), they are endogenous to contemporaneously set inputs in the firm’s profit maximization problem. I assume that only price is set contemporaneously.

The instruments \(Z_{ft}\) for \(G^3\) that I use are variables that affect \(f\)’s price at time \(t\) but do not depend on \(\xi_{ft}\). I assume that the menu of download speeds evolves exogenously, according to background technological progress that enables faster speeds over the same infrastructure. Functions of competitors’ contemporaneous menu of download speeds, as well as \(f\)’s own speeds, are valid instruments under this assumption. I also use lagged functions of the instruments to separately identify preferences from latent switching costs, as in Scherbakov (2015).

The instruments \(Z_{fmt}\) for \(G^2\) I use are similar to the above: I include a constant, the weighted average of ISP minimum, mean, and maximum offered download speeds across ISPs of the same technology \(g\), as well as a weighted average over all competitors’ minimum, average and maximum download speeds within each market \(m\).

I stack \(G^2(\cdot)\) and \(G^3(\cdot)\) and use two-step GMM to recover \(\hat{\theta}_d^h\) as the parameter that minimizes the objective function. As Hansen (1982) shows, provided that \(R \to \infty\) and the ACS sample sizes go to infinity, the estimator will be consistent.

### Estimating the Mean Parameters

Given an estimate of \(\hat{\theta}_d^h\) that minimizes the GMM objective function, I use the recovered \(\hat{\delta}_{ft}\) to estimate the mean parameters \((\bar{\gamma}, \bar{\alpha})\). From Equation (1), \(\hat{\delta}_{ft}\) is comprised of ISP-specific fixed effects and time trends, as well as the mean effect of the slowdown.

In my baseline case, I estimate Equation (1) by a fixed effects regression with instruments for the slowdown dummy. My timing assumption is that firms observe \(\xi_{ft}\) before they optimize over the offer they make to Netflix. Thus, an anticipated demand shock will change the marginal value
of agreement, inducing different screening and a correlation in the distributions of $\xi_{ft}$ and $a_{ft}$. I instrument for $a_{ft}$ using a subset of the markup-shifting instruments $Z_{ft}$ described above. If $f$’s opponents exhibit changes in their menu of offered speeds, this change also affects $f$’s marginal returns to agreement with Netflix but is plausibly exogenous to $\xi_{ft}$.

Falsifying an Alternative Demand Model

A concern that arises from my formulation of the demand model is that it does not directly allow the Netflix slowdown to affect consumers based on their chosen download speed. One can imagine that if the slowdown is a proportional reduction in throughput to Netflix, higher download speed consumers will suffer less since they can absorb greater absolute throughput reductions before streaming quality becomes a problem.

If this concern is valid, then it introduces another reason for ISPs to delay bargaining: ISPs may throttle Netflix traffic to force consumers to purchase faster plans to upgrade their way out of the slowdown. Since faster plans are higher margin, ISPs stand to benefit, especially if consumers experience a ratcheting effect in their preferences for speed.

I examine whether consumers change their speed upgrading behaviour at affected ISPs during periods of disagreement. I use the panel of MBBA consumers to show using individual level data that consumers do not disproportionately increase their rate of upgrading at ISPs affected by the disagreement.

I run LPM specifications of the following form:

$$P_{it}(j'|j,f) = \gamma disagree_{ft} + \beta \Delta \log p_{ft} + \alpha_{i} + \alpha_{t},$$

where $P_{it}(j'|j,f)$ is the probability that consumer $i$ changes their plan at ISP $f$ to any $j'$ with speeds greater than those of their current plan $j$, $disagree_{ft}$ is a dummy indicating whether ISP $f$ is still negotiating, and $p_{ft}$ is the price of $f$’s entry level plan. Results are presented in Table 8 and indicate a robust correlation between the probability of exiting an ISP and whether that ISP is currently experiencing degraded Netflix quality. The coefficient on the $disagree_{ft}$ variable is consistently negative and significant. Far from upgrading their speed during the slowdown, consumers in fact slowed down their rate of upgrading, which provides evidence against the "forced upgrading" rationale for prolonging negotiations with Netflix.

6.2 Upstream Bargaining

The supply side parameters to estimate are $\theta_{s}$, a vector that governs the distribution of $\mu_{f}$,

$$F(\mu_{f}|w_{f},\theta_{s}).$$

I assume that $\mu_{f}$ is the product of an observable function of ISP attributes $w_{f}$,
and an ISP-specific shock \( \zeta_f \) that is observed by Netflix but not by the ISP or the econometrician:

\[
\mu_f = \exp(\mu' w_f) \exp(\sigma \zeta_f),
\]

I assume that \( \zeta_f \) is distributed normal but truncated from below, and that each draw \( \zeta_f \) is independent and identically distributed, which implies a truncated lognormal distribution for \( \mu_f \).

To estimate \( \theta_s \equiv (\mu, \sigma, \zeta) \), I will rely on maximum likelihood. Given a guess of the parameters, I solve the optimal state contingent policy functions for ISPs, which generates a joint probability distribution of agreement timings and offers. From the data section, I only have observed agreement/disagreement timings \( \{T_f\} \) so the likelihood function will have the form:

\[
L(\{T\}_f; \mu, \sigma) = P(\hat{T}_1(\mu, \sigma) = T_1, \ldots, \hat{T}_F(\mu, \sigma) = T_F),
\]

where \( \hat{T}_f(\mu, \sigma) \) are agreement times predicted by the model for a given parameter vector. I suppress the implicit dependence of predicted agreement times on demand side parameters.

For the likelihood to be well-identified, one of two situations must be true: the model may give unique predictions for agreement times for a given set of parameter values. Alternatively, the model may have multiple equilibria for given \( \theta_s \), but as long as the data is only generated by one equilibrium and I select the correct predicted equilibrium when forming the likelihood I will recover the correct parameter values.

To construct the likelihood I must find the predicted agreement times as a function of parameters, which will follow from recovering the optimal policies. I first detail what variation in the data will identify the parameters of the distribution, then describe how I recover optimal policies and in doing so, select an equilibrium to input into the likelihood.

**Identification of \((\mu, \sigma, \zeta)\)**

To identify the supply side parameters, I rely on (1) cross-sectional variation in the disagreement durations, and (2) the cross sectional correlation in covariates and durations, conditional on the marginal increase in flow profits from agreement.

Estimating \( \sigma \zeta \) is straightforward: only \( \sigma \zeta > 0 \) allows the model can generate positive disagreement durations, since \( w_f \) is observed. Variation in disagreement times across ISPs that look similar in terms of covariates and flow profits will identify the dispersion parameter \( \sigma \zeta \).

Recovering \( \mu \) is more challenging: in the standard screening model with linearly transferable utility and no outside stream of profits, the rate of screening is independent of the parameter \( \mu \). Increasing \( \mu \) does not affect the relative cost of postponing agreement, so the probability of an agreement time appearing in the data remains the same for different \( \mu \). In other words, the duration based likelihood is flat in \( \mu \). However, with side payments, if high \( w_f \) ISPs that face large
dips in profits if agreement is not reached have long disagreement lengths in the data, then $\mu$ must be positive and significant. This follows because $\mu$ increases both the mean and the variance of $\mu_f$: if increasing $\mu$ lead to a pure mean shift, then $\mu$ would still be unidentified even with side payments.

**Solving for Policy Functions**

To form the likelihood, I must solve for optimal policies. If firms care about the states and strategies of all other firms the model quickly becomes intractable. I adopt a cutoff rule to mitigate this curse of dimensionality. First, for $f$ consider all $-f$ such that each $-f$ overlaps at least 15% of $f$’s footprint. Starting with Comcast, I determine all such $-f$—Comcast’s primary competitors—and then determine the $-f$ of those primary competitors. Following this procedure until no new firms are added will form a minimal group that cares about the actions of all other members of that group, even if some members’ footprints do not overlap.

The minimal group constructed in such a way is Comcast, AT&T, TimeWarner and Verizon; call this set of ISPs $\mathcal{F}_L$. I assume when solving these firms' optimal policies that they pay attention to the markets that are exclusively served by members of the group. Other ISPs react to the policies of the biggest four, but do not affect the four in turn, which keeps the state space of the large ISPs manageable.

Small ISPs primarily compete with large ones (see Table 9), so I assume small ISPs do not pay attention to each other. I also assume that small ISPs play strategies such that large ISPs with which they do not overlap behave deterministically according to their durations in the data. For instance, the small cable internet provider Mediacom’s state space includes the information state of AT&T and Verizon, but Mediacom assumes Comcast—a large cable provider that AT&T and Verizon care about—deterministically reaches agreement in the third quarter of negotiations.

The equilibrium I select gives Comcast the first mover role. As in Jia (2008) or Björkegren (2015), I begin by specifying that all other $f \in \mathcal{F}_L$ agree immediately. After solving Comcast’s optimal response, I perform a round robin algorithm, updating the optimal strategies of each of the four large ISPs in turn until their policy functions converge. I then recover the policy functions of the smaller ISPs given the optimal behaviour of $f \in \mathcal{F}_L$.

The full set of policy functions gives the joint distribution over agreement timings for the chosen $\theta_s$. Since large ISPs do not pay attention to small ISPs and small ISPs only pay attention to large ISPs, the likelihood function can now be written as

$$
\mathcal{L}(\{T\}_f; \mu, \sigma_\zeta) = P\left(\left\{\hat{T}_f(\mu, \sigma_\zeta) = T_f\right\}_{f \in \mathcal{F}_L}\right) \prod_{f \in \mathcal{F}_S} P\left(\hat{T}_f(\mu, \sigma_\zeta) = T_f \mid \left\{\hat{T}_f(\mu, \sigma_\zeta) = T_f\right\}_{f \in \mathcal{F}_L}\right),
$$

---

21 Jia (2008) uses this approach for estimation as I do, while Björkegren (2015) uses it for computing counterfactual equilibria. By choosing the first mover and the order of responses, this procedure selects an equilibrium; recent papers that mention this feature of the algorithm include Wollman (2016) and Lee and Pakes (2009).
where $\mathcal{F}_S$ is the set of smaller ISPs.

**Terminal Dates**

Since ISP value functions depend on $t$ and not states alone, policy functions will be solved backwards from a terminal condition. My condition is dictated by data limitations: I have price data until the end of 2014, and the National Broadband Map extends only through the middle of 2014. I assume that bargaining terminates in December 2014 with the minimal offer, which is always accepted.

I predict the evolution of profits after 2014 with a flexible time series. This is necessary since firms that exit bargaining enjoy their discounted payoff into the infinite future. Given the terminal condition, I solve policy functions by iterating backwards.

**Shape of Joint Density of Agreement**

Each ISP will offer a strictly decreasing sequence of fees to screen Netflix’s unobserved ISP specific type. Indeed, even without flow profits it is never optimal to make an offer outside the updated conditional support of $\mu_f$, and the fact that slowdowns always hurt ISP flow profits intensifies the incentives to reduce offered fees over time.

The question remains whether an ISP will decrease its offers more quickly or more slowly once a rival has concluded agreement. This feature of the model will be important for the counterfactual merger analysis. If a rival’s agreement increases the marginal benefit (from flow profits) to own agreement (supermodularity in flow payoffs), then if the merged firm screens faster so too will the other firms. If a rival’s agreement decreases the marginal benefit to own agreement (submodularity in payoffs), then faster screening by the merged firm will lead to slower agreement times on average by the other firms. Figure 11 and Figure 12 give the shape of the joint density of agreement timings for two ISPs in the case where flow profits are submodular and supermodular. *Ex ante*, analytic derivations of the flow profits imply submodular profits as in Jia (2008). Full tests of the degree of submodularity are presented in the online appendix.

### 7 Empirical Results

This section presents estimation results of the demand model and dynamic bargaining framework.

#### 7.1 Demand estimates

Table 1 summarizes the key estimated parameters for the demand model. The first column refers to the ISP characteristic, and the second the household characteristic that it is being interacted with. The mean effect of disagreement is negative and significant, implying a baseline level of

---

22I will evaluate different assumptions on the terminal date $T$ in future robustness checks.
disutility from disagreement as reflected in the aggregate market share movements. Unobserved consumer preferences against the slowdown are large and significant while observed heterogeneity is mostly insignificant, suggesting that latent Netflix subscribership patterns are not captured by the observable covariates.

The coefficients on price and download interactions are mostly significant, and unobserved heterogeneity is very important. Recall that the price coefficient is of the form

$$\alpha_{ip} = -\exp(- (\alpha_{o1} + \sigma_{ip} \nu_{ip} + \alpha_{o2} Inc + \alpha_{o3} Inc \times q_{25, Inc})).$$

Coefficient signs are intuitive: increases in income reduce the disutility of price increases, although these effects are dampened for income earners in the first quartile. For download speed, larger households have preferences for higher speeds, but this sharply drops off for households larger than 4 members.

The dispersion in unobserved preference for the price will help recover a non-degenerate predicted distribution of plan shares. This feature of the model is important not only to match the data, but to recover meaningful price elasticities. With degenerate plan shares, the price elasticity for plans with no share will be zero or infinite. Moreover, the elasticity for plans with a positive share will be too small if price changes mostly induce switching across ISPs and not switching within an ISP’s own menu.

I estimate a large set of heterogeneity parameters for the cable technology dummy. Since bundling opportunities are most prevalent with cable, allowing valuation of different technologies to vary by household characteristics helps recover credible estimates of the price coefficient. I find that larger households and households headed by men draw greater utility from having a cable subscription.

The demand curve’s main purpose is as an input to the bargaining game. Consumer substitution in response to a slowdown makes lengthy bargaining costly, and will identify the parameters of the distribution of unobserved surplus in combination with disagreement durations. I present the substitution patterns for the four largest ISPs in table Table 2. The experiment is to turn on the disagreement dummy for each ISP in turn, assuming that all other ISPs have finished bargaining. Since demand is static, this experiment captures the marginal consumers an ISP has to lose if it does not conclude negotiations with Netflix if all other ISPs have already agreed.

In response to the slowdown, consumers at cable internet providers (Comcast, TimeWarner) mostly switch to AT&T, while consumers at non-cable providers switch to Comcast. These patterns reflect the overwhelming market presence of Comcast and AT&T as the providers with the largest footprints. This also reflects my assumptions on the functional form of utility: the best alternative to 1.50Mb/s AT&T is not 6 Mb/s AT&T because the disutility of lower streaming quality does not decrease in the purchased download speed.
Table 1: Demand Model Parameter Estimates

<table>
<thead>
<tr>
<th>ISP char.</th>
<th>HH char.</th>
<th>Notation</th>
<th>Parameter</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disagree</td>
<td>Constant</td>
<td>$\gamma$</td>
<td>-0.011*</td>
<td>0.004*</td>
</tr>
<tr>
<td></td>
<td>HH size</td>
<td>$\alpha_{s1}$</td>
<td>-0.040</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>HH size $\times 1[\text{size } \geq 5]$</td>
<td>$\alpha_{s2}$</td>
<td>-0.076</td>
<td>0.040</td>
</tr>
<tr>
<td></td>
<td>Speak English</td>
<td>$\alpha_{s3}$</td>
<td>0.294</td>
<td>0.152</td>
</tr>
<tr>
<td></td>
<td>Male head</td>
<td>$\alpha_{s4}$</td>
<td>-0.002</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Unobs. het</td>
<td>$\sigma_s$</td>
<td>0.544*</td>
<td>0.247</td>
</tr>
<tr>
<td>Price</td>
<td>Constant</td>
<td>$\alpha_{p1}$</td>
<td>3.698***</td>
<td>1.099</td>
</tr>
<tr>
<td></td>
<td>Income</td>
<td>$\alpha_{p2}$</td>
<td>0.093**</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Income $\times q_{25,Inc}$</td>
<td>$\alpha_{p3}$</td>
<td>-0.020</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>Unobs. het</td>
<td>$\sigma_p$</td>
<td>0.686***</td>
<td>0.203</td>
</tr>
<tr>
<td>Download</td>
<td>Constant</td>
<td>$\alpha_{q1}$</td>
<td>0.027***</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>HH size</td>
<td>$\alpha_{q2}$</td>
<td>0.762***</td>
<td>0.202</td>
</tr>
<tr>
<td></td>
<td>HH size $\times 1[\text{size } \geq 5]$</td>
<td>$\alpha_{q3}$</td>
<td>-0.365**</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td>Speak English</td>
<td>$\alpha_{q4}$</td>
<td>0.559</td>
<td>0.455</td>
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<tr>
<td></td>
<td>Male head</td>
<td>$\alpha_{q5}$</td>
<td>0.489***</td>
<td>0.145</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>$\alpha_{q6}$</td>
<td>0.010*</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>Unobs. het</td>
<td>$\sigma_q$</td>
<td>1.157***</td>
<td>0.330</td>
</tr>
<tr>
<td>Cable Dummy</td>
<td>HH size</td>
<td>$\alpha_{g1}$</td>
<td>0.061*</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>HH size $\times 1[\text{size } \geq 5]$</td>
<td>$\alpha_{g2}$</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>Speak English</td>
<td>$\alpha_{g3}$</td>
<td>0.034</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Male head</td>
<td>$\alpha_{g4}$</td>
<td>0.107*</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>$\alpha_{g5}$</td>
<td>0.041</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td>Unobs. het.</td>
<td>$\sigma_g$</td>
<td>0.239</td>
<td>0.162</td>
</tr>
</tbody>
</table>

This table presents estimates of the non-linear consumer preference parameters, as well as the linear effect of disagreement $\gamma$. Standard errors for the non-linear parameters are computed from the numerical derivatives of the GMM moments at the estimated parameters. The linear parameter estimate standard errors come from the linear IV with fixed effects regression of $\delta(\theta^d)$ on firm dummies and time trends, and the disagreement dummy.
Switching rates increase mostly uniformly by download speed: individuals with higher speeds switch more in response to the slowdown. The increase is especially steep for Comcast and Verizon, while at AT&T higher speed subscribers do not switch much more than lower speed ones. Since different speeds of internet are provided at roughly the same marginal cost, high speed customers are also high margin customers. Results from this table imply that Comcast and Verizon have an especially strong incentive to conclude negotiations quickly, whereas the marginal loss to AT&T from prolonged disagreement is lower.

Table 2: Consumer Substitution in Response to Streaming Quality Degradation

<table>
<thead>
<tr>
<th>ISP</th>
<th>Plan</th>
<th>% Switch</th>
<th>Best Alt.</th>
<th>Best Plan</th>
<th>% Switch cond.</th>
<th>% Out cond.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T</td>
<td>1.50</td>
<td>0.31</td>
<td>Comcast</td>
<td>3</td>
<td>22.27</td>
<td>46.88</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>6</td>
<td>0.29</td>
<td>Comcast</td>
<td>3</td>
<td>23.20</td>
<td>40.30</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>12</td>
<td>0.32</td>
<td>Comcast</td>
<td>3</td>
<td>22.87</td>
<td>40.38</td>
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<tr>
<td>AT&amp;T</td>
<td>18</td>
<td>0.34</td>
<td>Comcast</td>
<td>50</td>
<td>27.08</td>
<td>36.15</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>24</td>
<td>0.34</td>
<td>Comcast</td>
<td>50</td>
<td>26.46</td>
<td>22.00</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>45</td>
<td>0.36</td>
<td>Comcast</td>
<td>50</td>
<td>21.95</td>
<td>9.28</td>
</tr>
<tr>
<td>Comcast</td>
<td>3</td>
<td>0.38</td>
<td>AT&amp;T</td>
<td>1.50</td>
<td>16.27</td>
<td>46.90</td>
</tr>
<tr>
<td>Comcast</td>
<td>50</td>
<td>0.52</td>
<td>AT&amp;T</td>
<td>24</td>
<td>20.41</td>
<td>25.14</td>
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<tr>
<td>Comcast</td>
<td>105</td>
<td>0.65</td>
<td>AT&amp;T</td>
<td>45</td>
<td>30.35</td>
<td>6.43</td>
</tr>
<tr>
<td>TimeWarner</td>
<td>1</td>
<td>0.43</td>
<td>AT&amp;T</td>
<td>1.50</td>
<td>20.56</td>
<td>49.06</td>
</tr>
<tr>
<td>TimeWarner</td>
<td>15</td>
<td>0.43</td>
<td>AT&amp;T</td>
<td>24</td>
<td>21.18</td>
<td>37.28</td>
</tr>
<tr>
<td>TimeWarner</td>
<td>20</td>
<td>0.45</td>
<td>AT&amp;T</td>
<td>24</td>
<td>40.14</td>
<td>10.64</td>
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<td>50</td>
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<td>AT&amp;T</td>
<td>45</td>
<td>20.72</td>
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<tr>
<td>Verizon</td>
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<td>0.29</td>
<td>Comcast</td>
<td>3</td>
<td>18.41</td>
<td>46.68</td>
</tr>
<tr>
<td>Verizon</td>
<td>7.10</td>
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<td>Comcast</td>
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<tr>
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<td>25.62</td>
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<td>Verizon</td>
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<td>0.47</td>
<td>Comcast</td>
<td>105</td>
<td>37.68</td>
<td>2.52</td>
</tr>
</tbody>
</table>

The experiment in this table is to turn on the disagreement dummy for each ISP in turn, assuming that all other ISPs have agreed already. I use data from 2013-06-01. The Best Alt. and Best Plan columns give the ISP and plan to which the most subscribers switch conditional on switching. The last two columns give the percent of individuals who switch to the next most popular plan, and the percentage who switch to the outside option, conditional on switching.

The demand curve must be combined with a method for deriving the price-cost margin to recover profits. I compute the price elasticity for every plan in every quarter, and find that the median elasticity across offered plans in all quarters is 2.667. However, there is large variation, with an interquartile range of over 10 and almost 30% of plan price elasticities falling below one. In theory all elasticities should be above one, although elasticities for broadband below one are consistent with recent estimates in Dutz, Orszag and Willig (2012). The substantial fraction of
elasticities falling below one precludes using a demand system inversion to recover marginal costs, so I assume a marginal cost of zero and take the evolution of prices over time as exogenous in my base case for estimating the supply parameters.

To assess model fit, I regress the model predicted conditional plan shares against actual plan shares from the MBBA data. I recover an $R^2$ of 0.76, and across the entire sample I cannot reject the null that the slope is one. I also find that the model predicts degenerate within-ISP plan shares in only 6% of quarter-ISP combinations, and never for any of the largest four ISPs. To indirectly validate the predictions in Table 2 and verify that the model does not do poorly during the periods of the slowdowns, I calculate the quarter by quarter $R^2$ and slope estimates for the regression of predictions on data.\textsuperscript{23} I find that the $R^2$ has a slight inverted u-shape, with the highest values during 2013. The model’s good performance even during the slowdown is encouraging, although it also likely reflects the fact that unobserved price and download heterogeneity in the model does not vary over time but plan characteristics are slowly improving.

7.2 Upstream Bargaining Estimates

The demand estimates from the previous section are combined with the dynamic multilateral bargaining assumptions and disagreement durations to estimate the distribution of Netflix’s marginal value of agreement vis-à-vis each ISP. Estimates of the coefficients of the mean shifting variables $w_f$, as well as the standard error of the dispersion of information $\sigma_\zeta$, are presented in Table 3.

<table>
<thead>
<tr>
<th>Table 3: Supply model estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLE</td>
</tr>
<tr>
<td>$\sigma_\zeta$</td>
</tr>
<tr>
<td>footprint</td>
</tr>
<tr>
<td>footprint squared</td>
</tr>
<tr>
<td>DSL dummy</td>
</tr>
</tbody>
</table>

The DSL dummy takes a value of 1 if the ISP’s primary transmission technology in the last-mile is DSL. Pass-by is the number of houses connected to the internet by the ISP in hundreds of millions. Standard errors coming soon.

The most parsimonious version of the model in column (1) features $\sigma_\zeta$ only, so that $\mu_f = \exp(\sigma_\zeta \zeta_f)$, with $\zeta_f$ unobserved by the ISPs. With no shifters $w_f$, the ISPs whose marginal loss in subscribers is largest would be predicted to agree most quickly. In the data the largest ISPs have the greatest marginal loss in subscribers but also take the longest time to agree, which will require the presence of the shifters $w_f$ to rationalize.

\textsuperscript{23}Unfortunately the MBBA does not track well consumers who switch ISPs, so there is no way to directly verify in the data if the substitution patterns in response to a slowdown predicted in hold.
Since the number of ISP that bargain is limited \((N = 22)\), I restrict the number of covariates to functions of the footprint—the number of housing units in each ISP’s physical network—and the ISP’s connection technology. My preferred estimates are column (3), where I allow a quadratic term in pass-by. The quadratic term allows for increasing or decreasing returns to scale for Netflix in installing the interconnection technology; the positive estimated coefficient in specification (3) suggests increasing returns to scale, so that Netflix’s cost savings from making the investment increase in the size of the ISP’s network. This agrees with Netflix’s own statements that there are returns to scale in interconnection. All else equal, the larger a provider’s network, the greater the value in interconnection: evaluated at mean pass-by, increasing the number of households passed by 10 million increases the mean of the surplus distribution by 3.2 million.

Combining firm optimal screening strategies with the supply model estimates yields a key prediction of the model: the expected share of bilateral surplus that accrues to Netflix and each ISP. Understanding how this share varies with ISP size is crucial to understanding whether how Netflix’s incentive to make its quality investment changes with the size of a negotiating ISP’s network.

To see how the model predicts shares, suppose that ISP \( f \) makes offer \( \tau_{ft} \) that is accepted by Netflix. The model predicts that the surplus is distributed \( F(\mu_f | \mu_f < \tau_{ft-1}; w_f, \theta_s) \), so that Netflix’s expected surplus share in that period is \( E(\mu_f | \mu_f < \tau_{ft-1})/\mu_f | \mu_f < \tau_{ft-1} \). Integrating over the marginal distribution of agreement timing offers for a given ISP will give Netflix’s expected share for that ISP.

Netflix’s \textit{ex ante} expected share against the four largest ISPs ranges between 28% against AT&T and 33% against Comcast. On average, Netflix retains 34% of its surplus against smaller firms. That Netflix’s share is low even though its subscribers are inelastic is partially driven by modelling assumptions: myopia substantially increases Netflix’s willingness to accept high fee offers, decreasing their share of the surplus. However, variation in shares across ISPs will incorporate differences in ISP subscriber elasticities, which reflects ISP’s consumer-facing market power, as well as the size and dispersion of Netflix’s surplus for that ISP, which reflects the how the model rationalizes systematic differences in agreement times.

Large ISPs are predicted to take their time in bargaining because the surplus they stand to extract from Netflix is relatively large compared to their subscriber loss. Since it is more worthwhile to try and extract surplus with a fine screening strategy for these ISPs, they will naturally appropriate a greater share in equilibrium.

Since the surplus is only divided after a delay, from the \textit{ex ante} perspective a certain fraction

---

\[ ^{24} \text{...our actual costs rise with every additional point of interconnection...Moreover, interconnecting at more locations can be less efficient, and thus more expensive, for Netflix. With each additional location, the costs associated with placing and maintain each location—e.g., servers, routers, rent, cabling costs—are spread across a smaller amount of capacity.} \] Paragraph 20, Statement of Ken Florance, Vice President of Content Delivery at Netflix since 2012.
of surplus will be lost by pushing its realization into the future. On average lost surplus is roughly 12%, with a high of 14% against AT&T. Recall that this inefficient delay is necessary in order for Netflix to signal its true valuation: the only credible way Netflix can claim to have a low surplus from investing vis-a-vis a particular ISP is by rejecting high fee offers, which will push bargaining and the realization of the surplus into the future.

I assess the model fit by plotting the predicted time to a successful offer against the actual time in Figure 7. The correlation is positive and significant and while an unweighted regression is nowhere near the 45 degree line, the model does perform better for the larger ISPs. The ISPs that agree immediately in the data are predicted to take just over a quarter longer to agree in the model. Since their pass-by is so small, their average time to agreement mostly reflects the estimate of $\sigma_\zeta$. Recall that the observable component on $\mu_f$ can increase dispersion and time to agreement, but cannot ensure positive probabilities of delay on its own. Since the estimate of $\sigma_\zeta$ must also rationalize the presence of small ISPs who still take time to bargain, it will tend to overpredict delays for ISPs that agree quickly in the data and underpredict delays for ISPs that take more time. This is not a problem with the model however, as differences in agreement times for similar ISPs simply reflects variation in the draws of $\mu_f$.

Note also that the model fit improves with the additional of the quadratic surplus, validating the inclusion of this term as a mean shifter in the surplus distribution. The positive estimated quadratic term helps with fit, and will be especially important for the merger counterfactual, since it implies that interconnecting with Comcast and TimeWarner’s networks separately is not as valuable as interconnecting with the single, merged provider whose network is equal in size to the sum of the other two.

Finally, as a byproduct of estimation, the model predicts the exact offers that are made in the period where Netflix agrees. These fees are potentially of interest to other large content providers if the practice of paying terminating fees to last-mile ISPs becomes more prevalent in the future. I find lump sum transfers of 19.0 million USD to AT&T, 12.64 million to Comcast, and 3.89 million and 4.90 million to TimeWarner and Verizon, respectively. Smaller ISPs recoup fees around 1 million USD, with the lowest fees going to Mediacom and Brighthouse—two small ISPs whose bargaining only resolved after a 4 quarter delay. The largest ISPs and Netflix earn billions of dollars in yearly revenue, so these interconnection fees are comparatively small.
8 Counterfactuals

8.1 Comcast-TimeWarner merger

With both the supply and demand estimates in hand, I turn to the paper’s main counterfactual—the effect of a merger between Comcast and TimeWarner. There are three dimensions on which to evaluate the merger. First, does the hold-up problem for Netflix’s capacity investment change? That is, do the ex ante predicted splits of the upstream surplus change, both at the merged firm and its competitors? Second, does consumer welfare change? Third, and related to the second point, how do bargaining times—and the fraction of ex ante surplus lost due to delays—change?

The first criterion speaks to the increased degree of extractive power held by the larger merged firm which affects the split of surplus, and disincentivizes Netflix from making the quality investment. The last two criteria speak directly to dead weight loss and consumer welfare, which are the typical targets for judging the value of a merger. In this case the delay in agreement generates a deadweight loss, both because streaming quality degradation directly reduces welfare and because it pushes realization of surplus to the (discounted) future.

I first examine how bargaining times vary across all ISPs. I plot the change in the ex ante expected bargaining times in Figure 8 for ISPs that experience a non-negligible change. The merged ISP has an ex ante expected disagreement length of 3.69; while this is not a huge percentage
increase in duration length for customers who were previously with Comcast (3.43 quarters), it is quite large for former TimeWarner customers (2.84 quarters). Other ISPs that experience changes in bargaining duration due to the merger uniformly experience slight decreases. From Table 9, notice that these ISPs are all ones that have a great deal of market overlap with Comcast and/or TimeWarner.

The quadratic term in the mean-shifting component of the surplus distribution drives the result that bargaining takes more time. The merged firm has the combined footprint of Comcast and TimeWarner, but the mean and dispersion in $\mu_f$ increase more than linearly. Meanwhile, since there is 0% market overlap between these ISPs, the merged firm’s marginal loss in subscriber revenue as a result of disagreement is simply the sum of Comcast and TimeWarner’s marginal losses. However, the surplus they stand to gain from finer screening is greater than the sum of the surpluses that Comcast and TimeWarner stood to get individually. To reiterate, this intuitively represents that for Netflix, there are more cost-savings associated with investing in one large network than two smaller ones.

To understand why direct competitors of the merged firm take slightly less time, recall that since profits are submodular in the agreement vector, ISPs have more subscriber revenue to (re)gain on the margin by being the first to agree. In equilibrium the merged firms will screen slightly faster on average to capture the greater expected marginal gain of being the first to agree.

I estimate aggregate consumer surplus under three scenarios: without any quality degradation, with the joint distribution of quality degradation predicted by the model, and with the counter-
factual joint distribution of degradation when Comcast and TimeWarner are allowed to merge. I use the standard closed-form logit formula to derive individual surplus and then aggregate across consumers and markets.\footnote{26}

The \textit{ex ante} aggregate consumer surplus decreases by 0.51 percent moving from no quality degradation to the expected degradation lengths produced by the fitted model in Figure 7. Aggregate surplus decreases by 0.54 percent moving from no quality degradation to the expected degradation lengths produced in the new competitive environment after the merger, a roughly 4.3 percentage point increase in magnitude. The aggregate decrease masks heterogeneity in responses across choice sets. The 20 percent of households facing choice sets that previously included Time-Warner see the magnitude of their aggregate welfare loss increase by 17.6 percentage points (to 0.60 percent), while the 34 percent of households in choice sets that include Comcast see their aggregate welfare loss increase by 6.5 percentage points. Households facing choice sets that include a DSL or Fiber provider that share a large footprint with the merged firm, but that do not include the firm itself actually enjoy an increase in aggregate surplus of 0.3 percentage points due to slightly shorter expected slowdown durations.

The merger affects the amount of surplus that is lost due to delays. The substantial increase in \textit{ex ante} predicted disagreement times compared to the base case implies that 16 percent of the upstream surplus is expected to be lost in the bargaining game between Netflix and the merged ISP, an increase of almost 30 percentage points from the case with no merger. Reductions in \textit{ex ante} disagreement times for other ISPs imply that the share of surplus that is lost in bargaining decreases slightly from 12 to 11 percent on average. Netflix’s \textit{ex ante} expected share of the surplus with respect to the merged firm decreases to 29 percent, from an aggregate (combined Comcast and TimeWarner) share of 32 percent, a decrease of just over 9 percentage points.

The split and size of upstream surplus matters for Netflix’s decision to invest in the CDN infrastructure. In particular, if the bargaining environment grows more adverse then there will be a hold-up problem, as either bargaining delays or greater ISP bargaining power prevents Netflix from realizing all of the surplus from its investment. I investigate the effect of the merger on Netflix’s incentive to invest by analyzing how the merger changes the \textit{ex ante} distribution of aggregate surplus net of transfers to ISPs. I will compare these distributions of aggregate surplus to an estimate of Netflix’s upfront investment cost to develop the CDN.

I assume that Netflix first draws ISP specific surpluses, then pays the R&D cost.\footnote{27} From the model, I can recover the \textit{ex ante} distribution of aggregate surplus net of transfers accruing to Netflix

\begin{align*}
\hat{W}_{rmt} &= \frac{1}{\alpha_r} \log\left( \sum_{f \in F_{rmt}} \exp(\delta_{ft} + \lambda_{r,fnt}) \right), \\
\hat{W}_t &= \sum_m w_{mt} \frac{1}{R} \sum_r \hat{W}_{rmt}
\end{align*}

\footnote{27Intuitively, this reflects the idea that Netflix does a cost benefit analysis before committing to the project.}
given optimal firm strategies in both the original and merger cases:

\[
\sum_f \beta^{\hat{T}_f} \left( \mu_f - \tau_f, \hat{T}_f(\mu_f) \right) \sim G, \quad \sum_f \beta^{\hat{T}_f} \left( \mu'_f - \tau'_f, \hat{T}'_f(\mu'_f) \right) \sim G',
\]

where \( \mu_f \) is random, \( \hat{T}_f(\mu_F) \) is the random stopping time predicted from optimal strategies that depends on the draw \( \mu_f \), and the variables with primes denote the same quantities drawn under the counterfactual industry structure where Comcast and Time Warner merged.

I do not observe the initial fixed cost Netflix must expend on research and development before it can begin offering to install the CDN in ISP networks. I recover an estimate of the maximum possible fixed costs: given the actual observed agreement times, the model predicts the actual offer and an upper bound on each ISP-specific surplus as the previous period’s rejected offer.\(^{28}\) The sum of the upper bounds minus the actual offer (appropriately discounted) gives Netflix’s maximum possible surplus from negotiation, which is an upper bound on its fixed cost. I estimate this quantity as 9.03 million USD. The lower bound on the fixed cost is zero: if Netflix’s surplus is exactly equal to ISPs’ fee in the periods Netflix accepts, then Netflix retains no surplus, and may therefore have been indifferent about initiating bargaining:

\[
0 \leq FC \leq \sum_f \beta^{\hat{T}_f} (\tau_f, T_f - 1 - \tau_f, T_f)
\]

I plot the histograms of \( G \) and \( G' \) in Section 8.1. The distribution of net surpluses without the merger first order stochastically dominates the distribution of surpluses with the merger. Given the fixed cost, the leftward shift in the distribution of surpluses reduces the probability that Netflix invests in the CDN by 5.1 percentage points, from 19.4 percent to 18.4 percent. These probabilities of investment are low because the fixed cost is an upper bound.

A fixed cost of zero implies there is no disincentive effect from not retaining additional surplus. However, for any non-zero fixed cost, that the original Netflix retained surplus distribution first order stochastically dominates implies that the hold-up problem grows worse with the new market structure after the merger.

### 8.2 Prohibiting Quality Degradation During Bargaining

In this section I analyze how outcomes would change if bargaining was not linked to quality degradation of the content provider’s content.\(^{29}\) Insofar as degradation is a choice made by one or both

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\(^{28}\)Since the surplus distribution is unbounded from above, for ISPs that agree in the first period of bargaining I assume that maximum surplus is the 97.5% quantile of their surplus distribution. Moreover, to recover this estimate requires that Netflix is able to forecast ISPs’ demand shocks to know ISPs’ exact offers in each period.

\(^{29}\)Explicitly regulation the rules of bargaining is not an unusual counterfactual. In Gowrisankaran, Nevo and Town (2015), the authors analyze the effect of a counterfactual hospital merger if the constituents are still forced to bargain separately.
Figure 9: Distributions of Netflix Surplus Net of Transfers

The blue histogram is the distribution of aggregate net surplus accruing to Netflix under the merged regime, the red histogram is the distribution under the base regime. Distributions are recovered by sampling the vector $\zeta_f R = 10000$ times and deriving the surpluses net of transfers from ISP optimal strategies under each regime.

bargaining parties to gain leverage in the bargaining game, prohibiting quality degradation can be implemented.

This constraint is a more general form of what is referred to as "network neutrality." Network neutrality is a policy—recently affirmed by the FCC—that ISPs cannot differentially throttle or privilege the transmission of different content, and is partly intended to prevent them from exercising their market power to extract payments from content providers. In my model, the marginal consumer will switch ISPs to prevent Netflix quality degradation, so it is Netflix that has the incentive to degrade quality to induce faster screening by ISPs. The idea that a content provider with market power may degrade quality to extract concessions in bargaining with ISPs is a new one in the network neutrality literature, since in typical theory models ISPs are assumed to be monopolists.\(^\text{30}\)

Preventing quality degradation during bargaining increases aggregate welfare by 0.54 percent (the reverse of the 0.51 percent decrease in the previous section). ISPs with longer delays such as AT&T and Comcast see consumers in their choice sets have the largest increases in welfare of 0.58 percent and 0.56 percent respectively.

Netflix’s share of the \textit{ex ante} bargaining surplus goes down and the delay to agreement increases. Without the marginal loss in subscribers affecting the screening tradeoff between finer offers and

\(^{30}\text{See, for instance, Economides and Hermalin (2012)}\)
a higher payout, and coarser offers and a quicker payout, the ISPs screen much more slowly. I summarize the effects in the graph of *ex ante* distributions of consumer surplus versus the fixed investment cost Section 8.2.

The blue histogram is the distribution of aggregate net surplus accruing to Netflix under the regime with no quality degradation during bargaining, the red histogram is the distribution under the base regime. Distributions are recovered by sampling the vector $\zeta_f R = 10000$ times and deriving the surpluses net of transfers from ISP optimal strategies under each regime.

The probability of investment declines by 8.7 percentage points under the regime where quality degradation is prohibited during bargaining. In general, there is a two-sided holdup problem since infrastructure investment will only come on line if both sides in a bilateral monopoly agree to its installation. My setup analyzes a major investment by Netflix, and shows that the holdup problem grows more severe when quality degradation is prohibited since the marginal consumer is more elastic with respect to ISPs than Netflix subscriptions.

9 Conclusion

This paper combines a model of dynamic multilateral bargaining with demand for broadband internet to evaluate a counterfactual merger and a change in bargaining regime policy. I estimate an industry model of demand for internet access, plan choice, pricing and interconnection bargaining using data on plan prices, consumer choice sets and bargaining delays between U.S ISPs and the leading purveyor of streaming video content, Netflix. The model rationalizes a cross-section of bargaining delays between Netflix and U.S. ISPs, where the bargaining was over how to split the

Figure 10: Distributions of Netflix Surplus Net of Transfers

![Graph showing distributions of Netflix surplus net of transfers. The blue histogram represents the distribution under the regime with no quality degradation during bargaining, and the red histogram represents the distribution under the base regime. Distributions are recovered by sampling the vector $\zeta_f R = 10000$ times and deriving the surpluses net of transfers from ISP optimal strategies under each regime. The graph illustrates that the probability of investment declines by 8.7 percentage points under the regime where quality degradation is prohibited during bargaining. In general, there is a two-sided holdup problem since infrastructure investment will only come on line if both sides in a bilateral monopoly agree to its installation. My setup analyzes a major investment by Netflix, and shows that the holdup problem grows more severe when quality degradation is prohibited since the marginal consumer is more elastic with respect to ISPs than Netflix subscriptions.](image-url)
surplus from investments that Netflix wanted to make at each ISP that would save Netflix operating costs and improve video streaming quality.

I find that a proposed merger between TimeWarner and Comcast that was challenged by the Federal Communications Commission would have both raised the fees Netflix paid to make its investment and increased bargaining length, increasing the magnitude of aggregate consumer welfare loss and disincentivizing Netflix from making the investment. A regime where quality degradation is prohibited during bargaining improves consumer welfare compared to the base bargaining case, but Netflix has a lower share of surplus in this regime and is less likely to invest in the infrastructure project whose surplus is being bargaining over. This result follows because allowing quality degradation during bargaining actually improves Netflix’s bargaining position, since marginal consumers in the data would rather switch ISPs to get better Netflix than cancel Netflix.

There are two portable insights from this paper. The first is that increasing returns to scale from a content provider’s intermediary-specific investment can be a source of bargaining power for larger intermediaries. Even if a large intermediary does not have more market power against the consumers it serves, if it serves many consumers then the content provider benefits especially from any investment (with a fixed cost component) that it makes in that intermediary, implying a lower outside option for the intermediary. The content provider will retain a smaller share of a larger surplus; whether the net effect is to disincentive investment is an empirical question.

The second insight is that adding an investment margin for content providers implies that intermediaries that negotiate better prices on content may actually harm consumers by doing so, since retaining a lower share of the surplus from the content they deliver may disincentivize content providers from making investments in the quality of their content. Since content provider investment in quality in a salient feature in most two-sided markets, adding this margin is potentially important for welfare and merger analysis in a broad range of industries.
References


A Auxiliary Figures and Tables

Table 4: Cross-sectional ISP disagreement durations

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>Duration</th>
<th>Duration*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>log(footprint)</td>
<td>0.481**</td>
<td>0.727***</td>
</tr>
<tr>
<td></td>
<td>(0.191)</td>
<td>(0.207)</td>
</tr>
<tr>
<td>share</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>log(connect)</td>
<td>0.289</td>
<td>0.278</td>
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<tr>
<td></td>
<td>(0.322)</td>
<td>(0.329)</td>
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<td>avg.num.comp.</td>
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<td>−1.326</td>
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<td></td>
<td>(2.218)</td>
<td>(2.366)</td>
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<tr>
<td>comp.price</td>
<td>0.007</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>(0.039)</td>
<td>(0.044)</td>
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</table>

Tech. Controls     No  Yes  Yes  Yes  Yes  Yes  Yes  Yes
Observations       23  23  23  23  23  23  23  23
R²                 0.231 0.424 0.450 0.460 0.461 0.317 0.573 0.405

The dependent variables are the disagreement durations. Duration* provides an alternate construction of disagreement durations where durations are increased for some ISPs. log(footprint) gives the number of housing units the ISP network includes, log(connect) is a measure of the connectedness of the ISP physical network, avg.num.comp. gives the average number of competitors the ISP faces, comp. price gives the average minimum price offered by competitors. share gives the share of subscribers in mid-2013, and is an alternative measure of size. Tech. controls indicates whether technology (cable, DSL, fiber) dummies are included. *p<0.1; **p<0.05; ***p<0.01.
### Table 5: Panel of correlated ISP agreement timings

<table>
<thead>
<tr>
<th></th>
<th>agree(_t)</th>
<th>agree(_t-1)</th>
<th>agree(_t)</th>
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<td></td>
<td>(1) (2) (3) (4) (5) (6) (7) (8)</td>
<td>(1) (2) (3) (4) (5) (6) (7) (8)</td>
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<tr>
<td>comp.agree(_t)</td>
<td>0.267** (0.101)</td>
<td>0.385*** (0.116)</td>
<td>0.028 (0.112)</td>
<td>0.046 (0.111)</td>
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<td>comp.agree(_t-1)</td>
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<td>0.058 (0.209)</td>
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<td>0.141 (0.120)</td>
<td>-0.021 (0.122)</td>
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<tr>
<td>comp.agree(_t-1)</td>
<td>0.412** (0.161)</td>
<td>-0.018 (0.194)</td>
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<table>
<thead>
<tr>
<th>ISP FE</th>
<th>No</th>
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<tr>
<td>Time FE</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Observations</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.094</td>
<td>0.270</td>
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</tbody>
</table>

The dependent variables are dummies that take a value of 1 in the period when an ISP concludes negotiations with Netflix. The covariates are dummies equal to one when an ISP’s primary competitor concludes negotiations, or lags thereof. Stars on a variable indicate the alternative duration construction. *p<0.1; **p<0.05; ***p<0.01. Standard errors are clustered at the ISP level.
Table 6: Panel of household ISP switching

<table>
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<tr>
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<th>(1)</th>
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<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
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<tbody>
<tr>
<td>disagree</td>
<td>0.010***</td>
<td>0.011**</td>
<td>0.007***</td>
<td>0.009*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.004)</td>
<td>(0.003)</td>
<td>(0.004)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>\Delta p_{jt}</td>
<td>-0.002***</td>
<td>-0.001***</td>
<td></td>
<td></td>
<td>-0.002***</td>
<td>-0.001***</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>(0.0001)</td>
<td>(0.0002)</td>
<td></td>
<td></td>
<td>(0.0001)</td>
<td>(0.0002)</td>
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<tr>
<td>disagree*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.010***</td>
<td>0.011**</td>
<td>0.008***</td>
<td>0.010**</td>
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<td></td>
<td></td>
<td>(0.003)</td>
<td>(0.005)</td>
<td>(0.003)</td>
<td>(0.005)</td>
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</table>

Household FE: Yes Yes Yes Yes Yes Yes Yes Yes
Time FE: Yes Yes Yes Yes Yes Yes Yes Yes
Balanced Panel: No Yes No Yes Yes Yes Yes Yes
Observations: 33,560 12,126 33,560 12,126 33,560 12,126 33,560 12,126
R²: 0.235 0.159 0.242 0.164 0.235 0.159 0.242 0.164

The dependent variable is a dummy that equals one if a consumer exits ISP \( j \). disagree and disagree* are dummies that equal one if ISP \( j \) is negotiating in that quarter with Netflix. \( \Delta p_{jt} \) is the change in price of ISP \( j \)'s entry level plan. *\( p < 0.1 \); **\( p < 0.05 \); ***\( p < 0.01 \). Standard errors at clustered at the household level.

Table 7: Panel of ISP subscriber share changes

<table>
<thead>
<tr>
<th></th>
<th>OLS</th>
<th>FE</th>
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<tbody>
<tr>
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<td>(1)</td>
<td>(2)</td>
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<tr>
<td>disagree</td>
<td>-0.007*</td>
<td>-0.06***</td>
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<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
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<tr>
<td>disagree*</td>
<td>-0.008</td>
<td>-0.004***</td>
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<tr>
<td></td>
<td>(0.011)</td>
<td>(0.002)</td>
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<tr>
<td>\Delta log(price)</td>
<td></td>
<td>-0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.004)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.013***</td>
<td>0.006***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.001)</td>
</tr>
</tbody>
</table>

ISP FE: No No No No Yes Yes Yes Yes
Time FE: No No No No Yes Yes Yes Yes
Observations: 541 526 541 526 526 526 526 526
R²: 0.006 0.019 0.005 0.012 0.641 0.638 0.641 0.638

The dependent variable in all specifications is the log difference in ISP shares between \( t \) and \( t - 1 \). (1) includes all data, including time periods when a merger happens; (2) removes mergers—as these are large, noisy events, removing them increases significance even as it reduces the point estimates; (3) and (4) repeat these exercises for the alternative formulation of disagreement times; (5) and (6) add in ISP and time fixed effects; (7) and (8) also control for ISPs' median price. ***, ** and *: 0.1%, 1% and 5% significance. Standard errors are clustered at the ISP level.
<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
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<tbody>
<tr>
<td>speed_up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>disagree</td>
<td>−0.029***</td>
<td>−0.017</td>
<td>−0.033***</td>
<td>−0.020</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.014)</td>
<td>(0.008)</td>
<td>(0.014)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\Delta p_{jt})</td>
<td></td>
<td></td>
<td>−0.002***</td>
<td>−0.002***</td>
<td>−0.002***</td>
<td>−0.002***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.001)</td>
<td>(0.0004)</td>
<td>(0.001)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>disagree*</td>
<td></td>
<td></td>
<td></td>
<td>−0.028***</td>
<td>−0.020</td>
<td>−0.030***</td>
<td>−0.021</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.015)</td>
<td>(0.009)</td>
<td>(0.015)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Balanced Panel</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>33,560</td>
<td>12,126</td>
<td>33,560</td>
<td>12,126</td>
<td>33,560</td>
<td>12,126</td>
<td>33,560</td>
<td>12,126</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.138</td>
<td>0.089</td>
<td>0.139</td>
<td>0.090</td>
<td>0.138</td>
<td>0.089</td>
<td>0.139</td>
<td>0.090</td>
</tr>
</tbody>
</table>

The dependent variable is a dummy that equals one if a consumer upgrades their plan speed. `disagree` and `disagree*` are dummies that equal one if ISP \(j\) is negotiating in that quarter with Netflix. \(\Delta p_{jt}\) is the change in price of ISP \(j\)'s entry level plan. *p<0.1; **p<0.05; ***p<0.01. Standard errors are clustered at the household level.
Table 9: Choice set stats

<table>
<thead>
<tr>
<th>Market</th>
<th>Fraction</th>
<th>Cumulative Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T-COMCAST</td>
<td>0.154</td>
<td>0.154</td>
</tr>
<tr>
<td>AT&amp;T-TIMEWARNER</td>
<td>0.098</td>
<td>0.252</td>
</tr>
<tr>
<td>COMCAST-VERIZON</td>
<td>0.091</td>
<td>0.343</td>
</tr>
<tr>
<td>CENTURYLINK-COMCAST</td>
<td>0.067</td>
<td>0.410</td>
</tr>
<tr>
<td>TIMEWARNER-VERIZON</td>
<td>0.053</td>
<td>0.463</td>
</tr>
<tr>
<td>AT&amp;T-CHARTER</td>
<td>0.051</td>
<td>0.514</td>
</tr>
<tr>
<td>CABLEVISION-VERIZON</td>
<td>0.044</td>
<td>0.558</td>
</tr>
<tr>
<td>AT&amp;T-COX</td>
<td>0.030</td>
<td>0.588</td>
</tr>
<tr>
<td>HUGHES</td>
<td>0.026</td>
<td>0.614</td>
</tr>
<tr>
<td>CENTURYLINK-COX</td>
<td>0.026</td>
<td>0.639</td>
</tr>
<tr>
<td>RCN-VERIZON</td>
<td>0.019</td>
<td>0.658</td>
</tr>
<tr>
<td>COMCAST-FRONTIER</td>
<td>0.017</td>
<td>0.675</td>
</tr>
<tr>
<td>CENTURYLINK-CHARTER</td>
<td>0.016</td>
<td>0.691</td>
</tr>
<tr>
<td>FRONTIER-TIMEWARNER</td>
<td>0.016</td>
<td>0.707</td>
</tr>
<tr>
<td>AT&amp;T-SUDDENLINK</td>
<td>0.013</td>
<td>0.721</td>
</tr>
<tr>
<td>AT&amp;T-BRIGHTHOUSE</td>
<td>0.013</td>
<td>0.734</td>
</tr>
<tr>
<td>CENTURYLINK-TIMEWARNER</td>
<td>0.013</td>
<td>0.746</td>
</tr>
<tr>
<td>COX-VERIZON</td>
<td>0.012</td>
<td>0.759</td>
</tr>
<tr>
<td>AT&amp;T-WIDOPENWEST</td>
<td>0.012</td>
<td>0.771</td>
</tr>
<tr>
<td>BRIGHTHOUSE-VERIZON</td>
<td>0.011</td>
<td>0.782</td>
</tr>
</tbody>
</table>

Table 10: Conditional means of demographics from the ACS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Income</th>
<th>HH Size</th>
<th>Speak English</th>
<th>Male Head</th>
<th>Age of Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncond.</td>
<td>—</td>
<td>89.220</td>
<td>2.193</td>
<td>0.970</td>
<td>0.591</td>
</tr>
<tr>
<td>Internet</td>
<td>No</td>
<td>43.774</td>
<td>1.789</td>
<td>0.939</td>
<td>0.512</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>97.801</td>
<td>2.489</td>
<td>0.979</td>
<td>0.614</td>
</tr>
<tr>
<td>Tech</td>
<td>Cable</td>
<td>100.704</td>
<td>2.460</td>
<td>0.979</td>
<td>0.606</td>
</tr>
<tr>
<td></td>
<td>Dialup</td>
<td>63.112</td>
<td>2.067</td>
<td>0.975</td>
<td>0.590</td>
</tr>
<tr>
<td></td>
<td>DSL</td>
<td>90.060</td>
<td>2.531</td>
<td>0.979</td>
<td>0.625</td>
</tr>
<tr>
<td></td>
<td>Fiber</td>
<td>121.480</td>
<td>2.607</td>
<td>0.984</td>
<td>0.636</td>
</tr>
<tr>
<td></td>
<td>Mobile</td>
<td>79.529</td>
<td>2.495</td>
<td>0.970</td>
<td>0.602</td>
</tr>
<tr>
<td></td>
<td>Satellite</td>
<td>77.424</td>
<td>2.440</td>
<td>0.981</td>
<td>0.631</td>
</tr>
</tbody>
</table>
B  Network neutrality

Early architects of the internet promoted a design such that all content could be equally accessible by all consumers, regardless of where the content originates or which last-mile ISP the consumer subscribes to. This equal treatment of content is the principle of "network neutrality", which was finally codified by the FCC in 2015. The principle does not rule out paywalls erected by content providers themselves, but does prohibit last-mile IPSs from acting as gatekeepers for internet content.

In the Netflix event, \textit{ex post} testimony makes it difficult to determine whether ISPs were acting as gatekeepers and throttling Netflix content in exchange for payment. Instead, there were numerous opportunities for both last-mile ISPs and transit ISPs (acting on Netflix’s behalf) to maintain transmission capacity, but both parties failed to do so.\footnote{From consultations with an economist who was with the FCC at the time the slowdown was occurring.} The inability to assign responsibility to last-mile ISPs even after the fact raises two questions: first, whether regulations that prohibit "gatekeeper" behaviour can be reasonably enforced, either at all or in a timely enough fashion to protect consumers; second, whether prohibiting "gatekeeper" behaviour is the key to avoiding quality of service degradation to consumers.
C Data Construction

C.1 Supply Data

I draw on Netflix’s throughput data, as well as MLab measurement data, CAIDA data on interconnection, and Netflix qualitative business filings data to argue that (1) quality reductions were for business reasons, not technical ones and (2) the duration of quality reductions corresponds to the duration of bargaining over interconnection.

A key document in my analysis is the public (partially redacted) version of Netflix’s ”Petition to Deny”. The Petition to Deny is a legal document filed by Netflix to the Federal Communications Commission to argue against the application for merger of Comcast and Time Warner that was announced in mid 2014. In making its case for why these entities should not merge, Netflix detailed the difficulties it had during the installation of its Open Connect servers in 2013. Perhaps because its goal in the Petition to Deny was to argue the dangers of too much market power, only the four largest ISPs are explicitly named in the document. While I take statements in the document about agreement timings at face value, statements that the ISPs are to blame for the slowdown will need to be evaluated.

C.1.1 Ruling Out ISP Technical Difficulties

From the Netflix data it is clear that some ISPs experience a slowdown and others do not. However, it is possible that affected ISPs were suffering from general network problems and not Netflix-specific problems. I falsify this hypothesis with data from MLab, an independent research group that measures the rate of transmission of data between last-mile ISPs and transit ISPs. Since Netflix primarily uses the service of the transit ISP Cogent during this time, if slowdowns occur between Cogent and the affected ISPs but not between other transit providers and the affected ISPs, then it will be evidence of a Netflix-ISP specific problem. Figure 13 illustrates that starting in July 2013, there was a sharp drop in Netflix streaming quality to Comcast, Verizon and TimeWarner. Throughput of other content to these ISPs was not affected, and throughput of Netflix to ISPs such as Cox—a large provider with roughly 5.5% share of subscribers nationwide—was also not affected. Although the MLab data is not comprehensive in its coverage of ISPs, it strongly suggests that slowdowns occurred pairwise. Combined with the qualitative data cited in Section 2.2, it is clear that the slowdowns were business driven.

C.1.2 Assigning Responsibility for the Slowdown

Although Netflix’s standing offer to install Open Connect servers was not taken up by the largest ISPs until 2013, transmission of Netflix content to the end users remained reliable until mid-2013. At that point, Netflix, the last-mile ISPs, or both Netflix and last-mile ISPs either actively precipitated
Figure 13: ISP-Netflix Pairwise Throughput in NYC, LA and DC

Netflix Throughput, NYC

NetflixCablevision Comcast Verizon

Non-Netflix Throughput, NYC

Non-Netflix Throughput, LA

Non-Netflix Throughput, DC
a collapse in reliable transmission, or failed to proceed with status quo network upgrades.\textsuperscript{32} The end result was that quality of service plummeted for the largest ISPs.

From Netflix’s point of view, it is the ISPs that were at fault: Netflix argues that Comcast, Verizon, Time Warner and AT&T "presumably made the business decision that the present discounted value of benefits from degrading the quality of the Netflix video stream to [their] subscribers was greater than the present discounted value of the costs." \textsuperscript{33}

However, from CAIDA data, Netflix cancelled service with a crucial third party in late 2013. Limelight was a large CDN that Netflix had relied on to smooth delivery of its services, but after November 2013—the low point of quality degradation from Figure 1—they no longer interconnected. Meanwhile, Comcast claimed that Netflix’s throughput problems could be solved if they purchased more bandwidth from transit providers—a statement reported and dismissed by Netflix.\textsuperscript{34}

In the model, I show that Netflix had the incentive to degrade quality of service to induce faster agreement times from ISPs. I also show that some ISPs had positive \textit{ex ante} expected payoffs from the dispute even with quality degradation. However, since the marginal consumer appears to be more elastic with respect to switching ISPs than canceling Netflix, there is no incentive for ISPs to slow down traffic.

C.1.3 Constructing Durations

I assume that bargaining begins for all ISPs in 2013Q3, corresponding to the sharp drop off in quality in Figure 13.

The duration of disagreement is constructed in the following steps:

1. Using the Netflix data in Figure 1, for each ISP for which there is data, I regress throughput on a linear time trend and code a "slowdown" dummy as 1 if throughput falls below 80% of its predicted value. This is a necessary condition for ISPs to be considered as having a lengthy slowdown, and provides candidate disagreement durations.

2. If an ISP is explicitly mentioned in Netflix’s Q-10 or Petition to Deny Filings as having reached agreement or not by a certain time, I adjust the disagreement durations to reflect this (Comcast, Time Warner, and Verizon reach agreement in 2014Q1, while AT&T does not. No other ISPs are mentioned.)\textsuperscript{35}

\textsuperscript{32}Harvard Business School case N9-616-007.
\textsuperscript{33}Petition to deny, pg. 52, paragraph 2.
\textsuperscript{34}Statement of Ken Florance, Vice President of Content Delivery at Netflix since 2012.
\textsuperscript{35}In its first quarter letter to investors issued on April 21, 2014, pg. 5 paragraph 3, Netflix notes "now nearly all cable Internet households receive great quality Internet video", implying that Time Warner Cable also concluded negotiations by the first quarter of 2014. From the same document, Netflix mentions the extremely poor streaming quality that AT&T U-Verse customers receive, and argues that "[it] is free and easy for AT&T to interconnect directly with Netflix and quickly improve their customers' experience, should AT&T so desire.”, implying that the slowdown could be alleviated as soon as Netflix and AT&T could settle on a price. From this report it is clear that AT&T actually took longer to resolve negotiations, so that the slowdown truly indicates negotiation time and not just greater
3. If any remaining ISP appears in the CAIDA data as interconnecting with OpenConnect at a certain time, I adjust the disagreement data to reflect this timing.

4. All remaining ISPs are those that did not experience a quality degradation. Netflix pursued a policy of installing Open Connect infrastructure in the networks of even small ISPs, so I assume that these ISPs reached agreement with Netflix immediately.\(^{36}\) CAIDA data indicates that some small ISPs reached agreement earlier—for instance, RCN interconnects with Open Connect in late 2012. I assume that ISPs that agree immediately do so in the first period of bargaining in 2013Q3.

The full set of derived durations is displayed in Table 11. I include Hughes and Wildblue, the two satellite operators in the sample, but I do not assume that these providers bargain with Netflix over interconnection since their infrastructure is not amenable to Open Connect. There is no slowdown vis-a-vis these providers however, so their bargaining duration is set to zero and they are not used in the supply estimation.

<table>
<thead>
<tr>
<th>isp</th>
<th>duration</th>
<th>isp</th>
<th>duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T</td>
<td>4</td>
<td>FRONTIER</td>
<td>3</td>
</tr>
<tr>
<td>BRIGHTHOUSE</td>
<td>4</td>
<td>HAWAIIAN TELCOM</td>
<td>0</td>
</tr>
<tr>
<td>CABLE ONE</td>
<td>0</td>
<td>HUGHES</td>
<td>0</td>
</tr>
<tr>
<td>CABLEVISION</td>
<td>0</td>
<td>MEDIACOM</td>
<td>4</td>
</tr>
<tr>
<td>CENTURYLINK</td>
<td>3</td>
<td>RCN</td>
<td>0</td>
</tr>
<tr>
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<td>2</td>
<td>SUDDENLINK</td>
<td>0</td>
</tr>
<tr>
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<td>TDS TELECOM</td>
<td>0</td>
</tr>
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<td>TIMEWARNER</td>
<td>2</td>
</tr>
<tr>
<td>CONSOLIDATED</td>
<td>0</td>
<td>VERIZON</td>
<td>2</td>
</tr>
<tr>
<td>COX</td>
<td>0</td>
<td>WIDEOPENWEST</td>
<td>0</td>
</tr>
<tr>
<td>EARTHLINK</td>
<td>0</td>
<td>WINDSTREAM</td>
<td>0</td>
</tr>
<tr>
<td>FAIRPOINT</td>
<td>0</td>
<td>FRONTIER</td>
<td>3</td>
</tr>
</tbody>
</table>

\(^{36}\)"if an ISP has an individual market area serving a population of at least 100,000 subscribers, Netflix will install Open Connect appliances at that location at no charge to the ISP."., pg.49, paragraph 2, Netflix Petition to Deny.