Essays on the Industrial Organization of Telecommunications Markets

by

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Dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy
in the Department of Economics
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ABSTRACT

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Abstract

This dissertation is an empirical study of the industrial organization of telecommunications markets. In recent years, online video has disrupted the telecommunications industry, driving large-scale investments in infrastructure and raising policy questions about what role internet service providers (ISPs) should have in the treatment of online content. In the following three chapters, I study ISP incentives and the welfare implications of internet pricing policies.

The second chapter asks whether ISPs have an incentive to steer or influence the product choices of consumers. To answer this question, my coauthors and I leverage unique household-level panel data from a North American internet service provider (ISP). We exploit a change in internet pricing policy occurring when the firm implements usage-based pricing (UBP) in a subset of the observed markets. We find that the introduction of UBP led consumers to upgrade their internet service plans, lower overall internet usage, and increase the share of usage allocated to video. Our findings suggest that while steering consumers towards TV services is possible, it does not seem to be profitable as long as the ISP can offer rich pricing menus that allow it to capture some of the surplus generated by a better internet service. With the introduction of UBP, some third-party streaming video services lose subscribers, but overall usage of these services remains strong.

The third chapter studies the joint pricing of internet and TV subscriptions. Using a new panel of household-level data, I estimate a discrete-continuous model of household choices and find that when access to online video is removed, the average household's willingness-to-pay for their preferred bundle falls by 20%. Next, I use a model of bundle pricing to study the implications of alternative ISP strategies for pricing internet content. I find that foreclosure of online video is not profitable due

to (i): the large contribution of online video access to internet valuations and (ii): low ISP margins on TV relative to internet. When given the option to set add-on prices for access to online video, the ISP chooses positive prices, and new surplus is unlocked through substitution from online video to TV.

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Chapter 2 is based on work with my coauthors Brian McManus, Aviv Nevo, and Jonathan Williams.

Chapter 3 benefited greatly from the generosity of anonymous industry participants who were willing to provide data and institutional knowledge, and from discussions with Jacob Malone and Ron Reuss at CableLabs. The NET Institute provided summer research support.

On a more personal note, I thank my family–Mom, Dad, and Max–for their encouragement. Finally, I thank my fiancée Carmen, who through her love and support has elevated every high and low of these last six years.

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Chapter 1

Introduction

In recent years, the telecommunications industry has made up a significant part of the United States economy, with trillions of dollars spent on investment. It has occupied a central place in consumer lives, with hours per day of consumer attention devoted to broadband internet, media, and mobile devices. The industry has also solidified a central place in our policy discussions, with contentious debates centered around net neutrality, media mergers, and platform regulations. This dissertation focuses on how internet service providers (ISPs) navigate various trade-offs associated with the rise in popularity of online video using novel data on internet and media consumption.

Chapter 2 (based on joint work with Brian McManus, Aviv Nevo, and Jonathan Williams) studies an ISP's incentive to steer consumers across product choices that vary in profitability. ISPs provide broadband internet access, which connects consumers to online content that may serve as an alternative to the ISP's second product offering, TV service. As streaming video increases in popularity, broadband providers face a trade-off: access to online video content increases the value of an internet subscription, but also competes directly with TV subscriptions. The ISP may exploit its gatekeeper position to steer consumers away from online video (and towards its own TV service), or accommodate these new alternatives in order to improve its internet offerings. In this chapter we ask, how does the availability of various pricing strategies impact the ISP's response to this trade-off, and how does the trade-off balance in the data?

We proceed in three steps. First, we leverage unique household-level panel data from a North American ISP to document empirical facts on internet usage and video subscription choices. A unique feature of the data is visibility into the use of online video applications at both the extensive and intensive margins. Using these data, we show that online video

accounts for nearly two thirds of all data usage on the internet. In addition, households that choose the ISP's TV service use less data and engage less frequently with online video.

Next, we develop a model of bundling to characterize the forces driving the firm's fundamental trade-off. The model differs from the standard mixed bundling framework in two ways: it includes additional quantity choices over how much of each product to use and an additional parameter that describes internet subscribers' access to online video applications. We find that an increase in streaming video access leads to increased cord-cutting, creating an incentive for ISPs to partly foreclose online video. However, as firms are given more tools to use in pricing (service tiers and data caps), we find that the best pricing strategy shifts from foreclosure to accommodation of online video. Intuitively, when the ISP has a more flexible pricing structure, it can more effectively extract rents from high-demand consumers. In the context of the net neutrality debate, we show that ISPs may have the incentive to improve online video quality when these pricing tools are available.

In the third step of the analysis, we turn to the data and find support for our theoretical conclusions. Our empirical analysis leverages an observed change in pricing. During the sample period, the ISP implemented usage-based pricing (UBP) in a subset of the markets it services. This change in pricing policy offers an opportunity to measure consumers' responses to steering strategies and assess implications for ISP incentives. We find first that UBP caused consumers to reconsider their plan choices, with the strongest changes coming from heavy internet users upgrading their internet tiers, implying that ISPs can separate users according to their internet usage and collect additional revenue from heavier users. Second, we find no statistically significant effect on either cord-cutting or additions of TV service from the policy change. The muted movement we observe in TV subscription changes reveals difficulties in steering consumers along this margin relative to internet plans. Third, we find that households exposed to UBP reduce their internet usage by roughly 10% relative to a control group of households. The largest reductions came from households that were heavy users before the policy change and chose not to upgrade their tier post-treatment, while households that did upgrade their tier increased their usage at

approximately the same rate as households not exposed to UBP. Both these results suggest that the ISP's introduction of tiers may not lead to pressure for an expanded network and higher long-run investment costs. Finally, we find that when adjusting their usage levels, UBP consumers tend to increase the video share of overall internet usage. This suggests that households favor streaming over other types of internet content, and therefore reductions in online video quality would have a substantial impact on consumers. Taken together, these outcomes represent an effective reallocation of surplus attained from online video from households to the ISP. Overall, these results support the theoretical conclusions that while steering consumers is possible, an accommodation strategy is more profitable as long as firms have sufficient ability to price discriminate.

In chapter 3, I ask how platforms should navigate the joint decisions of pricing and assortment. When firms sell standalone products in addition to providing an access network, they face a trade-off between promoting these standalone products and maintaining the value of the access network as a whole. In choosing a set of products to provide on the platform, the firm may promote its standalone good by excluding its close substitutes, but in doing so reduces the value of platform access to some consumers. In the context of ISPs, the trade-off is between the traditional platform role of selling internet access and a content provider role of selling TV subscriptions. While third-party video streaming applications like Netflix or Sling TV increase the value of internet access, they also compete with TV, with many applications offering the same content.

At the time of this writing, the treatment of third-party content by ISPs is a contentious policy issue, but current net neutrality regulations place decisions over the assortment of content to offer largely within the purview of ISPs. However, ISPs have not yet modified the set of content available on their networks and as such the ideal natural experiment needed to study the implications of this type of strategy does not exist. I proceed instead by simulating counterfactual settings using a model of ISP pricing and a continuous-discrete choice model of demand for internet and video content, in which the utility derived from access to content depends on the time allocated to it. I take the model to a novel dataset on household-level

purchases and usage obtained from an anonymous North American ISP. Unique features of these data relative to the panel used in chapter 2 include set-top box data, which provides visibility into TV consumption at the channel level rather than subscription information alone, and more detailed information on a broader set of online video applications, with consumption information in both time (minutes duration) and data (byte count) units.

I estimate the model using a two-step mixture estimator related to the methodology of Fox et al. (2011) and Fox et al. (2016), where the objective is to find mixture weights for a set of basis densities describing model heterogeneity. The estimated choice model reveals much less elastic demand for internet than TV subscriptions and provides information on willingness-to-pay for streaming services. I find that when access to streaming applications is removed, willingness-to-pay for the average household's preferred bundle falls by 20%. The first finding from counterfactual simulations is that foreclosing on streaming is not profitable. This test is a study of the FCC's former "no blocking" rule, and suggests that foreclosure concerns may be somewhat mitigated given current ISP pricing practices. Although TV prices rise with less online video competition, these revenue gains are offset by a loss in the profitability of internet subscriptions as the ISP is not able to charge as much for internet without streaming. In blocking access to content, ISPs damage the value of internet access as a whole, and consumer surplus falls.

Chapter 2

Steering Incentives in Telecommunications Markets

2.1 Introduction

In a variety of industries, consumers access products or services through a platform, or gatekeeper. When a platform has market power, it faces a trade-off between steering consumers' choices within the platform versus capturing surplus from allowing consumers free choice among the platform's products. On one hand, steering may allow the gatekeeper to direct consumers' choices toward high-margin options, which give it a greater share of the surplus generated on the platform. On the other hand, allowing consumers to have more or better choices may increase the value of the platform, which could allow the gatekeeper to charge more for access. The platform's prices, in addition to directly affecting consumers' welfare, affect the third-party firms that depend on the platform for access to consumers.[1]

In this paper, we analyze the steering incentives of an Internet Service Provider (ISP)

[1]Examples of industries where gatekeepers are important and might have incentives to steers include the following. In health care markets, consumers enroll in an insurance plan and then access health care providers mostly through the insurer's network. The network's structure and the plan's prices will reflect the insurance company's incentive to steer consumers towards certain providers and reduce moral hazard in health care consumption, while also providing a broad set of care options so that enrollment is attractive for a variety of individuals (Ho and Lee (2019)). Similarly, consumers might reach online shopping sites through a search platform that could have incentives to steer consumers to its own sites or sites that pay a higher fee. Steering activity, however, might turn off some consumers who prefer different products, and therefore reduce total visits to the platform. Indeed, such steering incentives are the basis for the fine imposed on Google in June 2017 by the European Commission. Similarly, in March 2018, Spotify filed a complaint with the European Commission saying that Apple, the gatekeeper of the App Store, "has introduced rules to the App Store that purposely limit choice and stifle innovation at the expense of the user experience – essentially acting as both a player and referee to deliberately disadvantage other app developers."

that sells TV services as well as internet access, and therefore serves as a gatekeeper to online content, some of which is an alternative to the TV service the ISP sells. As streaming services gain popularity and the value of over-the-top-video (OTTV) increases, the ISP faces a trade-off: OTTV video directly competes with the video service but it also increases the value of the internet service. The ISP, therefore, needs to choose between trying to steer consumers away from OTTV towards its own video service and supporting the growth on OTTV in order to improve its internet offering. We specifically aim to answer what are the forces that drive the trade-off faced by the ISP? How does the trade-off change with the availability of various pricing, and other strategies, that allow the ISP to share some of the rents generated from OTTV? And where does this trade-off balance in our data?

To answer these questions we proceed in three steps. First, we utilize a unique household-level panel data set from a North American ISP to document some relevant facts. The data include information on internet usage and TV subscription choices of a large number of households over nearly one year. A unique feature of the data is that we observe which over-the-top video (OTTV) services a household uses and the volume of traffic generated by these services. Using these data we show that in our sample, OTTV services (e.g., Netflix, Hulu) account for nearly two-thirds of all data usage on the internet. In addition, we show that households with subscriptions to the ISP's TV service use less data and engage less frequently with OTTV. Furthermore, we document that when a household cuts the cord (i.e., drops TV), it increases its internet usage by nearly one-quarter.

From the ISP's prospective, OTTV services generate substantial network costs, in contrast to traditional TV services for which costs are essentially fixed.[2] This implies that improvements in OTTV quality and access create the risk of higher cost and lower revenue to the ISP, and therefore create an incentive to steer customers towards TV services or even foreclose some OTTV services. The incentives to foreclose some services has been discussed in the context of Net Neutrality, where the discussion has focused on upstream pricing, between the platform and the content providers. We show that some of the same

[2]The differences in the two services' costs are related to OTTV's "unicast" nature, which can have a unique transmission for each consumer, in contrast to the "broadcast" nature of traditional TV.

effects can be achieved downstream by the ISP steering consumers. Steering may impose some costs on consumers, but it can be socially beneficial if the steering strategies help align consumers' choices with the asymmetry in the firm's costs for OTTV versus traditional TV.

In the second step of the analysis we aim to understand the forces driving the trade-off the ISP faces. To do so, we develop a model of bundling that includes TV and internet subscriptions in the presence of competitively supplied third-party OTTV services. We add two elements to the standard bundling framework: quantity choices by consumers for the services they receive, and a parameter that describes internet subscribers' access to OTTV services. We show that an increase in streaming video access, all else fixed, leads to increased cord-cutting, which creates incentives for the ISP to at least partly foreclose OTTV. However, as we give the ISP the ability to offer internet service tiers that vary by allowance we find that the ISP has less incentives to foreclose and instead it prefers to promote OTTV. The intuition is simple: when the ISP adds internet tiers which associate greater allowances with higher prices, it can extract more revenue from high-demand consumers. Contrary to concerns that usage-related prices or constraints are at odds with Net Neutrality's goal of robust third-party content creation, we show that ISPs may have an incentive to improve OTTV quality when these pricing tools are available.

In the final step of the analysis we return the the data in order to support the theoretical conclusions that the ISP likely does not an incentive to steer consumers away from OTTV is it has rich enough pricing tools.In this analysis we utilize an observed change in pricing. During our sample period, the ISP implemented usage-based pricing (UBP) in a subset of markets. The UBP takes the form of a menu of three-part tariffs, each of which includes an access fee, an internet usage allowance, and an overage charge. The policy's introduction offers an opportunity to measure consumers' responses to steering strategies in this industry and the implications it has for the ISP incentives.

We find the following. First, we find that UBP caused consumers, especially heavy users, to upgrade their internet tier. This suggests that the ISP can use UBP and a menu of internet plans to induce consumers to change their internet plan. Therefore implying that

the ISP can separate users according to their internet usage and collect additional revenue from heavy internet users, who value the internet service the most. Second, we find no statistically significant effect on either cord cutting or addition of TV service. The relatively muted movement in either direction for TV subscriptions reveals the potential difficulty in influencing consumers along this margin, which implies that ISPs may have broader success with other aspects of steering and surplus capture. Third, we find that households exposed to UBP reduced their internet usage by roughly 10%, on average, relative to households without UBP. The households that reduced usage by the most had relatively heavy pre-UBP usage and those that did not choose to purchase an increased usage allowance. Households that upgraded their internet tier, by contrast, used approximately the same amount of data as households not exposed to UBP. Both these results suggest that the ISP's introduction of tiers may not lead to pressure for an expanded network and higher ISP long-run investment costs. Finally, we find that in response to the introduction of UBP consumers tend to increase the video share of internet usage. This suggests that households favor streaming video over other types of internet content and therefore reductions in OTTV quality or its foreclosure would not bee viewed favorably by consumers.

These outcomes – upgraded internet tiers and reduced usage – represent an effective reallocation of OTTV surplus from households to the ISP. The consumers' responses also validate some of the assumptions underlying our theoretical model, which provides support for its conclusions on the varying incentives of ISPs to stimulate OTTV. Generally, the ISP's incentives to create new content and expand their networks may be stronger when ISPs capture a greater share of total surplus from OTTV. Overall, these results support the conclusions that while steering consumers towards TV services is possible, it does not seem to be profitable as long as the ISP has the ability to offer different tiers and UBP. This conclusion is consistent with the simulations from the theoretical model.

The impact on OTTV streaming services is a bit less clear. We find that Netflix subscriptions fell when UBP was introduced, primarily due to a reduction in new subscriptions by households without Netflix subscriptions at the start of our sample period. We do not

find a reduction in subscriptions for "linear" OTTV services such as Hulu and SlingTV. In fact, subscriptions to these services increase under UBP, which suggests that households could suggest that household reconsider the portfolio of internet content they consume once it is priced. Despite the reduction in new subscriptions, the share of consumption devoted to video increases.

Related Literature

Our analysis relates to previous research on video programming that has focused on traditional TV (Crawford et al. (2018), Crawford and Yurukoglu (2012), Crawford and Shum (2007), and Crawford and Shum (2015)). Relative to this work we look at OTTV, and the interaction between TV subscription and internet use in general, and OTTV usage specifically.

We follow Nevo et al. (2016), Malone et al. (2016), and Malone et al. (2014), who use high-frequency data to study subscriber behavior on residential broadband networks. These studies cannot separate streaming video activity from other internet usage, and therefore cannot consider ISPs' steering incentives due to OTTV's role in the interaction between internet and television services. Other studies of the demand for and consumers' value from broadband services include Goetz (2019), Tudon (2019), Goolsbee and Klenow (2006), Dutz et al. (2009), Rosston et al. (2013), Greenstein and McDevitt (2011), Goolsbee and Klenow (2006), Edell and Varaiya (2002), Varian (2002), and Hitte and Tambe (2007).

Relationships between ISPs and internet content providers are an active area for public policy, especially concerning merger approval and net neutrality.[3] These policy issues converge with the issue of vertical mergers between ISPs and media companies, which can affect ISPs' profits from various content sources and therefore induce steering activity. The literature on these issues largely began with Wu (2003), who introduced the term "net neutrality" and provides an excellent summary of the issues. Lee and Wu (2009) and Greenstein

[3]The FCC's 2015 Open Internet Order prevented ISPs from discriminating among various online applications. This order limited ISPs' ability to reduce usage of video services from some third-party providers. The FCC voted in 2017 to roll back the order, and future policy in this area continues to be debated.

et al. (2016) discuss and review the literature on the topic. However, most of the existing economic analysis of the topic is theoretical: Economides and Hermalin (2012), Armstrong (2006), Bourreau et al. (2015), Choi et al. (2015), Choi and Kim (2010), Economides and Tag (2012), Gans (2015), Reggiani and Valletti (2016), and Sidak (2006). Our empirical analysis on steering incentives complements these theoretical studies by providing insight into relevant elasticities for the debate.

More generally, our model and empirical analysis also contribute to literatures on firms' strategic efforts to steer and sort heterogeneous consumers across product menus. Ho and Lee (2019), Liebman (2017), and Raval and Rosenbaum (2017) study how insurers influence patients' choices across medical providers. Barwick et al. (2017) examine conflicts of interest and steering by residential real-estate brokers. Crawford et al. (2018) consider similar incentives in cable TV markets, and estimate the value to cable distributors of including vertically integrated versus non-integrated sports networks in their channel bundles.

The incentive to degrade product quality for discriminatory or steering purposes, as is present in our model, is related to the classic work of Mussa and Rosen (1978), which Crawford and Shum (2007) apply in the context of the telecommunications industry. In the bundling literature, Armstrong (2013) and Gentzkow (2007) study how the consumption of one product in a bundle affects utility from other products, which is similar to the relationship between OTTV and TV that we study. Chu et al. (2011) and Crawford and Yurukoglu (2012) empirically explore how variations on bundling and other pricing strategies can affect firms' profit and consumer welfare. Nonlinear-pricing strategies similar to those we examine have been studied in broadband markets (Economides and Hermalin (2015), Lambrecht et al. (2007)), phone service contracts (Miravete (2003), Grubb (2015), and Grubb and Osborne (2015)), and other markets (Hagemann (2017), McManus (2007)).

2.2 Data and Industry Background

In this section we introduce the data and present industry patterns that motivate the analysis that follows. Internet usage has been growing steadily over the last few years and that this increase is largely driven by an increase in streaming video. In our sample, 60% of internet usage is for OTTV, and is even higher among internet-only subscribers. The emergence and popularity of OTTV services coincides with a trend in "cord cutting." Between 2015 and 2017, the number of US households that received video exclusively through a broadband connection almost doubled to about 5.4M. We show that households that drop their video service increase their internet usage (and similarly household that add a video service decrease their internet usage). We demonstrate the revenue implications of this cord-cutting behavior and use the results to motivate the analysis in the next section, in which we provide a model that allows us to study ISPs' incentives.

2.2.1 Data

The data we use come from a North American ISP.[4] Our sample is drawn from a handful of markets during a recent one-year period, and it is nationally representative in terms of demographics, service offerings, and usage patterns. During our one-year sample period we observe roughly 350,000 consumers' billing information, subscriptions, and internet usage.

Like most North American ISPs, this ISP offers internet and TV services via mixed bundling, giving discounts off stand-alone prices when consumers subscribe to both services.[5] 30% of the ISP customers have internet-only subscriptions, and the remaining 70% subscribe to an internet-TV bundle; no ISP customers in the data we see subscribe to TV alone. The ISP also offers tiers of internet service differentiated by speed and, as we discuss

[4]Our agreement with the ISP prevents us from identifying the firm or any details that could be used to infer its identity. This includes the specific markets served, the exact dates and details of the implementation of UBP, as well as detailed characteristics of the ISP's product offerings.

[5]The ISP also offers telephone service, which about 40% of its customers subscribe to. We do not use the telephone service information in this paper.

below, usage allowance in some cases.

An important feature of our data is the introduction of UBP in a subset of markets partway through the sample period. The UBP is implemented through a menu of service tiers that consumers can choose from, where each tier is a three-part tariff. Depending on the service tier the household chooses, it is allocated a monthly usage allowance in gigabytes (GBs). Usage up to this allowance is covered by the monthly payment and does not entail any additional charge, but if the allowance is exceeded the household is charged a fee. During the treatment period, 8% of sample households (across all markets) use more than the allowance associated with their tier.

The ISP faced similar competitors across the markets we observe, with no apparent variation correlated with UBP's introduction. Satellite TV was available in each market, as was internet via DSL lines. During our sample period in the markets we study, the ISP offered internet service on a substantially higher-speed and higher-capacity network than the alternatives.[6]

For each household in the sample, we observe download and upload volume for each hour, although for much of the analysis we aggregate usage to the daily level. Households in the sample use a mean (median) of 4.7GB (1.4GB) of internet data per day. Internet usage differs substantially across households. Average usage in the highest-priced (and highest-speed) tier is nearly seven times as in the lowest-priced tier. Within-tier usage dispersion is also substantial; coefficients of variation range from 1.67 to 2.05 across tiers. Across combinations of TV and internet service, internet-only subscribers have mean (median) internet usage 61% (137%) greater than bundle subscribers. Overall, internet usage increased at a 44% annualized rate during our sample period. The growth rates were largest, on average, among consumers who began the sample at lower usage levels, but the increase in total usage volume is driven more by initially high-usage households.

Within a household's total usage, we observe the application (e.g., Netflix) or protocol

[6]Despite the rapid usage growth within our sample, we see little evidence that congestion affected internet use. Packet loss, which is a quality disruption often caused by congestion, averaged less than 0.01% during peak hours in our sample. See Malone et al. (2016) for a study of the impact of congestion on broadband networks.

(e.g., File Transfer Protocol or FTP) generating each byte used by a consumer, but not the specific content (e.g., particular movie title or website). Tables A.1 and A.2 in the Appendix present additional descriptive statistics for a simple grouping of the applications.

2.2.2 OTTV Usage

Between 2012 and 2017, per-person average daily use of online video increased twenty-fold from 3.5 minutes to 72 minutes. This usage increase coincides with the emergence and rapid growth of several prominent firms that offer OTTV services. In 2015 about 40% of US households subscribed to a streaming service such as Netflix (40M subscribers), Amazon Prime (14.5M), or Hulu (7M).

These trends are reflected in our data. To see this, we divide usage into five major categories: Browsing, Gaming, Music, Video, and Other. Video accounts for about 60% of all usage, and browsing accounts for another 30%. The remaining share is divided approximately equally across the other categories. In Table 2.1, we provide a breakdown of OTTV streaming across specific applications, separately for households who purchase an internet-TV bundle and those who purchase internet only. Adoption, defined as whether the household used the application at all during the sample period, and usage intensity of OTTV applications are both greater for internet-only households.

YouTube's free content is the most widely-accessed video application by households in our sample. Netflix, which offers a variety of original programming along with a library of previously distributed movies and television programs, is the most popular subscription service. HBO Go has a content structure similar to Netflix, while Hulu emphasizes opportunities to stream-on-demand TV shows currently airing on network TV. Other streaming services like SlingTV offer live TV over the internet.

Table 2.1: Adoption and Usage of Online Video Services

Application	Adoption (%)	Usage, All Households (GBs)	Usage, Adopters (GBs)
Internet-only subs			
HBO Go	11.3	0.03	0.25
Hulu	22.6	0.14	0.39
Netflix	72.4	2.00	2.66
SlingTV	2.93	0.05	1.59
YouTube	92.5	0.95	1.02
Bundle subs			
HBO Go	10.1	0.02	0.20
Hulu	12.0	0.05	0.19
Netflix	62.6	1.17	1.81
SlingTV	0.53	0.01	1.15
YouTube	84.5	0.65	0.76

Notes: This table reports the share of internet-only and bundled households that adopt each OTTV service. Average daily usage (measured in gigabytes) of each service is also reported, both across all households in the sample and within the set of adopters.

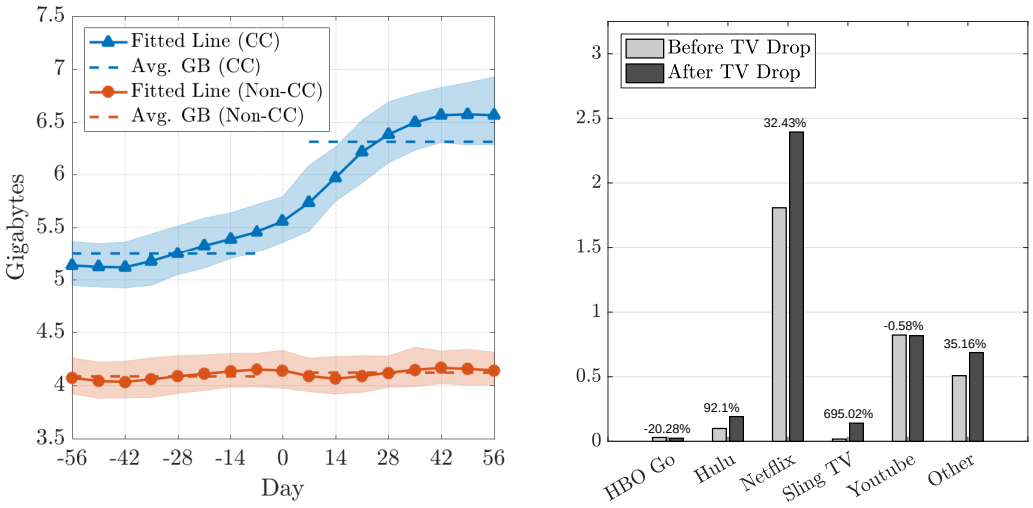
2.2.3 Cord Cutting

The emergence and popularity of OTTV services coincides with a trend in cord cutting. In this sub-section we provide a detailed description of cord cutters' changes in internet usage.

In Figure 2.1 Panel (a) we plot the shift in average internet usage by cord-cutting households, and, for comparison, we also plot the average usage of consumers who hold on to their TV subscriptions. The line labeled as "Fitted Line (CC)" is the average per-household usage on each day of the 12-week window centered around the date of subscription change. The line labeled "Fitted Line (Non-CC)" is the daily average per household, for households who did not drop their TV service. We compute the average for each calendar date and then average across the dates to match the windows presented for the cord cutters. We supplement the fitted lines with average levels of internet usage in the weeks before and after cord cutting. Together, these numbers show that the average (eventual) cord cutter's internet usage begins approximately 25% higher than other subscribers, and increases by

23% after cutting the cord (4.9 GB/day to 6.0 GB/day).[7] Thus, the individuals who drop TV in our sample tend to be heavier internet users. Unfortunately, we do not have any additional household demographics to further explore drivers of selection.

Figure 2.1: Internet Usage among Cord Cutters



(a) Usage (b) OTTV Adoption

Notes: Panel (a) summarizes the average daily usage (GBs) of internet subscribers in the eight weeks before and after dropping TV services (upper plots) in comparison to all other internet subscribers (lower plots). The points are average daily usage, and the dotted lines are average usage across days before and after the change. One week on either side of the cord cut date is omitted. Panel (b) summarizes the average daily usage (GBs) of online video applications by cord cutters in the eight weeks before and after dropping TV services. For each application, the percent change in usage level between the two periods is shown above the two bars.

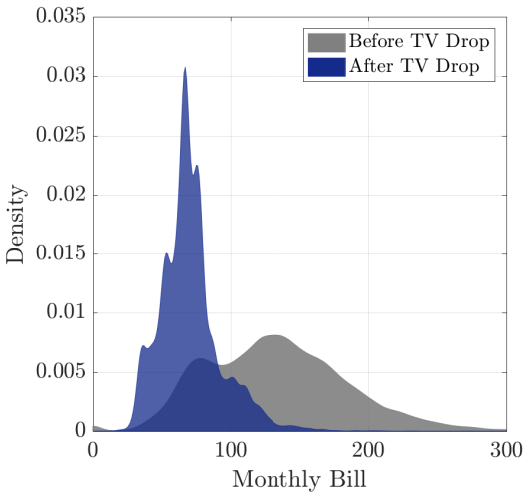
We explore the nature of cord cutters' changing internet usage by decomposing the 23% increase in traffic across types of applications. In Figure 2.1 Panel (b) we provide the change in usage across Browsing, Gaming, Music, Video Streaming, and Other applications. The online activities that increase the most (online video and webpage browsing) provide a fairly similar experience to watching TV. (Some online video delivered through websites,

[7]Our 23% estimate of cord cutting's impact is likely to be conservative. The data suggest that many consumers "prepare" to drop their TV subscriptions by adding and experimenting with online video services during the weeks before cutting the cord. Cord cutters' increased usage begins prior to the subscription change date, and consumers who do not alter their subscriptions do not have a corresponding usage change.

e.g. video on Facebook, appears in our data as browsing rather than video streaming.) Other entertainment applications (Gaming and Music) have increases in usage after cord cutting, as do cloud-based backup services (e.g. Dropbox).

Some changes in Figure 2.1 Panel (b) are due to increased subscription to third-party OTTV services and increased usage. Netflix, Hulu, and SlingTV subscriptions increase by 21%, 69%, and 425% among households who cut the cord.[8] Within cord-cutting households, total Netflix usage increases by more than 30%. Households that add Hulu use it for 6% of their pre-cut internet usage; those who add SlingTV use it for 18% of their total pre-cut usage.

Figure 2.2: Estimated Change in Total Monthly Payments Following Cord-cut



Notes: This figure shows the distribution of estimated monthly payments by cord cutters in the month before and after dropping pay TV. The total monthly operator bill is observed in the ISP billing data. Monthly OTTV expenditures are estimated using 2015 subscription fees for each of the video services observed in the usage data.

Consumers who cut the cord sacrifice a portion of their available video entertainment, and in exchange they pay less for for the video services they receive. We demonstrate this

[8] Absolute increases in subscribers are of the same order of magnitude across services. The differences in percentage increases follow from differences in subscription levels among bundle households.

change in payments by focusing on consumers who begin the sample with a bundle subscription and, at some point, drop TV but remain internet customers. Average payments from these consumers to the ISP fall by about 50%, from $132 to $68. We also calculate estimated total out-of-pocket spending by consumers to the ISP plus all subscription services using 2015 prices. In Figure 2.2 we plot the densities of consumers' total payments before and after cutting the cord. Average total spending per customer drops by half when the consumer drops a TV subscription. The variation around each distribution's mode is due to differences in consumers' subscription details (i.e., channel packages and internet tiers) and third-party OTTV subscriptions. The revenue reduction is accompanied by an increase in average internet usage, which requires greater data transmission and therefore greater network costs.

The usage, revenue, and cost impacts of cord cutting may be reversed, of course, if the ISP can induce an internet-only subscriber to switch to the bundle. In Appendix Figure A.6 we show that households who add TV subscriptions (i.e., "attach the cord") reduce their internet usage by about 25% within two weeks. This reduction is approximately equal in magnitude but opposite in sign to cord cutting's impact on usage. We document in Appendix Table A.3 that OTTV usage falls by more (proportionally and in absolute terms) than do Browsing, Gaming, and Music streaming.

2.3 A Simple Model

In this section introduce a model that allows us to study the trade-offs faced by the ISP in pricing (and offering) internet and TV services. To do so we augment the standard bundling model to incorporate a usage decision. Internet service is a gateway to online applications, including OTTV. Therefore, the ISP faces a trade-off: improvements in OTTV increase the value of the ISP's internet product, but also increase the ISP's costs while reducing demand for the ISP's TV service, both as a standalone product and in bundles. This trade-off is further magnified because consumers, in addition to making discrete choices over

subscription services, choose how much to use each product. The costs associated with building and maintaining internet networks are increasing in total traffic and therefore a change in usage has implications for the ISP's profits. We therefore incorporate a decision on usage into the standard bundling model, and use it to study the ISP's incentives to steer consumers away from OTTV using a variety of non-linear pricing options. We also investigate the ISP's incentives to directly impact the quality of OTTV video available to consumers, and how this depends on the flexibility of nonlinear prices.

2.3.1 The Setup

Consider a market in which an ISP offers consumers access to two services: non-video internet (1) and video entertainment (2). An individual consumer's taste for "units" (e.g. hours) of services 1 and 2, relative to the outside option, is given by $v = (v_1, v_2)$. We normalize the consumer population to one and assume that consumers' tastes are distributed independently and uniformly on $[0, 1] \times [0, 1]$.

To access the services, the ISP offers consumers subscription plans. We begin by assuming that the ISP offers three plans: broadband internet access (i), TV (t), and a bundle (b) that includes both i and t. The firm's mixed bundling pricing strategy includes prices for the stand-alone plans (p_i and p_t) and a price for the bundle (p_b). A consumer can subscribe to one of the firm's three plans, $\{i, t, b\}$ or an outside option denoted by 0 that provides utility normalized to zero. To capture the presence of OTTV, we assume that consumers can access some fraction of the video content (service 2) through an internet-only plan (i).

Utility

An individual consumer receives utility from consuming q_1 units of service 1 and q_2 units of service 2. The consumer decides on consumption based on their tastes (v) and subscription plan. The quantity choice for video services, q_2, can include both traditional TV, q_2^t, and OTTV, q_2^i, with $q_2 = q_2^i + q_2^t$. For simplicity, we assume that a consumer has marginal

utility equal to one for a service's units up to a satiation level equal to the taste parameter v, and then marginal utility is zero for any greater quantity.[9] For example, a consumer with taste v_2 and a TV-only subscription consumes $q_2 = q_2^t = v_2$ units of video entertainment through his TV and receives surplus of v_2 from this activity.

We incorporate OTTV into the model by assuming that a subscription to internet service allows a consumer to receive a fraction $\delta \in [0, 1)$ of his preferred video quantity. We initially treat δ as a given, but then explore the ISP incentives to impact it. The restriction $\delta < 1$ has several possible interpretations, including limited available OTTV content and diminished video quality, which could be due to transmission (e.g. congestion and buffering) or hardware limitations.We assume that OTTV is available at no additional expense to the consumer. The consumer's marginal utility from video hours remains equal to one up to δv_2, where it falls to zero. This can be viewed as a scenario where a consumer enjoys v_2 distinct shows available on TV, but only the fraction δ of the shows are available through OTTV. To simplify the consumption choices of bundle subscribers, we assume that TV subscribers receive all video entertainment through TV, with $q_2^t = v_2$ and $q_2^i = 0$.[10]

Putting this all together, subscribers in internet-only plans receive utility of $U_i = v_1 + \delta v_2 - p_i$, where the first and second terms capture utility (and quantities) from consuming non-video internet and OTTV applications, respectively. A subscription to the TV service, t, results in video consumption of $q_2^t = v_2$, zero non-video internet usage given the lack of access, and net utility equal to $U_t = v_2 - p_t$. Bundle subscribers consume quantities of video and non-video internet up to their satiation levels and receive utility equal to $U_b = v_1 + v_2 - p_b$. Finally, if the consumer selects the outside option, 0, quantities are zero for both services and utility is zero.

[9]This structure may arise if conventional TV carries v_2 shows that each yield utility of one, while all other shows yield a utility of zero.

[10]This assumption represents the best-case/least-cost outcome for the ISP and strengthens incentives to steer consumers to the bundle, but the assumption does not qualitatively change any of the model's predictions.

The ISP Profits and Costs

The ISP's profit from serving the market depends on the number of subscribers to each plan, the quantities they select, and the costs of providing these services. For simplicity, we assume that the ISP's costs depend only on the quantity of internet content it transmits; all other costs are zero. This means that we abstract-away from costs such as affiliate or retransmission fees paid to content firms for individual TV subscribers, or the fixed costs of operating the ISP's network.[11]

The ISP's internet-related costs increase with the bytes transmitted through its network and therefore are increasing in total usage, which is a function of the number of users and usage (and usage type) by each user. These costs capture the ISP's need to maintain a network that must grow with total usage to avoid congestion, content interruptions, or slowdowns during times of high total usage. We assume that the firm's transmission costs are given by a parameter, γ, times the gigabytes, g, required to transmit the quantities q_1 and q_2^i. We assume that one unit of non-video internet content requires the transmission of one gigabyte, so $q_1 = g$. We further assume that consumption of video content q_2^i requires βg gigabytes, with $\beta > 1$. This captures the greater bandwidth and immediacy needs to transmit video. Consumers' preferences and their choices, given the firm's prices, imply a mapping from tastes to quantities of internet usage, so we write a consumer's internet usage as a function of v. Without restrictions on usage, an internet-only subscriber uses $g_i(v) = v_1 + \beta\delta v_2$ internet units, while a bundle subscriber uses $g_b(v) = v_1$.

Combining consumers' choices with the firm's cost structure, the ISP's profit function is

$$\pi \quad = \quad \int_{v \in S_t} p_t dv + \int_{v \in S_i} \left[p_i - \gamma g_i(v)\right] dv + \int_{v \in S_b} \left[p_b - \gamma g_b(v)\right] dv.$$

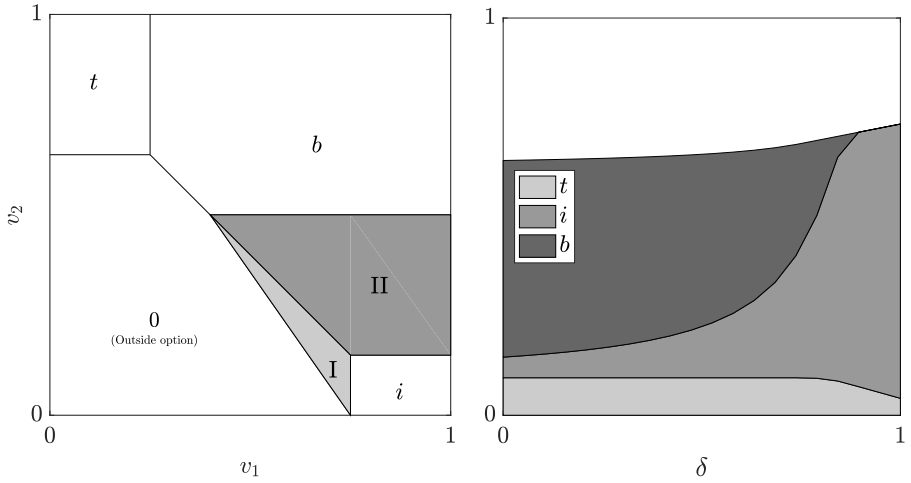
The terms S_t, S_i, and S_b are the sets of consumers who choose internet, TV, and the bundle, respectively.

[11] Our model's qualitative results would not change if we were to include positive per-subscriber costs for TV service. See additional discussion below.

2.3.2 Consumer Choice

We now turn to the choices consumers make in this setup. In Panel (a) of Figure 2.3 we present choices different consumers make for a fixed set of prices. When video can be consumed only through TV (i.e., $\delta = 0$), consumers in the areas labeled '0' and 'I' select the outside option, and those in areas 'b' and 'II' select the bundle. Consumers in areas i and t select the stand-alone internet and TV subscription plans. The split is intuitive: consumers with low valuations of both products choose the outside option. Consumers with high valuations for both products choose the bundle, and consumers with high valuation for one service and not the other choose the plan with just one service. The exact boundaries between the different choices depend on the prices of the various options.

Figure 2.3: Consumer Response to Change in δ



(a) Choices (b) Market Shares

Notes: These figures illustrate consumer choices for different levels of δ, holding prices fixed. In panel (a) we present consumer choices for δ equal to 0 and 0.7 holding prices fixed at $(p_i, p_t, p_b) = (0.75, 0.65, 0.9)$, which are the profit-maximizing prices for $\delta = 0$ and $\gamma = 0.2$. In panel (b), we present market shares when δ increases from 0 to 1 and prices are fixed at $(p_i, p_t, p_b) = (0.75, 0.65, 0.9)$.

We next consider the effect of OTTV becoming more attractive (i.e., the effect of an increase in δ) on choices. In Panel (a) we show the effect of δ increasing to 0.7, holding prices fixed at the optimal level for $\delta = 0$ and $\gamma = 0.2$. Two types of consumers change their

choices. First, some consumers (in area I) who did not purchase, despite moderately high valuation for internet or video, will now subscribe to i because it became more attractive. These new consumers can increase the ISP's profit and are one reason the ISP has an incentive to encourage OTTV. Second, some consumers (in area II) decide to "cut the cord." These consumers initially choose a bundle, but have relatively low video entertainment tastes among bundle subscribers. As δ increases, they prefer stand-alone internet service because they can consume video over-the-top using the internet service. The cord cutting by these consumers diminishes the ISP's revenue, since the bundle price is higher than the internet-only price, and increases the ISP's costs, since supplying video over the internet is costly to the ISP.[12]

These two groups of consumers have opposite effects on the ISP profits, and represent the basic trade-off the ISP faces: stronger OTTV makes the internet service more valuable but also competes with the TV service. In principle, which effect dominates depends on, among other things, the distribution of tastes. In Panel (b) of Figure 2.3 we show the effect when tastes are uniformly distributed. We plot market shares for each plan at different values of δ, holding prices fixed. The share of internet-only plans, i, grows monotonically in δ, and this largely comes from a reduction in the bundle market share, which is completely eliminated around $\delta = 0.85$. When OTTV is sufficiently beneficial, some consumers even convert their t subscriptions to i, as i offers services very similar to the original bundle.

Under our distributional and cost assumptions, OTTV improving, holding prices fixed, leads to a reduction in the ISP profits. Many consumers "cut the cord" and trade a more expensive subscription for one with a lower price. This reduces the ISP revenue and increases its costs from video usage previously delivered at no marginal cost. The modest increase in total subscriptions is not enough to make up for the decrease in profit from reduced bundle subscriptions.

[12]The ISP will lose profit on these consumers even with a positive cost per TV subscriber, as long there is a positive margin on the TV part of the bundle (specifically, the difference between the bundle price and the internet-only price is greater than the per-TV subscriber cost).

2.3.3 ISP Pricing Strategies

In the previous section we showed that, in our setup, an improvement in OTTV can lead to "cord cutting" and a loss in ISP profits, holding prices fixed. Of course, in equilibrium the ISP can and will respond. In this section we study some possible responses, including changing the relative prices of products, limits on internet usage, and tiered pricing of internet usage. We focus on these strategies because they share central elements with the ISP actions we see in the data. Our discussion in this section takes δ as fixed, but in the following section we consider the ISP's incentive to increase or decrease δ, which it could do by promoting or restricting access to OTTV.

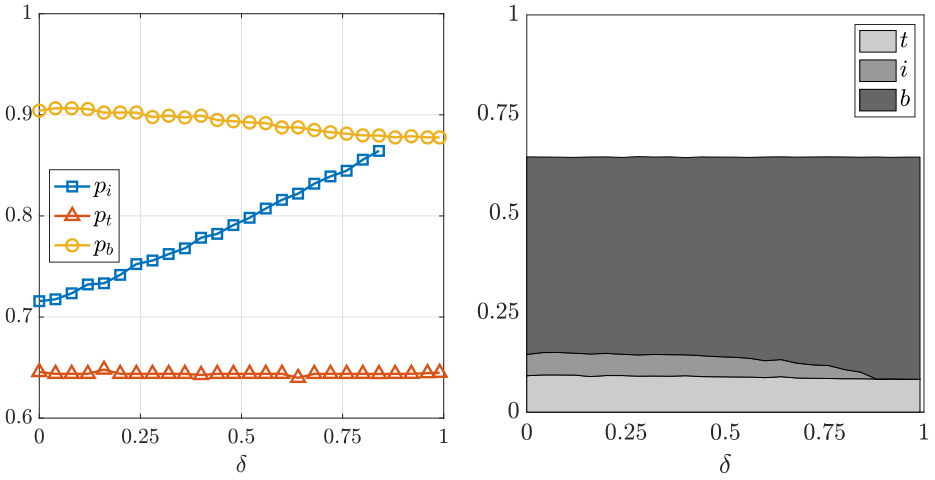
Subscription Prices and Bundle Discounts

In Figure 2.4 we illustrate the effects of allowing the ISP to set profit-maximizing bundling prices for different values of δ. In Panel (a) we display the prices, while in Panel (b) we present the market shares of t, i, and b given these prices. By comparing Figures 2.3 and 2.4, we can see clearly the steering effect prices can have. Greater values of δ drive the ISP to set greater values of p_i and greater bundle discounts, i.e. the difference between p_b and $p_i + p_t$. By increasing the price of the internet-only product, the ISP can push back and reverse the effect of an increase in δ on cord cutting. As we show in Panel (b) of Figure 2.4, with optimal mixed bundling prices the share of the internet-only plan actually decreases. The steering effects are especially strong for $\delta > 0.8$, when the optimal pricing sets $p_b = p_i$, and therefore the share of internet-only subscriptions goes to zero.[13] With the pricing instruments available in this case, the cost impact of δ is greater than ISP's opportunity to profit from the increased value of internet-only subscription plans, so it effectively shuts down this plan.

In the particular setting we evaluate above, we find that optimizing prices mitigates the

[13] Under our assumption that bundle subscribers receive all of their video entertainment via the TV subscription, the elimination of i also eliminates OTTV usage. In a more realistic model, bundle subscribers would consume video through both TV and the internet, and OTTV consumption would not be eliminated.

Figure 2.4: Effect of δ on Optimal Prices



(a) Prices (b) Market Shares

Notes: Panel (a) displays the ISP's profit-maximizing prices as δ varies from 0 to 1. Panel (b) provides the market shares resulting from these prices. We compute prices and shares numerically using the assumptions described in the text.

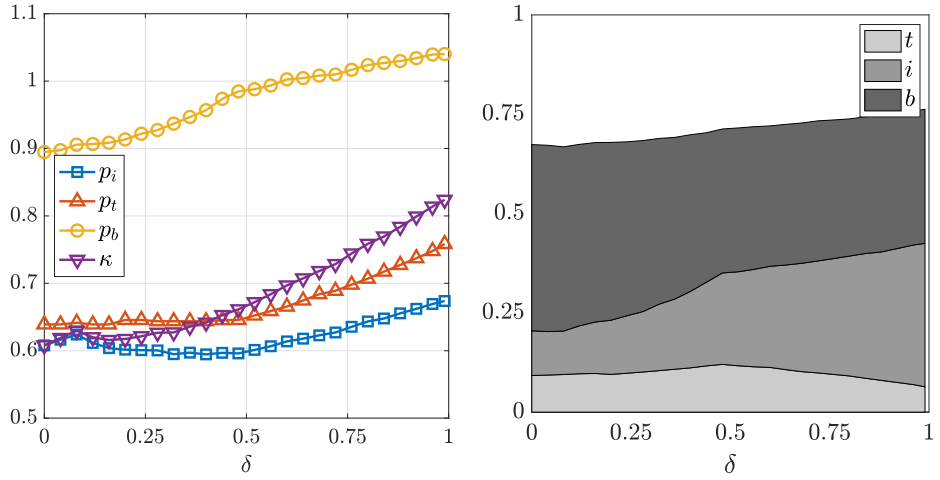
decline in profits but does not eliminate it completely. The ISP's profits decrease mildly in δ. We return to this point below.

Usage Limits

As we showed in the discussion above, firms may find it optimal to set prices such that the internet-only product is basically eliminated. However, if firms are permitted to use more sophisticated strategies, their incentives to steer consumers into the bundle may be reduced. One possible strategy is to charge consumers an access or subscription fee in return for a usage allowance which puts a strict cap on internet usage. This is a simplified version of the three-part tariff we see in our data, where the consumer pays an overage charge when he exceeds the allowance. With our assumption of marginal utility equal to either one or zero, depending on the quantity consumed, an optimally-set overage charge is equal to one, and ISP's only interesting strategic choice is the usage allowance.

Let κ denote the usage allowance in GBs. The effect of the allowance is straight-forward: as long as it is set low enough, the allowance will truncate the usage of any consumer with

Figure 2.5: Effect of δ on Optimal Prices under Usage Cap Strategy



(a) Prices and Allowance (b) Market Shares

Notes: Panel (a) displays the ISP's profit-maximizing prices and allowance when the ISP sets a usage allowance, as δ varies from 0 to 1. Panel (b) summarizes the change in market shares at each optimal price combination.

$v_1 > \kappa$, regardless of whether they purchase a bundle or the internet-only plan. This allows the ISP to keep cost down even as δ increases; namely, the ISP can limit how much consumers can increase their use of streaming video when δ improves.

In Figure 2.5 we illustrate the consequences of allowing the ISP to set κ. In Panel (a) we illustrate optimal prices and allowances for a range of δ values, and in Panel (b) we present the resulting market shares. The allowance has a significant impact on the ISP's choices of subscription plan prices and therefore market shares. The internet and bundle prices both increase gradually with δ, and internet-only subscriptions eventually overtake the bundle as the most popular option. Overall, the ISP serves a greater share of the full consumer population as δ rises. The usage cap, which is just above p_i for low values of δ, increases more quickly with δ than p_i, which effectively loosens the ISP's restrictions on internet usage as streaming video improves. (Some i subscribers with large v_1 and small v_2 use no OTTV, while others consume both internet services and streaming video.) Thus, introducing the allowance can permit the ISP to balance providing access to more consumers while also steering customers with greater video demand toward the bundle,

where they can receive video at lower cost to the ISP. A usage cap can actually lead the ISP to permit more internet and OTTV usage than it would if usage caps were prohibited, because the cap allows the ISP to influence usage choice more selectively.

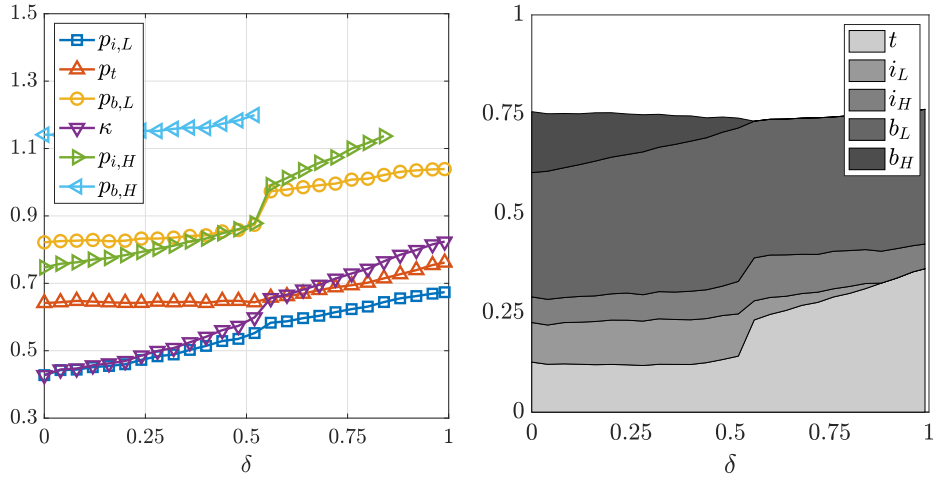
The opportunity to set a usage cap can lead to the ISP's profit increasing in δ. The firm receives the revenue benefits of increased prices (due to increased value to consumers) from consumers who would use a low or moderate amount of OTTV even without a cap, plus it can limit the OTTV-related costs of internet-only consumers who would use larger quantities of streaming video without a cap.

Usage Tiers

In addition to using base prices (p_t, p_i, p_b) and allowances (κ) to steer consumers among packages, ISPs also often separate their internet services into tiers that vary in allowances, overage prices, or connectivity speeds. We consider the effect of the ISP introducing a "low-usage" internet tier with a usage allowance κ and a "high-usage" tier with no usage limit. Consumers can select one of these internet tiers alone or as part of a bundle with conventional TV. For simplicity, and consistent with industry practice, we assume that the difference (i.e. discount) between the bundle price and the sum of TV and internet prices is the same regardless of which tier a consumer chooses.

When the ISP introduces tiers and allowances to a setting which had neither, several types of consumers are affected in distinct ways. First, some consumers who had internet-only subscriptions will stay with this type of plan, with consumers separating between capped and uncapped tiers based on their valuations of internet content (including OTTV). Second, some internet-only consumers with strong video tastes will switch to a bundle plan, with the internet tier depending on their value of v_1. Finally among initial i subscribers, some will cancel their subscriptions completely because their relatively strong taste for video entertainment and weak taste for non-video internet means that capped internet and bundle subscriptions are worth less than the outside option. Turning to consumers who previously choose a bundle, some with strong internet tastes will opt for the unlimited usage option

Figure 2.6: Effect of δ on Optimal Prices under Tier and Cap Strategy



(a) Prices and Allowance (b) Market Shares

Notes: Panel (a) depicts the ISP's optimal tier prices and usage allowance as δ varies from 0 to 1. Panel (b) summarizes the change in market shares at each optimal price and allowance combination.

so that they can consume more content. In the Appendix we provide additional discussion and graphical illustration of these effects.

Next, we consider how the ISP would set prices and tiers for different values of δ. In Panel (a) of Figure 2.6, we provide the ISP's optimal prices and cap values, and in Panel (b) of Figure 2.6, we show the resulting market shares. In this setting, the ISP has several levers for steering consumers' choices, extracting rents, and reducing costs, and as a consequence the ISP's strategy varies qualitatively with δ. For δ values less than about 0.5, the ISP allows prices to increase with δ so that it captures some of the additional value available to consumers through OTTV. (The high-usage bundle's share falls in δ because video usage opportunities remain constant for TV subscribers.) For relatively high values of δ, the ISP's strategy changes, and it raises the high-usage internet price substantially to shrink this plan's market share. When δ is large, the cost of offering unlimited internet usage is too great relative to the premium the ISP can charge consumers for the plan. As the ISP reduces the high-usage internet tier, it raises the low-usage tier's allowance, which accommodates more OTTV usage within this tier. The ISP benefits, on the whole, from

steering consumers into the low-usage internet tier where it can recover value from OTTV with an increased price, while also limiting the usage of inframarginal consumers whose OTTV usage choices, if unchecked, would be costly for the ISP.

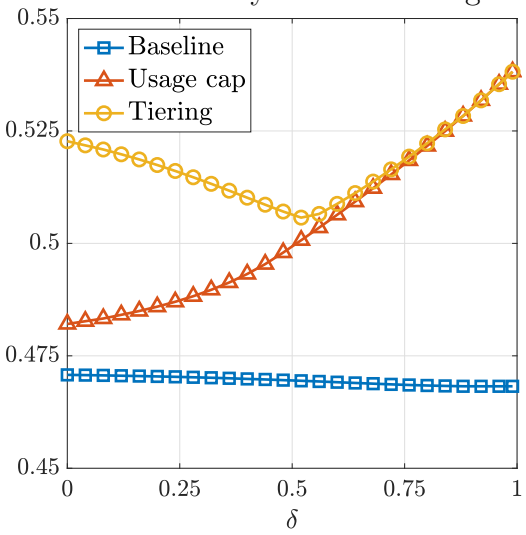
As δ increases from 0 to 1, the ISP's profit first falls in δ and then rises, with the reversal coinciding with the ISP's qualitative change in pricing strategy. When δ is zero, the ISP benefits strongly from the opportunity to segment consumers by their taste for non-video internet, but once δ increases there are additional costs from uncapped internet-only subscriptions. These costs reduce ISP profit until the firm (largely) turns to steering its internet-only consumers into capped subscriptions, where the ISP's price and profit rise as OTTV improves.

2.3.4 ISP Incentives to Promote or Restrict OTTV

As we show above, when the OTTV quality improves, the ISP faces a trade-off. On one hand, better OTTV products and services make the internet service more attractive, and therefore the ISP has an incentive to promote OTTV. On the other hand, OTTV is a substitute for the ISP's TV service, and therefore the ISP might have an incentive to restrict OTTV usage or degrade its quality. In the previous section, we explored what this trade-off implies for the ISP incentive to steer consumers using various pricing tools. We now explore the ISP's direct incentives to either improve or degrade the quality of OTTV. It is exactly these types of concerns that fuel the Net Neutrality debate. In the context of our model we can study the direct incentives to promote or restrict OTTV by allowing the ISP to impact δ.

In our analysis of the three pricing strategies discussed above–bundle pricing, usage limits, and usage tiers–the ISP's approach to OTTV varies substantially. With bundle pricing, OTTV usage first grows with δ and then falls as the ISP effectively eliminates its internet-only subscriptions. With usage limits and tiers, by contrast, the ISP allows OTTV usage to grow with δ within significant internet-only market shares. This divergence in

Figure 2.7: Profitability of each Pricing Strategy



Notes: This figure shows ISP profits when it uses optimal bundle prices, optimal prices and usage cap, and optimal prices and cap with usage tiers.

OTTV usage occurs because the more sophisticated pricing strategies allow the ISP to capture some of the value generated by OTTV while limiting its effects on the ISP's costs and TV demand. The same logic holds in the results below.

To demonstrate these effects, we plot in Figure 2.7 the ISP profits for different pricing strategies and different values of δ. These profits correspond to the prices and market shares presented in Figures 2.4, 2.5 and 2.6. As expected, Figure 2.7 shows that the firm's profit is weakly greater for any δ when it has more instruments in designing a pricing plan. More importantly, the strategies' profit levels vary in whether they increase or decrease in δ. The variation in the slope across strategies comes from differences in the ISP's ability to extract rents versus avoid additional costs when OTTV's quality improves.

The differences in profit slopes and levels across δ values come from the firm's opportunity to balance a complex set of trade-offs regarding consumer choices. Our model shows that, even in a simple framework, an ISP's policies toward OTTV will depend on the current quality of streaming video and what pricing tools ISPs may use. ISPs restricted from setting overage charges or creating tiered service might often benefit from stifling OTTV

access, while ISPs with more pricing tools may encourage OTTV usage. More generally, our model demonstrates that prices and plans offered to consumers are a key component of the Net Neutrality debate; restrictions and promotion of third-party internet content do not just happen at the level of ISP-to-firm negotiations upstream.

2.4 Lessons from the Introduction of UBP

The theoretical model in the previous section highlights the trade-off faced by the ISP when faced with new streaming services and improvement in the quality of OTTV. On one hand, the improvement in OTTV makes the internet service offered by the ISP more valuable. On the other hand, the new streaming services compete directly with the video service the ISP offers. Given this trade-off, the ISP needs to decide between trying to steer consumers from OTTV, and protect its TV service, or go along and improve its internet offering. The model highlights that the decision on which direction is more profitable for the ISP depends on the distribution of consumer preferences and on the ISP's ability to recover some of the value generated from improved internet service.

In this section, we utilize a change we observe in the marketplace to inform the theoretical discussion. As we described in Section 2, during our sample period the ISP introduced UBP, in the form of a three part tariff on internet usage prices, in a subset of the markets it serves. We use the introduction UBP to learn about the willingness of consumers to substitute along various dimensions. This is informative about ISPs' ability to steer consumers' choices and capture surplus from internet usage, and therefore the ISP's incentives to restrict or promote OTTV.

We start the empirical analysis by seeking to understand consumer behavior. Specifically, how do consumers respond to the introduction of UBP? Do they upgrade their tier? Do they add or drop TV service? Do they reduce internet usage in general and OTTV specifically? Do these responses vary between heavy and light users? We examine all this questions in Sections 4.2. With these estimates of consumer behavior, we turn in Section

4.3 to the implications for the ISPs and third-part OTTV providers.

2.4.1 The Introduction of UBP

We observe the introduction of UBP in "treated" market(s) plus contemporaneous data from "control" market(s) where the introduction did not happen during the sample period. The ISP's introduction of UBP came in two phases. First, the ISP announced that UBP would be implemented on a specified date, and it provided households with information about how their monthly usage compared to the data allowance within their current internet tier. During this phase, which we call the "announcement period," households were not billed if their usage exceeded their tier's allowance. In the next phase, which we call the "treatment period," the ISP assessed overage charges on households that exceeded their allowances. We observe several months of activity (a "pre-policy period"), immediately prior to the announcement and treatment periods, which each last a few months. During the pre-policy period the treated and control markets were subject to the same pricing policies by the ISP. Other than the introduction of UBP, the ISP's internet tiers were identical across markets in our sample. Across all markets we observe, competitors' subscription offerings did not change meaningfully during the sample period, including in response to the UBP policy's introduction.

In assessing the impact of internet usage prices on choices, one must consider the relative prices of different ISP subscriptions and the UBP overage charge. The ISP offers a menu of internet-TV bundles and internet-only options, where internet service is separated into tiers that vary in speed and possibly usage allowance (in the treated market). Like other ISPs, the average price difference (across internet tiers) between the bundle and internet-only subscriptions is about $100, while the typical price difference between adjacent internet tiers is about $15. As we describe in Section 2, a household that exceeds its usage allowance under UBP pays an overage charge that can be less than the tier-upgrading price to receive additional usage allowance.

2.4.2 Households' Responses to the Introduction of UBP

In this subsection we analyze households' responses to the introduction of UBP along various dimensions of choice. In the next subsection we discuss the implications of these results.

The Impact on choice of ISP Services

We start our analysis by studying the effect on the ISP services household choose. Specifically, we focus on the choice of which internet tier to join and whether to purchase TV access. We compare the change in the choices of households in the treated market, where UBP was introduced, to households in the control markets.

We utilize a Probit model to capture the probability that a household h changes a subscription decision, denoted by $y_h = 1$. Formally, the model is given by

$$\begin{aligned} Pr(y_h = 1) = &\Phi(\beta_0 + Treatment_h \times (\beta_1 + \sum_N ShareN_h \times \\ &(\beta_{2,N} + \beta_{3,N} LinOTTV_h + \beta_{4,N} Netflix_h)) + \theta X_h) \end{aligned} \tag{2.1}$$

where Φ is the CDF of the standard normal distribution, $Treatment_h$ is an indicator variable that is equal to 1 if household h resides in a market where the ISP introduced internet usage prices, $ShareN_h$ is a dummy variable equal to 1 if pre-policy household h usage was in range N, where N is below 50%, between 50% and 100%, or above 100% of household h internet tier's treatment-period allowance.[14] $LinOTTV_h$ and $Netflix_h$ are equal to 1 if household h has a linear OTTV or Netflix subscription, respectively, at any point during the pre-policy period. Finally, all specifications also include controls for households' pre-policy internet usage levels (divided into deciles) and their initial ISP subscriptions.

[14] Across all households, 80.5% have a usage share less than 50% of the allowance, 15.1% have usage between 50% and 100%, and 4.3% have pre-policy usage greater than 100% of the eventual allowance. Among households that subscribe to Netflix or a linear OTTV service during the pre-policy period, the proportions of households in the same usage share categories are 71.4%, 22.0%, and 6.6%, respectively.

In Table 2.2 we report the marginal effects from estimates of 2.1. In each pair of columns we study different decisions. In all cases, we ask whether the household changed the service between the end of the pre-policy period and the end of the sample period. In other words, an observation is a household and the dependent variable is equal to one if a household made the decision studied, regardless of whether this occurred during the announcement or treatment periods.

In columns (1) and (2) we ask whether a household upgraded the internet service tier after the policy was introduced. This decision directly informs whether an ISP can induce heavy internet users to pay tier-upgrading fees, in which case then the ISP may have less incentive to reduce access to OTTV. In the raw data we see that (between the end of the pre-policy period and the end of the sample) 7.29% of households in the treated market upgraded their internet tier compared to 3.45% in the control markets ($p < 0.01$). In column (1) we show that this difference persists once we control for observable differences across households: households in the treated market are 3.0 percentage points more likely to upgrade. This difference implies a 0.3% increase in ISP revenue from tier upgrades alone.

In column (2) we ask whether there is heterogeneity in the effect. The theoretical prediction, in Section 3, suggests that the effect will be larger on households who are heavier users. The estimates are consistent with this prediction. We find that households who are heavier users are significantly more likely to upgrade tier: Households without OTTV subscriptions who use less than 50% of their allowance in the pre-policy period are about 1.5 percentage points more likely to upgrade their tier, while households with usage shares between 50% and 100% upgrade 5 percentage points more frequently, and households with usage shares above 100% upgrade 10 percentage points more frequently. The interactions with linear OTTV and Netflix usage are generally not significant.

In columns (3) and (4) we study the decision to downgrade the service tier. In the data, 2.65% of households in the treated market downgraded their service, compared with 2.26% in the control markets. This result is unchanged once we we control for cross-market observable differences, in column (3). We find that UBP generates a 0.3 percentage point

Table 2.2: The Effect of UBP on Take-up of ISP Subscriptions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Upgrade Tier		Downgrade Tier		Add TV		Drop TV	
Treatment	0.030***		0.003***		0.003		0.001	
	(0.001)		(0.001)		(0.002)		(0.001)	
Treatment ×								
Share0-50		0.015***		0.003***		0.007		-0.002
		(0.001)		(0.001)		(0.004)		(0.002)
Share50-100		0.053***		-0.008		-0.013		0.003
		(0.006)		(0.007)		(0.015)		(0.009)
Share100+		0.100***		-0.002		0.009		-0.004
		(0.010)		(0.013)		(0.023)		(0.019)
× LinOTTV×								
Share0-50		-0.005		0.001		-0.001		-0.010*
		(0.006)		(0.004)		(0.008)		(0.006)
Share50-100		0.015***		0.000		0.032***		-0.001
		(0.005)		(0.008)		(0.010)		(0.009)
Share100+		0.007		0.018		0.012		0.021
		(0.007)		(0.012)		(0.016)		(0.013)
× Netflix ×								
Share0-50		-0.000		0.001		-0.002		0.008***
		(0.002)		(0.002)		(0.005)		(0.003)
Share50-100		-0.004		0.003		-0.002		0.002
		(0.006)		(0.008)		(0.016)		(0.009)
Share100+		0.007		-0.008		-0.017		-0.010
		(0.010)		(0.015)		(0.024)		(0.020)
Observations	322,197		322,197		99,455		226,270	

Notes: The table reports marginal effects from probit regressions. The dependent variable, listed in the first row of the table, is an indicator for whether the household makes the specified subscription transition between the announcement of UBP and the end of the sample. An observation is a household. All households eligible to make the specified subscription change are included. *ShareN* is a dummy equal if in the pre-policy period the household used N% of the their internet tier's treatment-period allowance, LinOTTV is a dummy variable equal to one if the household has a linear OTTV subscription, and Netflix is a dummy variable equal to one if the household has a Netflix subscription. All regressions include as controls the uninteracted $Share_h$ variables, position in the monthly total internet usage distribution (discretized into deciles), OTTV subscription indicators, and a TV subscription indicator. Standard errors are in parentheses, with stars indicating the following significance levels: $^{*}(p < 0.10)$,$^{**}(p < 0.05)$,$^{***}(p < 0.01)$.

increase in downgrades, which implies about 0.03% less subscription revenue for the ISP. In column (4) we show that the households most likely to downgrade used relatively low shares of their tier allowances. For these households, the informational aspects of UBP may have increased awareness that a household could fit all of its likely usage into a lower internet tier.

Next, we turn to the impact of internet usage prices on households' TV subscription choices. In columns (5) and (6) we analyze whether the introduction of UBP was successful in reversing cord cutting by asking if it steered internet-only households into the TV-internet bundle. We see that 4.18% of households in the treated market add TV, compared to 3.81% of households in the control markets ($p = 0.10$). Once we control for differences across household, in column (5), the estimate is a 0.3 percentage point, but statistically insignificant, increase in TV subscriptions. This modest change to TV subscriptions, which increases treated market revenue by about 0.05%, may be due to the relatively high price of adding TV compared to the household monitoring its internet usage and paying for a tier upgrade or occasional overage fee. As we how in column (6), the non-significant effect generally persists once will allow for more heterogeneity.

We generally find similar results for cord cutting. In the treated market 2.89% of households cut the cord, compared to 3.17% in the control markets ($p = 0.01$). As we show in column (7), this difference becomes statistically insignificant once we control for observable differences. In general, the non-significant effect UBP's overall effect on cord cutting persists once we allow for heterogeneity.

The Impact on Internet Usage

Next we study how the introduction of UBP impacted internet usage. To do so we regress run the following regression

$$\begin{aligned} log(q_{h,t}) =& \beta_0 + Treatment_{h,t} \times (\beta_1 + \sum_N ShareN_h \times (\beta_{2,N} + \beta_{3,N} LinOTTV_h + \beta_{4,N} Netflix_h)) \\ &+ \theta X_h + \beta_5 Announce_{h,t} + \tau Trend_{h,t} + \eta_h + \epsilon_{h,t}. \end{aligned} \tag{2.2}$$

where the dependent variable is the logarithm of Household h internet usage in month t, $Treatment_{h,t}$ and $Announce_{h,t}$ are dummy variables equal to 1 if h was in the treated market and t was during the treatment or announcement. As in the analysis in the previous sub-section, we interact $Treatmen_{h,t}$ with $ShareN$ indicators, $Netflix$, and $LinOTTV$.

We also allow household h fixed effects and for cubic time trends that vary with deciles of pre-policy internet usage.

We report the results in Table 2.3. In columns (1) and (2) we estimate the effects using all the households. In column (1) we find that UBP reduced overall usage during the treatment period by 10% relative to the pre-policy period; this difference is even greater (13.8%) during the announcement period. Both estimates are significantly different from zero and each other. It is not clear why households would reduce internet usage in advance of the UBP policy coming fully into effect. This could be due to confusion about the policy's details, or perhaps rational "preparation" for alternative usage patterns once internet usage is priced.

In column (2) we allow the effect to vary with the typical usage of the household. We find that the reduction is usage is significant for both light and heavy users, but that the reduction is greater for heavy users. Households without OTTV subscriptions in the two lowest usage categories reduced usage by about 10%, while households with usage shares above 100% made larger reductions in usage. Households with the lowest usage and with linear OTTV subscriptions reduced their usage even less. Finally, households with and without Netflix subscriptions respond similarly to UBP.

To explore the effects further we present separately, in columns (3)-(6), the effects for households who upgraded their tier and those who did not. Incentives to reduce usage are different between these two groups. We find that households that remained in their original tiers reduced usage by 11%, while those who upgraded reduced usage by only 1.7%. This difference in usage responses is consistent with our theoretical model, and it highlights an important channel for usage prices to increase ISP profits. Households have the option to reduce usage (thereby reducing costs) while keeping subscription payments fixed, or they can upgrade and continue their previous usage habits while allowing the ISP to capture a greater share of the surplus. The differences are even larger when allow the reduction to vary with the pre-policy usage. We find that households who did not upgrade have larger reductions in internet usage for each value in $ShareN$, including a 25% reduction in usage

by households in the highest category.

Table 2.3: The Effect of UBP on Internet Usage

	(1)	(2)	(3)	(4)	(5)	(6)
Announcement	-0.138***		-0.146***		-0.078***	
	(0.004)		(0.04)		(0.014)	
Treatment	-0.100***		-0.113***		-0.017	
	(0.004)		(0.004)		(0.014)	
Treatment ×						
Share0-50		-0.103***		-0.110***		-0.055***
		(0.005)		(0.005)		(0.019)
Share50-100		-0.099***		-0.140***		0.093*
		(0.020)		(0.022)		(0.052)
Share100+		-0.182***		-0.256***		-0.058
		(0.040)		(0.048)		(0.070)
× LinOTTV×						
Share0-50		0.054***		0.054***		0.095
		(0.014)		(0.014)		(0.069)
Share50-100		0.053***		0.052**		0.006
		(0.019)		(0.021)		(0.045)
Share100+		0.028		0.015		0.034
		(0.031)		(0.040)		(0.045)
× Netflix ×						
Share0-50		0.008		0.007		0.045
		(0.006)		(0.006)		(0.027)
Share50-100		-0.023		-0.018		-0.041
		(0.022)		(0.024)		(0.055)
Share100+		0.022		0.006		-0.011
		(0.042)		(0.052)		(0.071)
Constant	3.855***	3.849***	4.003***	3.855***	3.849***	4.003***
	(0.001)	(0.001)	(0.006)	(0.001)	(0.001)	(0.006)
Sample	All HHs		Upgr Tier = N		Upgr Tier = Y	
Observations	2,824,527		2,718,289		106,238	

Notes: The table reports estimates from linear regressions. An observation is a household-month. The dependent variable is log internet usage in gigabytes. Controls include household fixed effects and a heterogeneous time trend which interacts deciles in the distribution of total usage with a cubic time trend. *ShareN* is a dummy equal if in the pre-policy period the household used N% of the their internet tier's treatment-period allowance, LinOTTV is a dummy variable equal to one if the household has a linear OTTV subscription, and Netflix is a dummy variable equal to one if the household has a Netflix subscription. Standard errors are in parentheses, with stars indicating the following significance levels: $^{*}(p < 0.10)$,$^{**}(p < 0.05)$,$^{***}(p < 0.01)$.

In Table 2.4 we report estimates that explore the source of the reduction. We do so by running a version of equation 2.2 where we regress the monthly share of a household's h internet usage that is video in month t on the $Treatment_{h,t}$ and $Announcement_{h,t}$ indicator

variables. We include the same collection of control variables as in equation 2.2, including household-level fixed effects.

In column (1), we show that the effect of UBP is an increase in video share by 4.7 percentage points on a base of roughly 40%. This suggests that households place greater priority on streaming video than other types of internet content. This may reflect how difficult it is to move households from internet-only subscriptions into the bundle. In column (2), when we separate the effect of the treatment by pre-policy usage share, we find that higher-share households increase their video share by larger amounts. However, since higher-share households generally use more video, all the changes amount to approximately 15% increases in the share of video.[15] In column (3), we limit the sample to households that have a Netflix or linear OTTV subscription, and we find results similar to those presented in column (2).

In columns (4)-(7) we examine the share of all usage that is devoted to Netflix or linear OTTV. Columns (4) and (6) include all households in the analysis, while columns (5) and (7) condition on a household having a Netflix or linear OTTV subscription, respectively. In all cases, household internet usage becomes more focused on these large OTTV services under UBP.

The Impact on Subscriptions to Third-Party OTTV Providers

To further drill down on the effect of UBP on video usage, we investigate the impact on third-party OTTV firms through households' subscriptions. We focus on Netflix and linear OTTV (Sling or Hulu) services. To measure the impact of UBP, we ask whether a household subscribed to a particular service during the treatment period. As in the earlier analysis of ISP subscriptions, we estimate this effect using a Probit model with one observation per household. Namely, we estimate a version of equation 2.1, where the dependent variable is whether the household added a subscription to Netflix or LinOTTV. We present the results in Table 2.5.

[15]The video shares in the control markets are 30%, 45%, and 48% for households with less than 50%, 50%-100%, and 100%+ of their allowances, respectively.

Table 2.4: The Effect of UBP on Online Video Usage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Video share			Netflix share		LinOTTV share	
Announcement	0.005***	0.005***	0.016***	0.004***	0.014***	0.000	0.011***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.002)
Treatment	0.047***						
	(0.001)						
Treatment ×							
Share0-50		0.043***	0.062***	0.011***	0.034***	0.003***	0.018***
		(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.003)
Share50-100		0.067***	0.071***	0.024***	0.034***	0.008***	0.015***
		(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.003)
Share100+		0.075***	0.077***	0.029***	0.033***	0.010***	0.023***
		(0.003)	(0.003)	(0.003)	(0.003)	(0.001)	(0.005)
Constant	0.395***	0.395***	0.562***	0.205***	0.400***	0.011***	0.166***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Observations	2,824,527	2,824,527	1,524,410	2,824,527	1,495,527	2,824,527	215,950

Notes: The table reports estimates from linear regressions. An observation is a household-month. The dependent variable, depending on the column is the share of video/Netflix/Linear OTTV out of total internet usage. The sample in columns (1), (2), (4) and (6), includes all households-months, while other columns the sample includes household-months with a Netflix subscription (column (5)), linear OTTV subscription (column (7)) , or both (column (3)). Controls include household fixed effects and a heterogeneous time trend which interacts deciles in the distribution of total usage with a cubic time trend. $ShareN$ is a dummy equal if in the pre-policy period the household used N% of the their internet tier's treatment-period allowance. Standard errors are in parentheses, with stars indicating the following significance levels: $^{*}(p < 0.10)$,** $(p < 0.05)$,*** $(p < 0.01)$.

We find that Netflix subscriptions, which we observe in about half of households during the pre-policy period, fall by 3 percentage points in the treated market relative to the control markets. This overall outcome is driven by reductions in new subscriber enrollment for Netflix. In columns (2) and (3), we estimate separate effects by the household's value of $ShareN$. In column (2) we present results that restrict the sample to new Neflix subscriptions. We find that all households, regardless of usage share categories, lowered their probability of subscribing to Netflix in the treated market, relative to the control markets. Conversely, we find that households who subscribed to Netflix in the pre-policy period, were more likely to retain their Netflix subscriptions in the treated market. These effects are uniformly smaller than the corresponding reductions in new Netflix subscriptions leading to a net reduction in growth of Netflix in the treated market.

Table 2.5: The Effect of the Price Change on Take-up of OTTV Subscriptions

	Netflix			LinOTTV		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	-0.030***			0.010***		
	(0.002)			(0.002)		
Treatment ×						
Share0-50		-0.095***	0.017***		0.002	0.083***
		(0.004)	(0.003)		(0.002)	(0.013)
Share50-100		-0.079***	0.014**		0.013***	0.102***
		(0.018)	(0.006)		(0.004)	(0.017)
Share100+		-0.129***	0.028**		0.010	0.058**
		(0.037)	(0.012)		(0.007)	(0.026)
Sample	All	New	Keep	All	New	Keep
Observations	327,279	141,359	185,920	327,279	297,805	29,474

Notes: Each column contains marginal effects from a probit regression. Each observation is a single household. The dependent variable is an indicator for whether the household subscribes to the OTTV service specified in the first row of the table during the treatment period. Controls include the uninteracted $Share_h$ variable, position in the monthly total internet usage distribution (discretized into deciles), pre-policy period OTTV subscription indicators, and a TV subscription indicator. Standard errors are in parentheses, with stars indicating the following significance levels: $^{*}(p < 0.10)$,$^{**}(p < 0.05)$,$^{***}(p < 0.01)$.

We report results focusing on linear OTTV subscriptions, instead of Netflix, in columns (4)-(6). In contrast to Netflix subscriptions, linear OTTV subscriptions increased in the treated market after the ISP introduced internet usage prices. The overall effect of UBP was

a 1.0 percentage point increase in subscription frequency; this change is on a base of about 8% during the pre-policy period. The greater frequency of linear OTTV subscriptions under UBP is largely due to households who were pre-policy subscribers and kept their linear OTTV service during the treatment period.

These results, together with our findings on total usage, suggest that UBP leads to a mix of extensive and intensive margin impacts on OTTV. We find a reduction in Netflix subscriptions, but households generally shift their internet usage toward video (in percentage terms) when UBP puts a price on high usage. Our findings on linear OTTV suggest that these services may have benefited from households choosing to focus their internet usage on video content following UBP. Of course, UBP's impact to reduce overall usage implies that it must negatively affect some internet content, but these effects do not fall on the video sites we highlight in this paper.

2.4.3 Implications for ISPs' incentives for OTTV

Broadly speaking an ISP has two possible responses to new streaming services or more generally an improvement if the quality of OTTV. One possible response is to steer consumers away from these services and toward the ISP own TV products. alternatively, the ISP may decide to promote the OTTV, and enhance the quality of the internet offering. As we show in Section 3, this strategy is particularly profitable if the ISP can extract surplus from consumers who place higher value on OTTV using some form of price discrimination or nonlinear pricing. The former strategy is associated with reducing OTTV usage and possibly access, while the latter benefits from allowing third-party video content to grow. ISPs' choices between these strategies will depend on the pricing tools available and the difficulty or ease of moving consumers across products.

In Section 3, we provided simulation results for particular parameter values and specific distributions of tastes that suggest that while the first option (of steering consumers towards TV services) is possible, it did not seem to be profitable if the ISP has sufficient pricing tools

such as the ability to offer different tiers and UBP. The empirical results in the previous subsection support the same conclusion for the following reasons.

First, the results in Table 2.2 columns (1) -(4) show that that the ISP can use UBP and a menu of internet plans to induce consumers to change their internet plan. This allows the ISP to separate users according to their internet usage and collect additional revenue from heavy internet users, who value the internet service the most. Collecting more revenue makes the option of promoting OTTV more profitable because the ISP can extract more of the value generated from OTTV.

Second, the results in Table 2.2 (5) - (8) suggest that steering consumers towards TV service is difficult. We find that the internet usage price increase, implied by the introduction of UBP we observed, was insufficient to steer many consumers from internet-only subscriptions into the bundle. This is true for both light and heavy users, despite being sufficient to induce upgrades in plans. The relatively muted movement in either direction for TV subscriptions reveals the potential difficulty in influencing consumers along this margin and suggests that the ISP would need larger bundle discounts to steer more consumers across this margin, which would reduce the profitability of the steering-focused strategy.

Third, as the results in Table 2.3 show UBP was effective in reducing overall usage, especially for consumers who did not upgrade their plan. Furthermore, consumers who choose to upgrade their internet tier did not use significantly more data. Both these results suggest that the ISP's introduction of tiers may not lead to pressure for an expanded network and higher ISP long-run investment costs.

Fourth, the results in Tables2.4 and 2.5 show that consumers focus their usage on OTTV after UBP is introduced. This suggests that households favor streaming video over other types of internet content and therefore reductions in OTTV quality or its foreclosure would not bee viewed favorably by consumers.

The tier upgrades and reduced usage represent outcome that an effectively reallocate OTTV surplus from households to the ISP. We find that usage-allowances led to a 0.3% increase in ISP revenues via tier upgrades and a 1% increase in revenues via overage charges.

Tier downgrades caused a 0.03% decrease in revenues. Gains from new TV subscriptions and losses from cord-cutters had effects on revenue of 0.05% and 0.07%, respectively. In sum, the total effect was 1.25%, with non-negligible effects driven by internet usage-related revenue increases. Despite the fact that some UBP outcomes can have negative impacts on some consumers, ISPs' incentives to create new content and expand their networks may be stronger when ISPs capture a greater share of total surplus from OTTV. Both the theoretical results and empirical fings suggest that the ISP can use both bundle discounts and usage tiers simultaneously in response to households' demand for streaming video. If the ISP's pricing strategies are more restricted, in particular through restrictions on its ability to price internet usage, the firm may perceive greater benefits in steering consumers toward conventional TV and restricting access to OTTV.

In addition to these direct impacts on the ISP and its subscribers, the steering strategy has significant effects on OTTV firms. The results in Table 2.5 suggest that Netflix subscriptions fell significantly when UBP was introduced, primarily due to a reduction in new subscriptions by households without Netflix subscriptions at the start of our sample period. While Netflix offers a mix of original programming and older TV shows and movies, other OTTV services like Hulu and SlingTV offer content much more similar to conventional TV. We do not find a reduction in subscriptions for these services (in fact, they increase under UBP), which suggests that households are prompted to fully reconsider the portfolio of internet content they consume once it is priced. Despite the reduction in overall internet usage under UBP, the share of consumption devoted to video increases. Households' resistance from moving away from streaming video is consistent with the ISP having opportunities to capture surplus from consumers' usage of these services rather than shifting a large amount of consumers across different forms of video entertainment, both streaming and conventional. The ISP's ability to direct consumers across video entertainment sources may play a prominent role in future antitrust or regulatory debates, such as evaluating vertical mergers between content and distributor firms, or more horizontal mergers involving firms that compete in either content production, video distribution, or both.

2.5 Conclusions

This chapter studies the impact of online video services on the telecommunications industry and the incentives of ISPs with respect to these new services. We provide a model that describes some of the central incentives behind ISPs' prices. We show that indeed the ISP might have an incentive to steer consumers away from OTTV, but that those incentives decline as the ISP has richer pricing tools that allow it to share in the gains generated by OTTV. We then use household-level panel data which includes the introduction of usage-based pricing in a subset of markets to understand consumer behavior and its implications for the steering incentives. Consistent with the theoretical findings, the empirical results suggest that the ISP has an incentive to help improve internet access.

Chapter 3

Pricing Strategies in Telecommunications Markets

3.1 Introduction

In many industries, consumers rely on platforms to access goods or services. When platform firms vertically integrate, they face a trade-off between maintaining the standalone value of the access network and promoting integrated products. Integrated platforms possess a variety of tools to influence consumer behavior; they not only set prices for their own goods, but also control the assortment of third-party goods that consumers can access. Altering the assortment of available substitute goods allows the platform to gain market share by foreclosing third-parties. This paper studies the joint pricing and assortment decisions faced by platforms and the impact of new selling strategies on the distribution of industry surplus.

There are many examples of integrated platforms across different industries: Amazon offers private-label goods through AmazonBasics; Netflix produces original content; Apple owns applications on its App Store. Despite the growing use of platforms, several empirical questions remain unanswered: What is the optimal tariff structure in these settings? Are product assortment decisions by platforms anticompetitive? Are these industry structures harmful to consumers?

This paper contributes to the literature by studying the impact of internet service provider (ISP) decisions over the pricing and assortment of third-party video streaming applications available on their broadband networks. ISPs are platforms: they sell access to a network that connects consumers to a content providers such as Netflix or Sling TV.

They are also content providers, selling bundles of TV channels and dedicating a share of network resources towards the delivery of TV content. Third-party video streaming applications increase the value of internet access, but also compete with TV, with many applications offering the same content as the traditional TV product delivered by ISPs. An ISP's decision regarding which applications to make available over the internet thus evokes a trade-off between inducing substitution from online video to TV subscriptions and damaging the value of internet access.

Internet access and video content differ from other platform contexts because they are information goods, which are distinct from other commodities in two important ways. First, the value of access to content is not immediately realized, but rather depends on the amount of time spent consuming it. Attention is a scarce resource for consumers, making time-intensive goods inherent substitutes. Second, because the value of information content decays over time, these goods are sold using a subscription-based pricing model. In contrast to other platforms, ISPs charge a subscription fee for access to the internet in addition to a subscription fee for TV, resulting in multiple mechanisms by which they can extract surplus.

The treatment of third-party content by ISPs is a contentious policy issue. In 2017, the Federal Communications Commission voted to repeal rules established by an earlier 2015 decision which prohibited ISPs from blocking, throttling, or prioritizing individual websites or applications. The repeal of net neutrality protections broadens the scope of ISP control over the pricing of internet content, but the implications of newly permissible pricing strategies are not well-understood. Studying these pricing incentives is of particular interest given the recent wave of consolidation in the telecommunications industry involving both service providers and content providers, such as the 2018 merger between AT&T and Time Warner. Though the competitive implications of TV network ownership by TV distributors have been studied (Chipty, 2001; Suzuki, 2009; Crawford et al., 2018), the effect of AT&T's stake in Time Warner's online content on its internet pricing incentives is less-understood. For example, AT&T may stand to benefit post-merger from blocking or

otherwise degrading Netflix, so that more subscribers switch to HBO Now.

At the time of this writing, limiting the assortment of content on their networks is within the purview of ISP decision-making. However, ISPs have not yet modified the set of content available on their networks. As such, the ideal natural experiment needed to study the implications of this type of strategy, one in which the researcher observes the decisions of consumers who are offered alternative assortments, does not exist. I proceed instead by simulating counterfactual settings using a model of ISP pricing and a continuous-discrete choice model of demand for internet and video content in the spirit of Crawford and Yurukoglu (2012), in which the utility derived from access to content depends on the time allocated to it.

At the core of this effort is a novel dataset on household-level purchases and usage obtained from an anonymous North American ISP. The micro-data contain over 130 million household-day-hour observations of subscription information for both internet and television tiers, and utilization data collected from internet modems and TV set-top boxes. The average internet subscriber in the sample consumes 7.75 gigabytes per day, 62% of which is online video. The average Internet household watches nearly 4.75 hours of online video per day, while the average TV household watches 4.84 hours of TV per day. Households with internet and TV subscriptions consume 30% fewer hours of online video than internet-only households and 13% fewer hours of TV than TV-only households. A key feature of this dataset is visibility into streaming consumption at the application level. I infer streaming application subscriptions based on the timing and intensity of usage. The two most-used applications in the data are Netflix and YouTube, which respectively make up 15% and 12% of total internet traffic, and have penetration rates of 63% and 94% among internet subscribers.

I estimate the model using a two-step mixture estimator related to the methodology described in Fox et al. (2011) and Fox et al. (2016), where the objective is to find mixture weights for a set of basis densities describing model heterogeneity. The model estimates imply a much less elastic demand for internet than TV subscriptions, with an internet own-

price elasticity of -0.99 and TV tier elasticities ranging from -6.45 to -3.13, leading to much higher margins on internet than TV. I find that the average internet household is willing to pay $19 for Netflix and $32 for Streaming TV, and when access to streaming applications is removed, willingness-to-pay for the average household's preferred bundle falls by $38, or 20%.

The first finding of this paper concerning ISP strategies is that foreclosing on streaming is not profitable. The results of this counterfactual, a study of the implications of the FCC's "no blocking" rule repeal, suggest that foreclosure concerns may be somewhat mitigated given current ISP pricing practices. When access to third-party video applications is removed, the ISP's TV service benefits from less competition, and prices rise by 32%. However, this additional surplus capture from consumers with a taste for TV is offset by a loss in the profitability of internet subscriptions. The optimal internet price falls by 21% and ISP profits fall by $3 per subscriber-month. In blocking access to internet content, ISPs damage the value of internet access as a whole, and consumer surplus falls by $3.50 per subscriber-month.

Next, I explore the implications of more flexible pricing strategies in which the ISP is able to set not only a baseline price for internet access, but also add-on prices for access to specific third-party applications. Intuitively, this type of strategy aligns internet pricing more closely with TV pricing, with add-ons for premium online video subscriptions serving a similar role to higher-tier TV subscriptions that allow access to more channels. Though an add-on internet pricing model has not yet been implemented in practice, its implications are analogous to zero-rating practices employed by mobile and residential broadband providers that employ usage-based pricing. Just as zero-rating creates differences in the marginal price of consumption of certain content by not counting consumption against usage allowances, the add-on pricing strategy creates differences in the relative prices of subscriptions by charging additional fees.

I find that under add-on pricing, the ISP sets a dramatically higher price for standalone internet access, increasing the price by 50%, but a combination of lower TV prices (40%

reduction) and lower internet and TV bundle prices (27% decrease) cause nearly every internet household to switch to a bundle containing both internet access and TV. The optimal add-on prices for Netflix and Streaming TV are $6 and $40, respectively. Not surprisingly as it nests the ISP's baseline strategy, add-on pricing is profitable for ISPs, and leads to a $24 increase in profit per subscriber-month for ISPs. This profit increase comes from increased TV subscriptions as over 90% of previously internet-only households add TV, and increased revenue from previous online video users that retain their third-party subscriptions under the new pricing policy. Consumer surplus increases overall by 14$ per month, with 75% of the welfare gains captured by two groups—previously internet-only households that switched from online video to TV, and households that already purchased both TV and online video at baseline prices.

These findings are subject to several noted limitations. First, the pricing counterfactuals explored with the estimated model are "partial" in the sense that they do not account for the possible actions of competing ISPs, and do not allow online video prices to adjust. Price discrimination is possible under imperfect competition, but the implications of new strategies such as blocking or add-on pricing will change if the outside purchase option includes a competing ISP. Second, counterfactuals assume that the channel composition of the ISP's TV tiers does not adjust. Individual channels vary in their availability online from third-parties, so removing outside sources for some channels may increase the value of moving them into higher-revenue tiers. Third, due to a lack of ISP cost data, the results do not account for long-term investment savings from reduced internet consumption that may result from reducing online video use.

Contributions and Related Literature

Previous work studying the television and broadband industries has primarily focused on one or the other industry in isolation, whereas this paper seeks to understand joint pricing across internet and TV. In the cable industry, Chipty (2001), Suzuki (2009), and Crawford et al. (2018) study foreclosure incentives when programmers and distributors vertically

integrate. In this paper, TV distributors also sell broadband, which gives them vertical leverage over online video competitors. Other papers study the demand for broadband and ISP pricing strategies (Rosston et al., 2010; Greenstein and McDevitt, 2011; Nevo et al., 2016), as well as ISP relationships with content providers (Goetz (2019), Tudon (2019)). McManus et al. (2018) study ISP incentives to steer consumers from third-party online video to TV subscriptions. I extend their largely reduced-form results using a structural approach which allows me to make welfare statements and consider counterfactual pricing and assortment scenarios.

This paper takes a similar approach to previous studies that learn about valuations from time-allocation and usage decisions. Goolsbee and Klenow (2006) combine earnings information with time spent on the internet to learn about consumer benefits from broadband. Crawford and Yurukoglu (2012) use ratings data to learn about relative valuations of TV channels. Many other papers have studied TV viewing behavior, in particular with respect to advertising. (Wilbur, 2008; Deng and Mela, 2018).

Finally, this paper complements a literature pertaining to the economic analysis of net neutrality, the bulk of which is theoretical, dating back to Wu (2003). Definitions of net neutrality vary based on whether restrictions are placed on interactions between ISPs and content providers or ISPs and consumers (Economides and Hermalin, 2012; Armstrong, 2006; Bourreau et al., 2015; Choi et al., 2015; Choi and Kim, 2010; Economides and Tag, 2012; Gans, 2015; Reggiani and Valletti, 2016). This paper considers the relationship between ISPs and consumers. The literature is reviewed in Lee and Wu (2009) and Greenstein et al. (2016).

Road Map

In Section II, I describe the data sources used in the analysis and highlight key empirical facts. Section III contains a model of consumer demand for internet and video subscriptions and viewership, as well as a model of ISP pricing. Section IV is a discussion of the identification and estimation of the structural model, the results of which are presented in Section

V. I analyze counterfactual pricing and demand responses to varied product assortment in Section VI. Finally, I offer my conclusions in Section VII.

3.2 Data

In this section, I describe the data used in the empirical analysis and highlight the role of substitution from traditional TV to video streaming applications in driving internet traffic growth.

3.2.1 Data Sources and Description

The data used in this analysis come from an anonymous North American internet service provider (ISP), which provides information on subscriptions and utilization of internet and TV services.

The sample is collected from a market of approximately 20,000 addresses passed, i.e., addresses that are connected to the ISP's network and thus capable of receiving service. The panel spans a 15-month period between May 2017 and July 2018, and contains approximately 130 million household-day-hour observations.

The ISP sells broadband internet access, TV, and landline voice services. Information on household take-up of the ISP's offerings is provided at a daily frequency and includes characteristics of the chosen package, e.g., internet download speed and set of TV channels. Approximately 13,000 of the addresses passed purchase internet or TV from the ISP. Of these served households, 64% choose a bundle of internet and TV service, 35% choose internet without TV, and fewer than 1% choose TV alone.

For each household with an internet subscription, I observe aggregated information from a deep packet inspection (DPI) analysis that reports byte counts passed downstream and upstream, as well as a breakdown of total bytes passed into several traffic categories. The scope of the data include traffic on all devices, including mobile devices, as long as

it is directed over the home broadband network (i.e., via Ethernet or WiFi). Cellular data plans and internet consumption outside of the home are both unobserved. These data, aggregated from the household-day-hour to household-day level of observation, are summarized in Table 3.1.

The average sampled internet household consumes 7.75 gigabytes per day of bandwidth. The majority of internet traffic, nearly two thirds of the total, comes from the "Streaming/Video" category, which consists primarily of traffic consumed by online video applications such as Netflix, as well as some embedded video content on other websites.[1] The next-largest category is "Web Browsing", accounting for 11% of the average household's daily usage, with similar consumption also captured in the "Email" and "Social Networking" groups. The distributions of total usage and usage by traffic type are very heterogeneous, with the right-skewed 95th percentiles of total usage and streaming usage accounting for three and four times the respective mean levels.

Application-level usage information is available for all traffic falling under the video category. Each video byte can be matched to a specific application, e.g., Netflix, as well as information about the streaming session, such as the total time duration, the resolution, and the device used. Table 3.2 summarizes take-up and conditional usage of the most-used online video applications in the data. The largest application in terms of traffic is Netflix, with the average subscriber consuming nearly 2 gigabytes per day on the application. Its market share among internet subscribers in the sample is 66%. The application reaching the most households is YouTube, with nearly 100% penetration and over a gigabyte per day of consumption per household.

For each household with a TV subscription, I also observe tuning information from the household's set-top box. These tuning data are aggregated to the household-day-hour level. The average TV household watches 4.5 hours per day.

The rise in popularity of online video affects ISPs in two ways. As a potential substitute

[1]The majority of encrypted traffic is observable and sorted into the appropriate application type, though some encrypted video traffic for which a content provider is not identified is counted in the Bulk Transfer category.

Table 3.1: Daily Internet Usage by Traffic Type

	Mean	SD	p25	p50	p75	p95	p99
Traffic Types							
Bulk Transfer	0.89	2.38	0.13	0.32	0.75	3.68	9.14
Email	0.02	0.16	0.00	0.01	0.02	0.07	0.21
Gaming	0.18	0.89	0.00	0.00	0.04	0.85	3.60
Miscellaneous	0.23	1.08	0.04	0.10	0.22	0.65	1.66
Network Storage	0.27	5.32	0.02	0.06	0.16	0.69	2.44
Peer-to-peer	0.08	1.83	0.00	0.00	0.00	0.00	0.88
Communication/Voice	0.13	0.39	0.00	0.02	0.11	0.59	1.41
Social Networking	0.12	0.18	0.03	0.08	0.16	0.36	0.77
Tunnel	0.05	0.95	0.00	0.00	0.00	0.06	0.62
Web Browsing	0.93	4.80	0.27	0.56	1.05	2.57	5.63
Streaming/Video	4.81	6.45	0.44	2.38	6.75	17.35	29.95
Total (All Types)	7.75	11.94	1.52	4.49	10.58	24.72	42.26
Household-months	45741						

Notes: This table shows the distribution of daily household internet usage by traffic type measured in gigabytes. Observations are household-months. A description of traffic types with example applications and protocols in parentheses follows. Bulk Transfer is comprised of large file transfers (FTP). E-mail captures the use of service-provider and webmail e-mail services (Gmail, SMTP, POP3). Gaming consists of console and PC gaming (PlayStation, Xbox). Network Storage is primarily comprised of file-hosting and backup services (Dropbox, MegaUpload). Peer-to-peer consists of file-sharing applications (BitTorrent). Communication/Voice captures the use of interactive video and voice communications (Skype). Streaming/Video consists of applications involving "on-demand" entertainment that is consumed as it arrives (applications like Netflix, YouTube, protocols like RTSP, Flash). Social Networking comprises of the use of social networking websites (Facebook, Twitter). Tunnel traffic consists of encrypted channels used for VPN and secure web transactions (SSL, SSH). Web Browsing consists of the use of specific websites (HTTP).

Table 3.2: Consumption of Online Video Applications

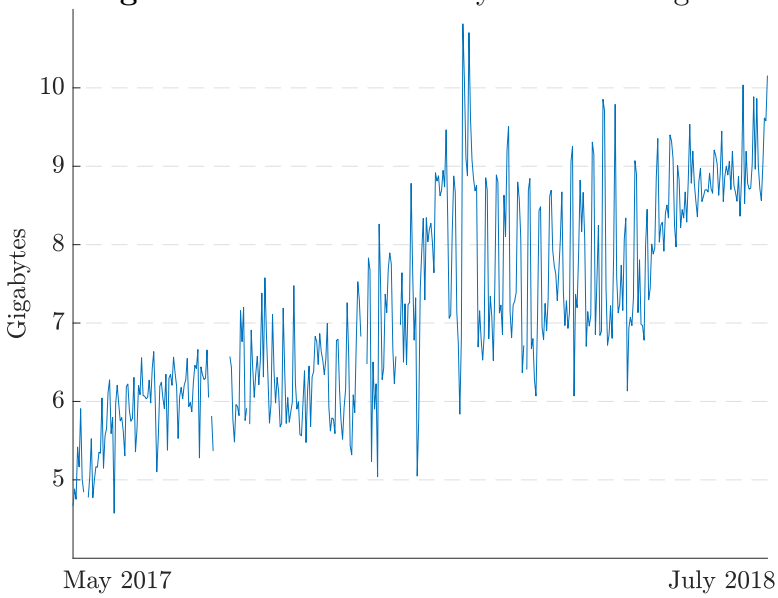
	Daily Usage	Penetration	Conditional Usage
Netflix	1.13	0.63	1.81
YouTube	0.90	0.94	0.95
Amazon Video	0.27	0.36	0.74
Hulu	0.09	0.10	0.89
Sling TV	0.08	0.03	2.66
Twitch	0.07	0.19	0.35
DirecTV Now	0.05	0.01	3.35
Facebook	0.04	0.89	0.04
HBO	0.03	0.04	0.59
Vudu	0.02	0.03	0.77
Household-months	45741	45741	43914

Notes: The applications listed are the top 10 ranked applications by total traffic volume. Observations are household-months. Usage is average daily consumption measured in gigabytes. Penetration is the share of internet households with positive usage. Conditional usage is daily consumption among households with positive usage.

to TV, it may impact ISP subscription revenue, and as a driver of traffic growth, it influences costs by increasing the burden on bandwidth-constrained network infrastructure.

Industry reports document annual growth rates of approximately 30% in residential broadband traffic (Cisco, 2017). Figure 3.1 shows the growth in internet traffic over the course of the sample. During the 15-month sample period, average daily consumption increased by over 50%.

Figure 3.1: Growth in Daily Internet Usage



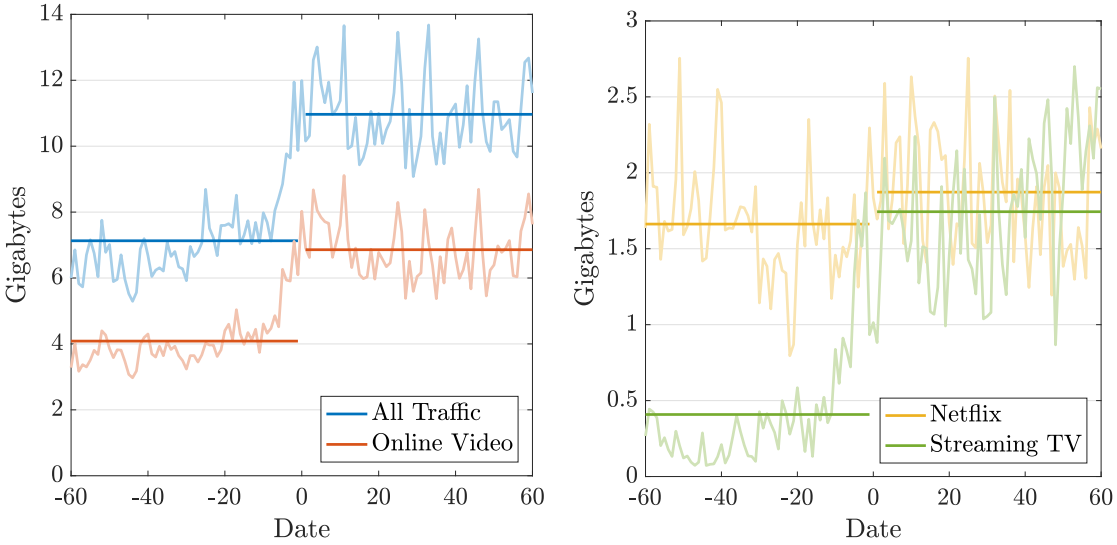
Notes: This plot depicts average daily internet usage over the course of the sample. Each point is the total count of gigabytes consumed by the average household.

3.2.2 Cord-cutting

Since the emergence of online video, the number of households with traditional TV has plateaued. Fewer new consumers purchase TV subscriptions, while an increasing number of previously "bundled" households, those with TV and internet access, opt to "cut the cord," or cancel their TV subscription in favor of an internet subscription alone. The decline in number of TV subscriptions observed in the sample is approximately 2.7%, consistent with Nielsen's (2019) estimate of an annual rate of 2-3%.

The fact that consumers are now switching from the bundle of TV and internet to internet-only subscriptions suggests that internet itself or specific internet applications may be substitutes for TV. Figure 3.2 shows the internet consumption habits of observed households that cut the cord. In particular, the two panels demonstrate how cross-household averages of total consumption as well as consumption of video streaming applications change in the 60 days preceding and following the cord-cut date. The horizontal lines indicate pre- and post-transition averages. From the left panel, we see that total consumption immedi-

Figure 3.2: Effect of Cord-cutting on Internet Usage



Notes: These figures show the average daily internet usage of cord-cutters in the 60 days before and after they cancel their TV subscription. The left panel depicts both total usage and online video usage over time. The right panel depicts Netflix and Streaming TV usage.

ately increases by nearly 4 gigabytes per day, or 54%, and that this increase is driven by a 2.8 gigabyte, or 68%, increase in online video consumption. For this group of households, video's share of total consumption increases from 57% to 63% after cutting the cord.

The right panel shows that the change in total online video consumption is heterogeneous across applications. Daily consumption of Netflix increases modestly, by 12%, while use of Streaming TV, defined as applications that offer the same content as the ISP's TV service—in this sample, Hulu, Sling TV, DirecTV Now, and PlayStation Vue—increases four-fold to 1.75 gigabytes per day. The difference in engagement between these two application types is suggestive of variation across online video applications in the degree of substitutability with TV. While cord-cutters may already be close to saturation levels with Netflix's original content before dropping TV, streaming TV's overlap in content with traditional TV makes it a natural substitution destination after a cancelled TV subscription.

In addition to the content itself, another reason online video and traditional TV may be substitutes is that they are both time-intensive activities that require attention. Table 3.3

Table 3.3: Cross-platform Media Consumption by TV Subscription

	Internet-only	Basic TV	Network Tier 1	Network Tier 2
TV	0.00	1.79	4.49	5.48
Streaming/Video	5.71	6.44	4.11	4.14
Netflix	0.84	0.92	0.59	0.50
YouTube	3.83	4.54	3.08	3.08
Amazon Video	0.23	0.32	0.17	0.16
Streaming TV	0.43	0.37	0.06	0.05
Other	0.38	0.28	0.20	0.35
Total	5.71	8.27	8.58	9.62
Household-months	13305	4571	18308	9557

Notes: This table shows average daily hours spent viewing media online and on TV for households with different ISP subscriptions. All households in the table have internet access, and vary based on their TV subscription. Observations are household-months.

shows how the distribution of time spent on media across internet and TV varies depending on the video subscription the household purchases from the ISP. In general, households that purchase a TV subscription which includes a greater number of channels watch more TV and relatively less streaming video. Although the increase in TV consumption moving into higher tiers is somewhat offset by a decline in streaming consumption, the total time allocated to media is increasing, suggesting that the two mediums are not fully substitutes.

3.2.3 Choice Set and Selection of Content Types

The ISP sells TV and internet access, offering a menu of differentiated tiers. TV tiers are nested packages of channels, with higher-revenue tiers containing tier-specific channels in addition to all channels offered by lower tiers. Internet tiers are differentiated by download speed. I group all internet tiers together and abstract from modeling a preference for speed for two reasons. First, internet tiers are not associated with bandwidth allowances in this market and thus do not restrict the level of internet consumption. Second, the ISP's network is modern and congestion-free, and without such capacity constraints the download speeds realized on even the slowest tier are well in excess of the speeds recommended by

video streaming providers.[2]

I dis-aggregate total time spent on media into several content types. In addition to the three sets of channels in the ISP's TV tiers, I focus on four types of internet content. Netflix is the most-used application in the data, accounting for 15% of total internet traffic, and makes up its own consumption type. I also distinguish streaming TV viewership (usage of Sling TV, DirecTV Now, Hulu, and PlayStation Vue) from other streaming for two reasons. First, it is marketed as a direct substitute to the ISP's TV product, and as such is intuitively a close competitor for which exclusion may be optimal for the ISP. Second, despite having a smaller reach than applications like Netflix, streaming TV subscribers engage with the service far more than subscribers of any other streaming application, viewing content on the application in excess of three hours per day. Since each consumption type requires additional model parameters, for feasibility of estimation, consumption of the remaining video applications is grouped into a single category. Time spent on non-video internet activities (web browsing, social networking, email, etc.) is grouped into a final category.[3]

In total there are eight consumption types including the outside option. The three sets of channels making up the ISP's TV tiers contribute three, while the remaining four require an internet subscription. These include Netflix and Streaming TV, each of which requires an additional third-party subscription to view, in addition to "Other Streaming" and "Other Web", both of which are available to any household with an internet subscription. Appendix Table B.1 lists the full set of subscription combinations from the ISP and third parties, and the consumption types that are available to households that choose each bundle.

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[2]Netflix recommends a 25 Mbps download speed for streaming Ultra HD/4K content, its highest available video quality.

[3]Consumption of non-video activities is observed in bytes rather than hours. I use conversion rates published by Cable One at https://www.cableone.net/data-calculator to obtain time allocated to this consumption type.

3.3 Model

In this section I describe a model of household decision-making and ISP pricing. First, households make choices over bundles of subscriptions, each of which includes internet access and TV tiers sold by the ISP in addition to third-party online video applications. Each subscription bundle grants access to a set of content types, which households allocate their time to in a second stage. The utility derived from a bundle is expressed in terms of the optimal allocation of time to the content it provides, as in Crawford and Yurukoglu (2012). Finally, ISPs set prices for internet access, three TV tiers, and a bundle discount given the population distribution of the preference parameters that guide household decision-making.

3.3.1 Subscription Choice and Content Usage

Each household chooses a product bundle b from a menu of available subscriptions. The available subscriptions include both products sold by the ISP (internet access and tiers of the ISP's TV service) and third-party video streaming applications, e.g., Netflix. For any bundle of subscriptions b, let $s(b)$ denote the assortment of content provided by the subscriptions in b.

Households compare the indirect utility $v(b;\boldsymbol{\theta})$ they would receive from viewing each set of content $s(b)$ with the posted price for the bundle b, p_b. The optimal bundle choice satisfies

$$\max_b u(b;\boldsymbol{\theta}) = v(b,\boldsymbol{\theta}) - p_b.$$

A household with access to content $s(b)$ allocates time $h_c(b)$ to each content type $c \in s(b)$ and its remaining time $h_0(b)$ to outside activities. A vector $\mathbf{h}(b)$ is a time-allocation decision, specifying the time allocated to each content type provided by b. For any time-allocation decision $\mathbf{h}(b)$, let the utility from viewing content be given by $w(\mathbf{h}(b);\boldsymbol{\theta})$, where $\boldsymbol{\theta}$ is a vector of parameters governing the shape of utility, henceforth referred to as a household type. The indirect viewing utility from set $s(b)$, attained from the optimal time allocation

decision $\mathbf{h}(b)$, is given by

$$v(b;\boldsymbol{\theta}) = \max_{\mathbf{h}} w(\mathbf{h}(b);\boldsymbol{\theta})$$
$$\text{s.t.} \sum_{c \in s(b)} h_c + h_0 = T$$

where T is the total amount of time available to the household. The utility of the outside bundle option $b = 0$ is given by the viewing utility associated with the time allocation $h_0 = T$ in which all time is allocated to the outside consumption option.

For the remainder of this section, I discuss the parameterization of viewing utility and its ability to capture key empirical features of consumption. Viewing utility takes a nested constant elasticity of substitution (CES)-type form in the time allocated across content:

$$w(\mathbf{h};\boldsymbol{\theta}) = \left[\delta_1 \left(\sum_{c \in s(b)} \delta_c h_c^{-\rho_2} \right)^{\rho_1/\rho_2} + \delta_0 h_0^{-\rho_1} \right]^{-1/\rho_1}$$

The δ_c parameters set the marginal utility of consuming content. The relative value of platform and outside option utility is controlled by δ_1 and δ_0, the latter of which is normalized to 1 for the estimation. The ρ_1 and ρ_2 parameters control the curvature of utility and affect willingness to substitute time between different activities. The ρ_2 parameter controls the flexibility of time spent on TV or internet activities, while the ρ_1 parameter governs willingness to substitute between platform content and the outside option.

The substitution parameters have two important implications for the shape of utility. First, they control the decay of the marginal utility of content. For small ρ_2, an individual will spend most of his time on the consumption type with the highest marginal utility. However, as ρ_2 increases, utility for a given consumption type decays more rapidly, and the model predicts that time is spread more evenly across consumption types. The second implication follows from the first, but concerns subscription utility. When ρ_2 is large, the value of choosing larger bundles with more content types increases. A larger set $s(b)$ means there are more content types to choose from, and the marginal instant of attention allocated to each type is subject to less decay. As such, for a pair of bundles b and b'

for which $s(b) \subset s(b')$, i.e., bundles for which b' offers at least as much content as b, the difference $v(b';\boldsymbol{\theta}) - v(b;\boldsymbol{\theta})$ is increasing in ρ_2.

The model provides an optimal time allocation $h_j^*(b,\boldsymbol{\theta})$ for each consumption type $j \in s(b)$. The Lagrangian for the time allocation problem is:

$$\mathcal{L} = w(\mathbf{h};\boldsymbol{\theta}) + \Lambda\left(T - \sum_{c\in s(b)} h_c + h_0\right)$$

The solution is defined by the following system of first-order conditions:

$$\partial u/\partial h_c : \left[\left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\rho_1/\rho_2} + \delta_0 h_0^{-\rho_1}\right]^{\frac{-1-\rho_1}{\rho_1}} \left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\frac{\rho_1-\rho_2}{\rho_2}} \delta_1 h_1^{-\rho_2-1} = \Lambda \quad (3.1)$$

$$\partial u/\partial h_0 : \left[\left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\rho_1/\rho_2} + \delta_0 h_0^{-\rho_1}\right]^{\frac{-1-\rho_1}{\rho_1}} \delta_0 h_0^{-\rho_1-1} = \Lambda \quad (3.2)$$

$$\partial u/\partial \Lambda : \sum_{c\in s(b)} h_c + h_0 = T \quad (3.3)$$

The optimal viewing of type j is related to the size of δ_j relative to the marginal utility parameters of other available consumption types. To see this, consider the case when $\rho_2 = \rho_1$ and $\delta_1 = 1$ so that there is no nest. The first-order conditions are all of the form given by equation (2) and optimal consumption has a simple closed form:

$$h_j^*(b;\boldsymbol{\theta}) = \frac{\delta_j^\sigma}{\sum_{c\in s(b)} \delta_c^\sigma + \delta_0^\sigma} \cdot T$$

where $\sigma \equiv 1/(1+\rho_1)$. Here it is easy to see the effect of the substitution parameters on time allocations. When ρ_1 and ρ_2 approach -1, viewing utility is linear and the optimal time allocation is a corner solution in which all time is allocated to the content type with the highest marginal utility parameter. As ρ_1 and ρ_2 approach 0, the utility function approaches the Cobb-Douglas utility function, and time is allocated exactly proportionally to the relative size of the δ parameters.

Table 3.4: Mixed Bundle Prices

	TV Tier			
Internet	None	Tier 1	Tier 2	Tier 3
Yes	0	$p_{0,1}$	$p_{0,2}$	$p_{0,3}$
No	$p_{1,0}$	$p_{1,0} + p_{0,1} - p_\delta$	$p_{1,0} + p_{0,2} - p_\delta$	$p_{1,0} + p_{0,3} - p_\delta$

3.3.2 ISP Bundling Problem

The ISP offers internet access and three TV service tiers, differentiated by the number of channels they contain. It sets a price for standalone internet and each TV tier in addition to a fixed bundling discount p_δ that applies when consumers purchase both internet and TV together. Prices are as shown in the following table.

The primary costs associated with TV are network affiliate fees paid by the ISP to the producer of each channel it broadcasts. These affiliate fees are a per-subscriber payment. The constant marginal cost of selling TV tier j is the sum of the affiliate fees associated with each channel in tier j, referred to henceforth as c_j. The bulk of the costs associated with supplying internet access are in the form of investments in internet infrastructure, which are infrequent and not observed in this sample. Without the data needed to inform a model of investment, I model only the short-run marginal cost of supplying internet access.[4] The profit function is

$$\pi(\mathbf{p}; F(\theta)) = \sum_b \left(p_b - \sum_{j \in b} c_j \right) s_b(\mathbf{p}; F(\theta)),$$

where the share of bundle b is determined by integrating across the distribution of types, $F(\theta)$, i.e.,

$$s_b(\mathbf{p}) = \int_\theta \mathbb{1}\left[b = \arg\max_{b'} \left(v(b', \theta) - p_b \right) \right] dF(\theta),$$

where p_b is the price of bundle b, i.e., the sum of the price indicated in the above table and any third-party subscriptions, and the sum over j adds up the individual marginal costs of

[4]The marginal costs associated with providing internet access consist of the electricity costs of delivering traffic, customer service, and exchange costs as traffic is routed from the access network to upstream sources outside of the ISP's network.

each component in bundle b.

3.4 Estimation and Identification

In this section, I outline the estimation procedure and discuss the identification of model parameters. It is well-known from the price discrimination literature that optimal pricing solutions are highly sensitive to parametric demand assumptions. For this reason, I take a flexible approach to estimating the distribution of random coefficients describing preference heterogeneity related to the methodology described in Fox et al. (2011) and Fox et al. (2016). The approach expresses the joint distribution of parameters as a mixture of normal densities. The estimation objective is to find mixing weights for each of these densities.

Table 3.5: Estimation Notation

θ	vector of model parameters
Θ	parameter space
K (index k)	dimension of parameter space (10)
S (index s)	number of simulated types (1,048,576)
I (index i)	number of moments
R (index r)	number of basis densities (1,024)
J (index j)	number of bundle choices (20)
β^r	mixture weight attached to basis r
$z_{i,j}$	ith model moment for bundle choice j
$y_{i,j}$	ith empirical moment for bundle choice j

Recall that a household's decisions are fully described by its type, a $K = 10$-dimensional vector of parameters $\theta = (\rho_1, \rho_2, \delta_1, \boldsymbol{\delta})$. The object of interest for estimation is the joint distribution of types $F(\theta)$.

I assume that $F(\theta)$ can be expressed as a mixture of $R = 1,024$ normal basis densities, which are chosen to cover the parameter space. Let $\phi(\theta \mid \mu^r, \sigma^r)$ denote the joint normal density corresponding to the rth basis. Each joint density is the product of K independent

marginal distributions, i.e.,

$$\phi(\theta \mid \mu^r, \sigma^r) = \prod_{k=1}^{K} \phi(\theta_k \mid \mu_k^r, \sigma_k^r).$$

The μ^r and σ^r parameters describing density r are fixed pre-estimation. Given a vector of probability weights $\boldsymbol{\beta}$, the resulting density function is

$$f(\theta) = \sum_{r=1}^{R} \beta^r \phi(\theta \mid \mu^r, \sigma^r).$$

The goal of estimation is to recover $\boldsymbol{\beta}$.

Estimation proceeds by "matching" a collection of I model moments, $m_{i,j}(\theta)$, for each of J bundle choices, with their empirical counterparts $y_{i,j}$. Each model moment is evaluated using each of the R basis densities to form "regressors" $z_{i,j}^r$:

$$z_{i,j}^r \equiv \int_{\Theta} m_{i,j}(\theta)\phi(\theta \mid \mu^r, \sigma^r)d\theta. \tag{3.4}$$

To simulate this integral, I use the importance sampling methodology of Ackerberg (2009), which is often employed when simulation is computationally intensive. Although solving my model for a single type is not computationally burdensome, the dimensionality of the parameter space requires a very large number of simulation draws. The benefit of importance sampling in this context is that each simulation draw can contribute to the evaluation of moment integrals with respect to multiple basis densities.

To this end, I pre-solve the model for a fixed grid of $S = 1,048,576$ (4^{10}) types, or all combinations of a uniform fixed grid of four values for each of the 10 parameters describing preference heterogeneity. When presented with a bundle j, each type θ^s has a unique time allocation solution specified by the model. These usage decisions, along with the optimal bundle choice, are saved.

To proceed, I rewrite Equation 3.4 as

$$z_{i,j}^r = \int_{\Theta} m_{i,j}(\theta)\frac{\phi(\theta \mid \mu^r, \sigma^r)}{h(\theta)}h(\theta)d\theta,$$

where $h(\theta)$ is the known (uniform) probability density from which the S simulation types were drawn in the first step. Finally, I approximate the integral as

$$z_{i,j}^r \approx \frac{1}{S}\sum_{s=1}^{S} m_{i,j}(\theta^s)\frac{\phi(\theta^s \mid \mu^r, \sigma^r)}{h(\theta^s)}.$$

I estimate the vector of weights β using inequality-constrained least squares. The estimator is

$$\hat{\boldsymbol{\beta}} = \arg\min_{\boldsymbol{\beta}} \frac{1}{NJ}\sum_{i=1}^{I}\sum_{j=1}^{J}\left(y_{i,j} - \sum_{r=1}^{R}\beta^r z_{i,j}^r\right)^2,$$

where the objective function is minimized subject to the constraint that $\boldsymbol{\beta}$ lies within the R-dimensional unit simplex.

The moments are chosen to capture the rich heterogeneity of empirical usage while maintaining computational ease. To this end, the selected moments are all linear in the type weights. Three types of moments are used in the estimation. First, to capture the marginal distribution of usage of each content type, I include percentiles from the population distribution of viewership of each type. Second, I include percentiles from the joint distribution of pairs of content types to capture correlation in tastes. Finally, bundle market shares are included to adjust the weights attached to the set of types that choose each bundle to match those in the data. Standard errors are obtained by resampling the dataset and repeating the estimation procedure (Lahiri, 2003). I sample the data with replacement 500 times, re-calculate the empirical moments for each sample, and then re-estimate the weights. I calculate standard errors for subsequent results and counterfactuals by repeating each calculation using each weight estimate.

3.4.1 Identification

The identification discussion is split into two parts. First, I discuss the identification of type weights. Second, I discuss the data variation that isolates the contribution of each model parameter to predicted behavior.

Type weights are recovered by finding the mixture of candidate types whose decisions best match the bundle shares and usage choices observed in the data. It is useful to think about the estimation as a process by which we update a prior about how the types are distributed across the population using layers of information from the data.

Empirical bundle market shares provide the first piece of information about the type distribution. Each type corresponds to an optimal bundle choice; types that choose bundles with larger market share receive more weight.

Next, usage moments provide additional information that allows the market share weights to be distributed across the set of types that choose each bundle. The "larger" a bundle, i.e., the larger the set of content it contains, the more information is provided by its usage moments. Smaller bundles provide less information on usage and will thus have more observationally equivalent types. For example, consider a household that purchases a bundle comprised of internet access and Netflix. Two bundle types containing the same substitution (ρ_1, ρ_2) and internet utility parameters, but with different TV utility parameters, are equivalent with respect to the observable usage moments (provided the TV utility parameters are both in the region that justify the observed choice).

Variation in usage comes from variation in quantiles of usage across choices. Each parameter affects behavior in a different way. The δ parameters, those governing the distribution of marginal utility, are determined by the relative amount of time a household spends on each content type. Those content types c that are viewed for longer durations will have higher values of δ_c. The substitution parameters are driven by the relative market shares of larger bundles and differences in time allocation between similar households with access to different content. When all other parameters of the model are held fixed, as the willingness to substitute between activities increases, the predicted share of smaller bundles increases. For example, if the only bundle options are TV, Internet, and "both services," when ρ_2 decreases, households are more willing to substitute Internet use for TV use, and the market share of "both services" will fall relative to the shares of TV and Internet alone.

Table 3.6: Parameter Estimates

Parameter	Mean	$(100 \times \text{SE}_{\text{Mean}})$	SD	$(1000 \times \text{SE}_{\text{SD}})$
ρ_1	-0.36	(0.15)	0.08	(0.25)
ρ_2	-0.52	(0.23)	0.12	(0.46)
δ_1	0.33	(0.16)	0.21	(0.36)
$\delta_{\text{Basic TV}}$	0.39	(0.27)	0.24	(0.76)
$\delta_{\text{Expanded TV 1}}$	0.37	(0.19)	0.24	(0.63)
$\delta_{\text{Expanded TV 2}}$	0.34	(0.19)	0.23	(0.59)
δ_{Netflix}	0.41	(0.16)	0.25	(0.26)
$\delta_{\text{Streaming TV}}$	0.39	(0.26)	0.24	(0.45)
$\delta_{\text{Other Streaming}}$	0.49	(0.28)	0.25	(0.29)
$\delta_{\text{Other Web}}$	0.32	(0.22)	0.22	(0.98)

Notes: This table describes the estimated marginal distribution of each model parameter. The mean and standard deviation of each parameter's distribution is reported, along with standard errors.

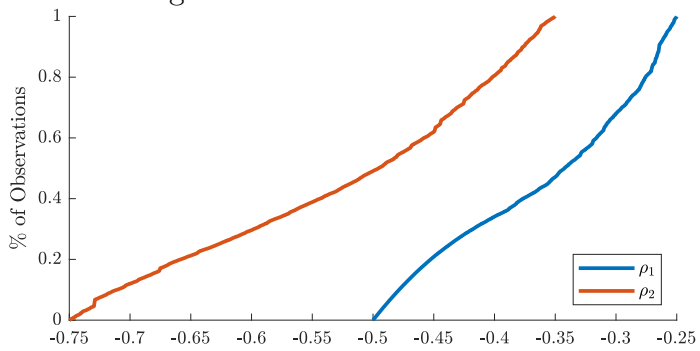
3.5 Results

Out of a total of 1,024 basis functions, I estimate mixture weights greater than 0.01% for 80. 90% of weight is given to the 33 highest-weighted basis densities and 99% of weight is given to the top 66. The type with the most weight chooses the bundle "Internet, Expanded TV 1".

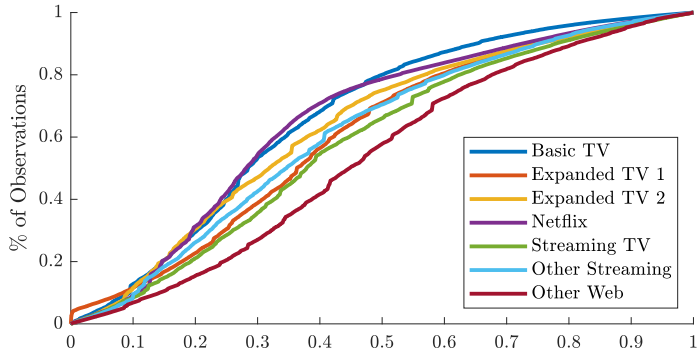
The set of weights attached to these basis functions translates to a 10-dimensional joint distribution of the model's parameters across the sample population. Table 3.6 reports the mean and standard deviation summarizing the marginal distribution of each parameter. These marginal distributions are plotted in Figure 3.3. From these plots, we see that the distribution of substitution parameters ρ_1 and ρ_2 implies less elastic substitution between the content nest and the outside option. In addition, the content types c that are consumed at higher frequency in the data tend to have larger estimated marginal utility parameters δ_c. Figure 3.4 shows selected joint distributions of estimated parameters. These irregular distributions show the value of the flexible estimation strategy; allowing empirical patterns to determine the joint distribution of parameters yields patterns that could not be captured by typical parametric approaches.

To show how the model fits the empirical distributions, figure B.1 shows the empirical

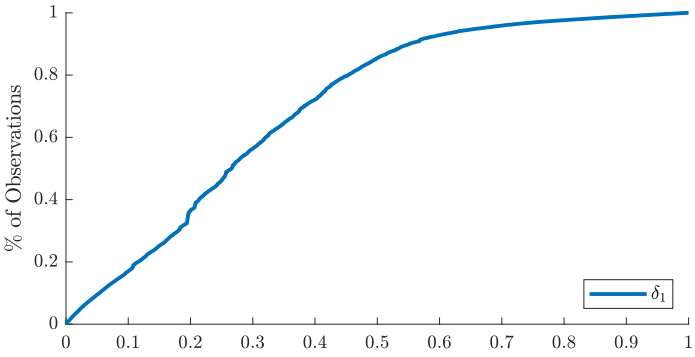
Figure 3.3: Marginal Distributions of Estimated Parameters



(a) Substitution Parameters



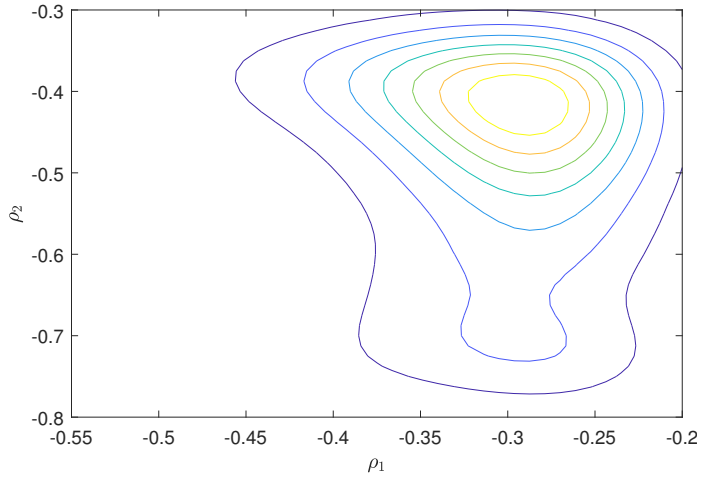
(b) Marginal Utility of Consumption Types (δ_c)



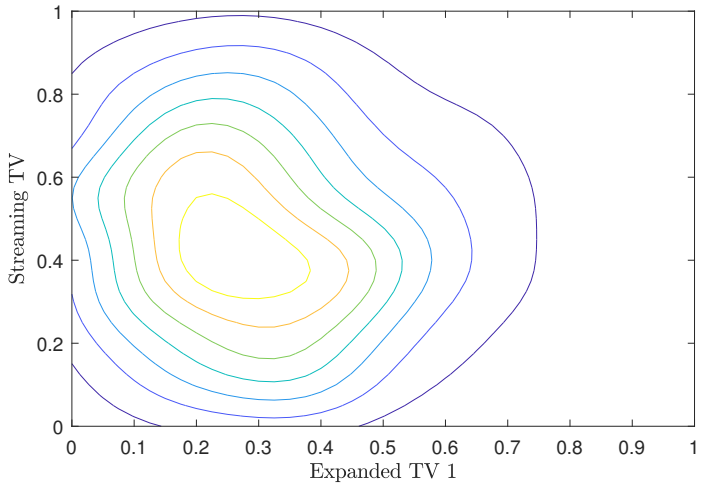
(c) Nest Utility

Notes: This figure shows the marginal CDFs of estimated parameters.

Figure 3.4: Selected Joint Distributions of Estimated Parameters



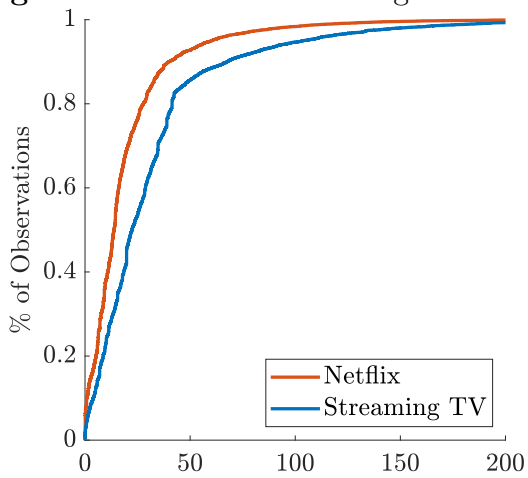
(a) Substitution Parameters (ρ_1, ρ_2)



(b) Expanded TV 1 & Streaming TV Marginal Utilities (δ_c)

Notes: This figure shows selected joint CDFs of pairs of estimated parameters.

Figure 3.5: Estimated Willingness-to-Pay



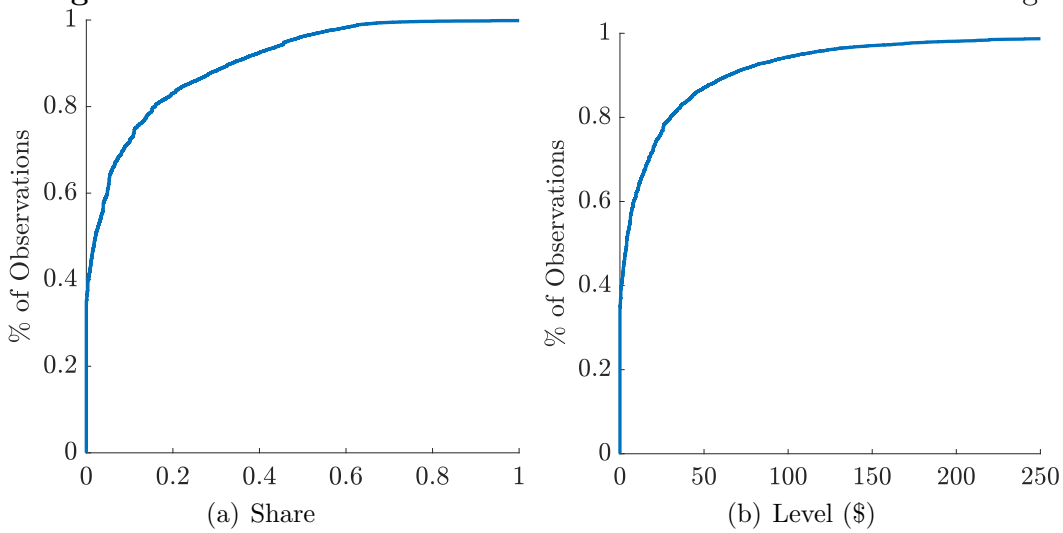
Notes: This figure shows the distribution of estimated willingness-to-pay for access to Netflix and Streaming TV content among internet subscribers.

and predicted distributions of viewing for each content type. Most distributions are matched quite well. In some cases, the model slightly over-estimates the use of consumption types that require a higher subscription fee in order to rationalize the purchase decision.

Another way to interpret the parameter results is to translate them into willingness-to-pay. Figure 3.5 shows the distribution of willingness-to-pay for online video applications among internet subscribers. I find that mean willingness-to-pay for Netflix is $19, the standard deviation is $22, and the median $13. For Streaming TV, mean willingness-to-pay is $32, the standard deviation is $36, and the median is $23.

Removing access to online video will be a large part of the counterfactual exercises discussed in the next section, so it is useful to first determine the contribution of access to online video to the willingness to pay for internet. Figure 3.6 quantifies this distribution. First, the willingness-to-pay is calculated for each type's preferred bundle. Next, third-party streaming applications are removed from the bundle and the willingness-to-pay is re-calculated. The two panels show both the share of willingness-to-pay that is retained when streaming is removed, and the decrease in the level of willingness-to-pay when streaming is removed. I find that, for the average household, willingness-to-pay decreases by 20%, or

Figure 3.6: Reduction in WTP for Preferred Bundle without Streaming



Notes: This figure shows the contribution of streaming access to willingness-to-pay (WTP) for ISP subscriptions. To construct the figure, first the WTP is calculated for each type's preferred bundle. Next, third-party streaming applications are removed from the preferred bundle and the WTP is re-calculated. The two panels show (a) the share of WTP that is retained when streaming is removed, and (b) the level decrease in WTP when streaming is removed.

$38, when streaming is removed from their preferred bundle.

I evaluate the substitution patterns implied by the model results by computing elasticities. Elasticities are computed by calculating the effect of raising the price of a product by 1% on subscription choices, with all other prices and model parameters held fixed. Table 3.7 shows these elasticities at the product level. Comparing own-price elasticities, we see that the most price-elastic good is Network Tier 1, with an own-price elasticity of -6.45. Network Tier 2 and Basic TV are also elastic relative to the other goods, with own-price elasticities of -4.70 and -3.13, respectively. Benchmarking against previous estimates, these elasticities are largely in line with other studies.[5]. In contrast, Internet, and both streaming services each have relatively lower own-price elasticities. The average internet elasticity is

[5]Crawford and Yurukoglu (2012) find average own-price elasticities of -4.1 and -6.3 for basic and expanded cable. Goolsbee and Petrin (2004) find elasticities ranging from -1.5 to -3.2. Studies using older data tend to find less elastic estimates. This pattern is consistent with FCC reports of increased competition from online video distributors and rising TV input costs (FCC 2017)

Table 3.7: Product Elasticities

	With respect to the price of:					
Price elasticity of:	Basic	ETV1	ETV2	Int.	Netflix	Str. TV
Basic TV	-3.13	7.53	1.46	5.28	0.45	0.00
Expanded TV 1	0.12	-6.45	0.73	0.11	0.00	-0.04
Expanded TV 2	0.16	7.10	-4.70	0.11	0.02	0.00
Internet	0.00	-0.02	-0.02	-0.99	-0.06	-0.01
Netflix	-0.01	-0.48	0.01	-0.48	-1.09	-0.05
Streaming TV	0.03	0.08	2.36	-0.09	-0.01	-0.79

Notes: This table shows own- and cross-price elasticities for the four products offered by the ISP and the two online video subscriptions. The estimate in row i and column j refers to the response in purchases of bundle i following a 1% increase in the price of product j.

slightly inelastic at -0.99.[6]

The average TV profit margins implied by these elasticities and the observed prices are 6% for Basic TV, 7% for Expanded TV 1, and 20% for Expanded TV 2, with an average TV margin of 11%. The internet margin is 88%. These lopsided margins are consistent with industry estimates. FCC (2017) cites video margins of "just over 10 percent" at the end of 2015, with continued year-over-year decreases in the profit margin on TV. The estimated internet margin is high, but not surprising as the majority of the costs faced by ISPs in providing data are large fixed investment costs. In contrast, the ISP pays a per-subscriber programming cost for every network it includes in its TV tiers.

Turning to cross-price elasticities to understand which products are the best substitutes, we see that the closest product substitutes for TV services are other tiers of TV service. There is also a larger cross-price elasticity of demand for Streaming TV with respect to the price of higher-tier TV subscriptions. The presence of bundle discounts and the fact that internet access is needed for online video lead to some non-standard results for cross-

[6]One useful benchmark is the elasticities reported in the FCC's modification of the merger analysis submitted by Berry and Haile in support of the AT&T-DirecTV merger case in 2015. This simulation is the only other study that structurally models TV and internet access in the same demand system, although the results were not peer-reviewed. The elasticities reported are -8.07 for cable TV and -0.66 for internet access. Although the difference is more extreme in the Berry and Haile results, my findings agree that demand for TV is much more elastic than internet access.

price elasticities involving online applications, as some elasticities imply that goods are actually slight complements. There are two challenges in interpreting these elasticities at the product level. First, the option value of access to third-party applications contributes to the value of internet access as a whole. When the value of these applications falls, as when their prices are increased for the elasticity calculations, so too does the value of internet access. Second, the ISP's strategy of discounting bundles of TV and internet access makes the two goods complements for some consumer types, meaning that a change in the price of one good may lead a bundled subscriber to drop all services.

An alternative way to understand substitution patterns is to compute elasticities with quantity responses calculated at the bundle level (Table 3.8). At the bundle level, negative elasticities are seen only for bundles containing the product for which the price increases. Elasticities with respect to the price of the ISP's TV products suggest that streaming applications are substitutes to higher TV tiers on their own, as well as when they are purchased in conjunction with basic TV. Netflix is best substituted by bundles containing Streaming TV, while the elasticities suggest that Streaming TV does not have a close substitute bundle.

Table 3.8: Bundle Elasticities

	With respect to the price of:					
Price elasticity of:	Basic	ETV1	ETV2	Int.	Netflix	Str. TV
Internet	0.33	3.15	0.79	-4.00	1.34	0.20
Internet, Netflix	0.19	0.42	0.88	-1.26	-1.19	0.27
Internet, Streaming TV	0.99	3.99	64.71	-0.44	12.96	-1.24
Internet, Netflix, Str. TV	0.33	0.91	0.11	-0.09	-0.90	-0.75
Internet, Basic TV	-4.92	17.37	0.72	-1.71	1.56	0.02
Internet, Basic TV, Netflix	-2.03	4.88	2.15	-0.54	-0.80	0.14
Internet, Basic TV, Str. TV	-3.47	6.72	1.40	-0.12	5.33	-0.82
Internet, Basic TV, Netflix, Str. TV	-3.27	0.64	0.16	-0.18	-0.41	-0.27
Internet, Expanded TV 1	0.27	-6.22	0.47	-0.12	1.86	0.04
Internet, Expanded TV 1, Netflix	0.01	-6.37	0.94	-0.24	-1.37	0.10
Internet, Expanded TV 1, Str. TV	0.27	-7.87	0.45	-0.21	10.18	-0.30
Internet, Exp. TV 1, Netflix, Str. TV	0.18	-7.73	0.58	-0.03	-0.93	-1.15
Internet, Expanded TV 2	0.06	6.28	-6.67	-2.29	1.10	0.00
Internet, Expanded TV 2, Netflix	0.13	6.96	-3.59	-0.20	-0.86	0.08
Internet, Expanded TV 2, Str. TV	0.54	9.76	-3.26	-0.11	8.01	-0.38
Internet, Exp. TV 2, Netflix, Str. TV	0.88	11.76	-1.96	-0.04	-0.53	-0.55

Notes: This table shows price elasticities at the bundle level. The estimate in row i and column j refers to the response in purchases of bundle i following a 1% increase in the price of product j.

3.6 Counterfactuals

In this section, I use the model's estimates to study the effect of counterfactual internet pricing strategies on consumer choices and the distribution of industry surplus.

First, I consider the profitability of two alternative product assortments, one in which all subscription streaming services are removed from the ISP's network ("no streaming"), and one in which only Streaming TV, the closest substitute to traditional TV, is blocked ("no Streaming TV"). Both of these actions were previously prohibited under the FCC's "no blocking" rules. In simulating these alternate assortments, the marginal utility attained from viewing each out-of-assortment product is set to zero. The ISP is allowed to adjust the prices it sets for each of its services and then consumers modify their subscription and usage decisions. Table 3.9 summarizes the results for both scenarios.

These policy changes have three effects on prices. First, the price of internet access falls by 21%, responding in kind to a lower willingness-to-pay for internet without streaming. Second, the removal of online video alleviates downward pressure on the price of TV, which rises by 32% in the "no streaming" case. Third, the average bundle price increases by 9%. Intuitively, removing online video reduces the degree of overlap between internet and TV valuations. This increases the value of having both products together relative to either component alone, meaning the ISP can offer a smaller discount on the purchase of the bundle.

Next, I describe the effect of the price change on consumer choices. Table B.2 depicts the frequencies of bundle transitions between the baseline pricing strategy and the "no streaming" strategy. The two bundle groups that include streaming subscriptions become infeasible under the streaming ban. Before discussing surplus changes, I ask whether subscribers who chose streaming services in the baseline case moved to the ISP's TV service under the streaming ban. While 90% of former TV and streaming subscribers retained both internet and TV, only 2% of former streaming subscribers without TV added a new TV subscription, 84% added no new service, and 13% moved to the outside option.

I find that the streaming ban strategy is not profitable for ISPs, with profits falling $3.15

Table 3.9: Summary of Pricing Counterfactuals

	No Streaming	No Streaming TV	Add-on Streaming
Surplus ($/HH-month)			
Δ ISP Profit	-3.27	-0.07	+24.11
Δ Consumer Surplus	-3.51	-2.76	+14.52
Δ Streaming Revenue	-4.27	-1.47	-2.34
ISP Price Changes			
Internet	−21%	−17%	+50%
TV	+32%	+13%	−40%
Internet + TV	+9%	+5%	−27%

Notes: This table summarizes the change in surplus and prices under three counterfactual ISP pricing strategies. No Streaming blocks all access to both Netflix and Streaming TV. No Streaming TV blocks access to Streaming TV. Add-on Streaming lets the ISP choose an add-on price for access to Netflix and Streaming TV.

per household-month; nor is it good for consumers, with consumer surplus falling $3.51 per household-month. Table B.3 decomposes the surplus change by bundle transition group. Most of the surplus decline comes from former streamers; the most-impacted group consists of former streamers who do not adopt TV after streaming is banned, whose surplus decline makes up 46% of the total loss. These results indicate that the surplus that is destroyed by banning streaming is not redistributed via new TV subscriptions.

In a final counterfactual, ISPs are allowed to set "add-on" prices for Netflix and Streaming TV. In this counterfactual, the ISP sets three prices for internet access: one price for internet without access to streaming, a second price for access to Netflix, and a third price for access to Streaming TV. This policy allows ISPs to increase the relative attractiveness of a TV subscription without fully banning access to streaming. Though an add-on internet pricing model has not yet been implemented in practice, its implications are analogous to zero-rating practices employed by mobile and residential broadband providers that employ usage-based pricing. Just as zero-rating creates differences in the marginal price of consumption of certain content by not counting consumption against usage allowances, the add-on pricing strategy creates differences in the relative prices of subscriptions by charging additional fees.

Under add-on pricing, the ISP sets prices so that the joint purchase of internet access

and TV is preferred by nearly every household to the purchase of internet access alone. The price for internet access increases 50%, the average TV subscription price falls by 40%, and the average price of TV and internet bundles falls by 27%. The ISP selects add-on prices of $6 per month for Netflix and $40 per month for Streaming TV. Table B.4 shows subscriber transition frequencies under add-on pricing and Table B.5 breaks down the surplus change by transition group.

In contrast to the streaming ban case, where the majority of subscribers who choose streaming without TV in the baseline did not take-up TV after the ban, nearly all (97%) former streamers take up TV under add-on pricing. In addition, 88% pay the add-on price to retain their subscriptions, while 9% transition from streaming to TV alone. Fewer than 7% of baseline internet-only and internet and streaming subscribers transition to the outside option. The add-on pricing strategy increases ISP profits by $24 per subscriber-month, driven by new TV subscriptions and increased revenue from add-on fees. Consumer surplus increases by $15 per subscriber-month. 58% of the increase in consumer surplus is captured by subscribers who originally purchased internet and TV, and an additional 19% of surplus is enjoyed by former streamers who add a new TV subscription.

3.7 Conclusion

This chapter studies the joint pricing decisions of platform firms and their incentives to foreclose competitors. I develop a framework for studying these trade-offs in the telecommunications industry that accounts for household time-allocation and subscription decisions as well as ISP pricing and online content assortment decisions.

My main results are as follows: (i) access to online video contributes substantially to the willingness-to-pay for internet access; (ii) foreclosure of online video applications is not profitable for ISPs, as increased TV revenue is offset by damage to internet valuations; (iii) more flexible strategies for pricing access to online content can be welfare-enhancing.

These results imply that discriminatory policies associated with the repeal of net neu-

trality protections may not be in firms' best interests, and as such may not decrease welfare. Looking to other industries in which firms provide access to third-party competitors, foreclosure concerns may be alleviated if firms earn greater profits as access providers than as sellers. In the telecommunications industry, these results may change as firms continue to consolidate and integrate into content production, and improving mobile quality leads to more competition for broadband provision. Each of these issues are fruitful areas for future research.

Chapter 4

Conclusions

This dissertation studies the impact of online video on the telecommunications industry, and how internet service providers (ISPs) navigate the trade-offs associated with its rise in popularity. Online video represents an opportunity for ISPs in that streaming video increases the demand for internet subscription services, but the new applications also present several important challenges. Online video improvements reduce demand for ISPs' television services, and delivering internet content can substantially increase ISPs' costs. Firms have in some cases responded with nonlinear pricing strategies to steer consumers across subscription options and possibly curtail internet and online video usage.

In Chapter 2, I provide a model that describes some of the central incentives behind ISPs' prices, showing that indeed ISPs might have an incentive to steer consumers away from online video, but that those incentives decline when the ISP has richer pricing tools that allow it to share in the gains it generates. The introduction of usage-based pricing (UBP) in a subset of markets helps understand consumer behavior and its implications for steering incentives. Consistent with the theoretical findings, the empirical results suggest that the ISP has an incentive to help improve internet access.

In Chapter 3, I develop a framework for studying the joint pricing decisions of platform firms. The discrete-continuous choice model accommodates household decisions over subscriptions and a time-allocation problem. The ISP pricing model allows for both pricing and product assortment decisions. I find that: (i) access to online video contributes substantially to the willingness-to-pay for internet access; (ii) foreclosure of online video applications is not profitable for ISPs, as increased TV revenue is offset by damage to internet valuations; (iii) more flexible strategies for pricing access to online content can be welfare-enhancing.

Understanding the incentives underlying ISP treatment of third-party content is a key input for antitrust policy. In particular, evaluation of mergers between content and distribution firms presents a number of challenges. First, market boundaries may be difficult for regulators and antitrust authorities to identify because little evidence exists on consumers' willingness to substitute across conventional TV, streaming video, and other non-video internet applications. These results show that consumers are willing to substitute between conventional TV and online video. Specifically, we find that cord cutters increase their usage of most online applications after dropping an ISP's TV service, and these increases are roughly proportional to usage levels prior to the subscription change. Thus, telecommunications antitrust analysis might need to consider broad market definitions that encompass many forms of digital entertainment (e.g., Facebook and NBC compete for a consumer's time), as well as the central role of ISPs in shaping how content is distributed and surplus is allocated.

In addition, antitrust authorities need to assess how existing or new vertical relationships may affect an ISP's incentives to introduce restrictive cross-licensing agreements or use price instruments to favor its own content over competitors'. The impact of these strategies depends on consumers' sensitivity to steering strategies, which we show can be significant. An ISP that is vertically integrated with a content-producing firm may foreclose some content from availability to consumers via a competing ISP.

More broadly, these results are also relevant for the Net Neutrality debate. Net Neutrality's repeal provides ISPs more latitude to discriminate across types of internet traffic. While we do not observe source-specific discrimination in the data, the results are informative about ISPs' incentives to discriminate when they have the opportunity. For example, I find that usage-based pricing's primary impact is in inducing consumers to upgrade their internet tiers and continuing using their preferred online applications (e.g., Netflix), although there are some exceptions like linear OTTV, where bundle subscriptions shift significantly. If an ISP can successfully use tier premiums to extract some of the rents associated with OTTV innovations, it may not seek more targeted mechanisms to foreclose or diminish

the attractiveness of OTTV. These incentives may change, however, as firms diversify and vertically integrate into media production, so more research is needed in this area.

There are several issues that our model and empirical results do not address, and that we leave for future research. While our model provides a useful framework for formalizing the steering incentives of ISPs, a richer specification is required to quantify the distributive welfare implications of discriminatory internet pricing. Similarly, the model makes simplifying assumptions on the interaction between firms, for example competitive OTTV supply. These results may change as firms continue to consolidate and integrate into content production, and improving mobile quality leads to more competition for broadband provision. Given the increasingly complex relationships between content providers and ISPs, and the evolving regulatory and antitrust environment, modeling and evaluating these policy issues is a fruitful area for future research.

Appendix A

Appendix to Chapter 2

A.1 Additional Descriptive Statistics on Usage Patterns

A.1.1 Internet Usage by Traffic Type

Table A.1: Description of Internet Traffic Composition Groups

Group	Description (Examples)	Share of All Traffic
Admin	System administrative tasks (STUN, ICMP)	1.19
Backup	Online storage (Dropbox, SkyDrive)	0.58
Browsing	General web browsing (HTTP, Facebook)	26.70
CDN	Content delivery networks (Akamai, Level3)	2.95
Gaming	Online gaming (Xbox Live, Clash of Clans)	3.06
Music	Streaming music services (Spotify, Pandora)	3.40
Sharing	File sharing protocols (BitTorrent, FTP)	0.20
Streaming	Generic media streams (RTMP, Plex)	6.26
Tunnel	Security and remote access (SSH, ESP)	0.07
Video	Video streaming services (Netflix, YouTube)	55.47
Other	Anything not included in above groups	0.13

Notes: This table describes and gives examples of each type of traffic observed in the DPI data. The share of each traffic group across all traffic is also reported.

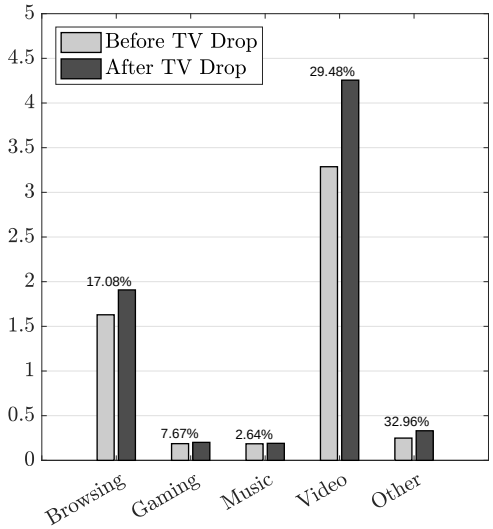
Table A.2: Distribution of Daily Usage by Traffic Type

	count	mean	std	min	25%	50%	75%	95%	max
Tunnel	119,878,359	0.00	0.20	0.00	0.00	0.00	0.00	0.00	360.01
Music	119,878,359	0.12	0.66	0.00	0.00	0.00	0.07	0.54	836.33
Gaming	119,878,359	0.12	1.13	0.00	0.00	0.00	0.00	0.29	789.63
Admin	119,878,359	0.05	0.41	0.00	0.00	0.00	0.01	0.18	246.95
Backup	119,878,359	0.03	0.58	0.00	0.00	0.00	0.00	0.05	694.27
CDN	119,878,359	0.11	0.77	0.00	0.00	0.00	0.01	0.38	542.75
Other	119,878,359	0.03	0.45	0.00	0.00	0.00	0.00	0.07	593.60
Sharing	119,878,359	0.01	0.32	0.00	0.00	0.00	0.00	0.00	408.40
Browsing	119,878,359	1.19	3.49	0.00	0.12	0.43	1.16	4.39	1,191.10
Streaming	119,878,359	0.32	1.40	0.00	0.00	0.01	0.14	1.46	841.76
Video	119,878,359	1.93	4.29	0.00	0.00	0.10	1.86	9.91	582.08

Notes: This table reports the distribution of usage of each internet traffic type. Observations are subscriber-days.

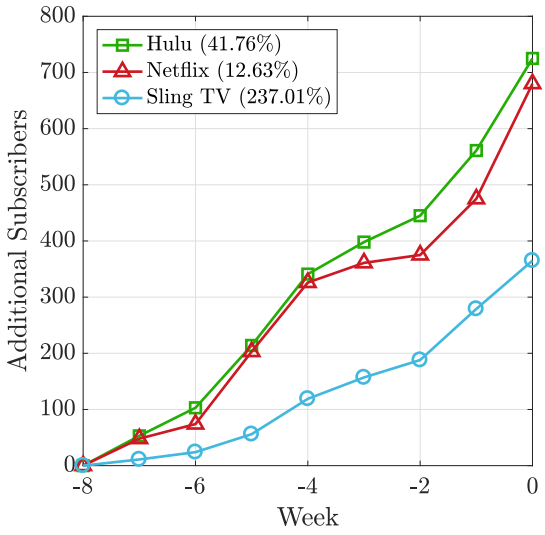
A.1.2 Cord-cutter Characteristics

Figure A.1: Changes in the Composition of Internet Usage among Cord Cutters



Notes: This figure summarizes the change in the composition of total internet usage among cord cutters in the eight weeks before and after dropping TV services. For each usage type, the percent change in usage level between the two periods is shown above the two bars.

Figure A.2: Cord-cutter Experimentation with Online Video



Notes: This figure documents increases in the number of active users of selected OTTV applications in the weeks before the observed cord-cutters drop TV.

A.2 Additional Discussion of Theoretical Model

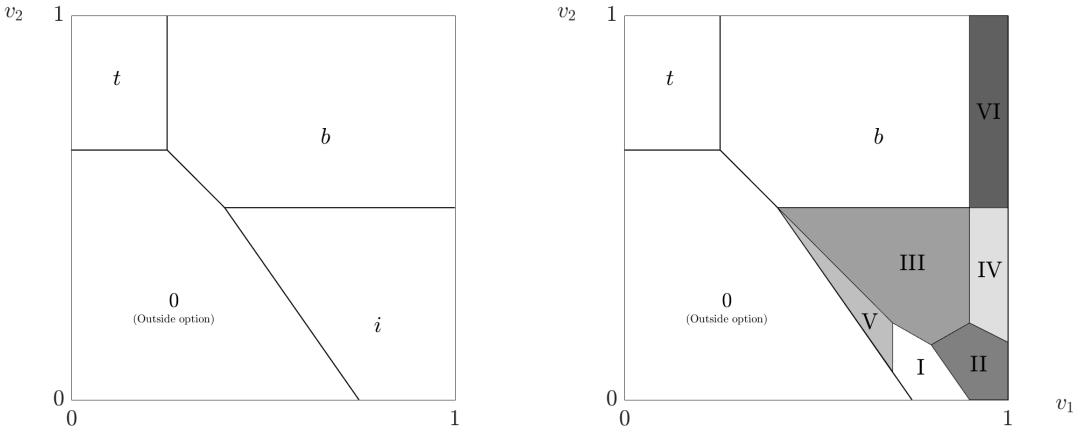
We provide a more detailed description of how consumers' choices would be affected when the ISP introduces usage tiers. In practice, the tiers may vary in terms of usage allowances, overage prices, or connectivity speeds. We focus on a case in which the ISP, facing $\delta > 0$, shifts from having no tiers and no usage allowances to having both. This is similar to the situation in our data, and it also resembles the implementation of the tiering and UBP strategy implemented by numerous North American ISPs.

In Figure A.3 we demonstrate the effect of the ISP introducing a "low-usage" tier which is subject to the usage allowance κ while a "high-usage" tier has no usage limit. The same tiers are available to both internet-only and bundle subscribers (i_L and b_L for low-usage tiers, and i_H and b_H for high usage). We impose a set of prices that facilitate reading the different regions of Figure A.3; the optimal prices and cap value would change the sizes and perhaps shapes of some regions.

Panel (a) of Figure A.3 provides an initial distribution of consumers across subscription

options, before any tiers or caps are offered. As in Figure 2.3 Panel (a), with $\delta > 0$ a significant share of consumers select the i subscription and satisfy their video entertainment tastes with OTTV. The introduction of usage tiers splits i and b subscribers into a new collection of actions, illustrated in Figure A.3 Panel (b).

Figure A.3: Market Shares under Tiering Strategy



(a) Baseline (b) Tiering

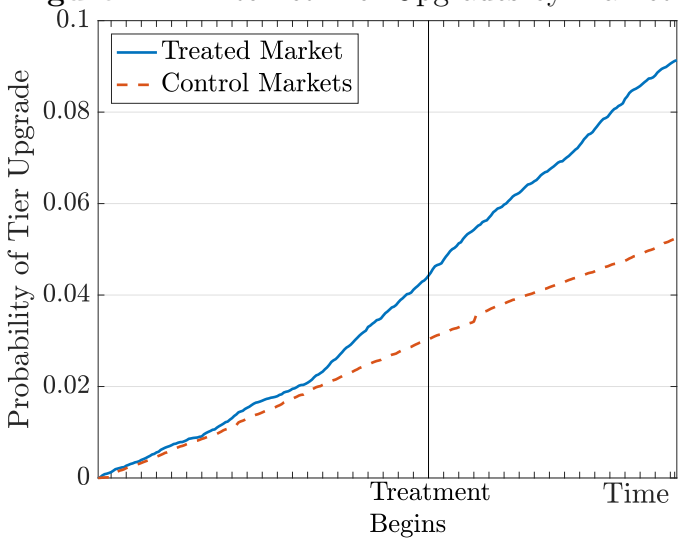
Notes: This figure shows the effect of the introduction of a tier with a usage allowance on subscription choices. Throughout, δ is fixed at 0.7. Market shares are first plotted for prices $(p_i, p_t, p_b) = (0.75, 0.65, 0.9)$. Next, a usage allowance is placed on the original internet tier, and a new premium internet tier is introduced with no allowance. The new prices are $(p_{i,L}, p_{i,H}, p_t, p_{b,L}, p_{b,H}) = (0.75, 0.85, 0.65, 0.9, 1.0)$. Each shaded region depicts a set of consumer types that makes a particular subscription change. The usage allowance $\kappa = 0.8$.

Former subscribers to the initial unlimited internet service (i) may update their subscription and usage choices in several ways. Some consumers, in Figure A.3 Panel (b)'s area I, will accept the usage cap κ and remain internet-only. Consumers with a stronger taste for internet usage, whether for video- or non-video entertainment, may "upgrade" their internet subscription to i_H; these consumers are in Panel (b)'s area II. From the ISP's perspective, the tier upgrade is a way to have area II's consumers pay a greater price for internet service that is equal to what the consumers received previously. Consumers with relatively strong values of v_2 switch from i into the bundle (areas III and IV). Of these consumers, those with high values of v_1 pay for a tier upgrade in addition to TV service

(area IV). When consumers switch to the bundle, they receive video entertainment through TV, so their OTTV usage falls to zero. Finally among initial i subscribers, some will cancel their subscriptions completely (area V) because their relatively strong taste for video entertainment and weak taste for non-video internet means that capped internet, at the present price, is worth less than the outside option. In addition to these margins for former i subscribers, some bundle subscribers with strong internet tastes (in area VI) will opt for b_H so that they can consume internet without a usage limit.

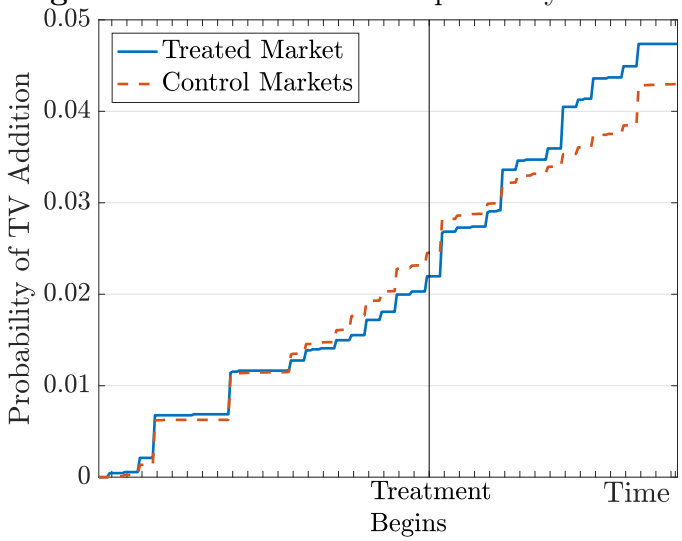
A.3 Control and Treated Market Differences

Figure A.4: Internet Tier Upgrades by Market



Notes: This figure shows the cumulative total of internet tier upgrades during the sample period.

Figure A.5: New TV Subscriptions by Market



Notes: This figure shows the cumulative total of new video subscriptions during the sample period.

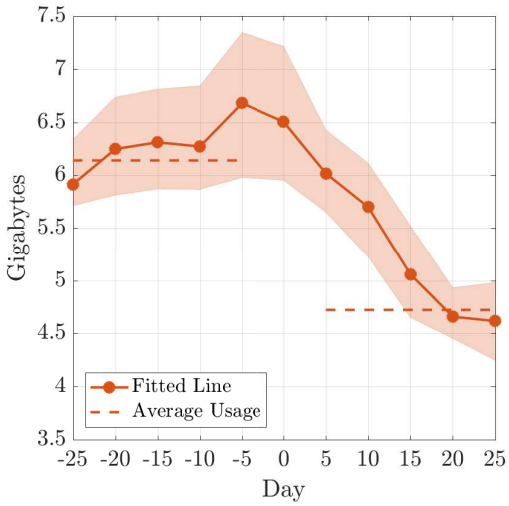
A.4 Internet Usage Changes

The ISP's UBP policy has two types of benefit for the firm. First, it may induce switches in households' subscriptions which increase revenue; this is the impact we studied above. Second, it may lead consumers to reduce their internet usage, which can reduce pressure on the ISP to make costly investments in network capacity. We now consider whether the ISP can induce reductions in internet usage following the introduction of UBP.

We begin by examining the case of initially internet-only households that added a conventional TV subscription in the treated market. In Figure A.6 we track the internet usage changes for households who added video to their subscriptions. Internet usage falls significantly after this subscription change. This reduction is consistent with the usage change described in Section 2's illustrative model. The reduction's magnitude (25%) is about equal in magnitude but opposite in sign to the change in internet usage that occurs after a household cuts the cord. Households induced by UBP to add video, therefore, appear to be steered away from heavy internet usage.

In addition to the revenue and cost implications for the ISP, third-party services that

Figure A.6: Usage before and after Addition of TV Service



Notes: This figure presents statistics summarizing average daily usage (GBs) of customers on the days before and after adding TV services. The dots are average daily usage, the hashed line is average usage across days before and after, and the solid line is a global local-linear regression fit of the data.

may also be impacted by steering. To examine this, in Table A.3 we decompose by application the decrease in usage in Figure A.6. Average usage of some types of applications like Music, Gaming, and Sharing increase slightly during our sample, while Streaming and Browsing remain at similar levels. The large and substantial usage decrease that we observe in Figure A.6 is almost entirely due to a reduction in OTTV usage. The largest absolute reduction in usage is Netflix, while the largest percentage reduction is SlingTV. This mirrors the application-level usage changes by cord-cutting households that we describe in Section 3. The closest substitutes for pay-TV, linear-OTTV services, are most heavily impacted by steering, while other on-demand services are impacted to a lesser degree.

Table A.3: Change in Usage after TV Added during UBP Implementation

Traffic Type	Average Usage (GBs)	
	Pre-Add	*Post-Add*
Browsing	1.67	1.43
Gaming	0.20	0.15
Music	0.18	0.16
OTTV	2.911	2.018
HBO Go	0.03	0.02
Hulu	0.17	0.07
Netflix	2.52	1.40
Sling TV	0.05	0.02
YouTube	1.00	0.74
Other Video	0.56	0.49
Other	0.26	0.21

Notes: This table reports average usage by traffic type for subscribers that add TV after UBP is implemented. Each average is taken across subscriber days for one month before and one month after adding pay TV.

Appendix B

Appendix to Chapter 3

B.1 Solutions to Time-allocation Problem

B.1.1 Utility Function without Nest

Setting $\rho_2 = \rho_1$ in the full utility function yields the following simplified non-nested maximization problem, the solution to which has a simple closed form.

$$\max_{\mathbf{h}} \tilde{u}(\mathbf{h};\boldsymbol{\theta}) = \left[\left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_1}\right) + \delta_0 h_0^{-\rho_1}\right]^{-1/\rho_1}$$
$$\text{s.t.} \sum_{c\in s(b)} h_c + h_0 = T$$

The first-order conditions reduce to (for Lagrange multiplier Λ_1):

$$\partial u/\partial h_c : -\rho_1 \delta_c h_c^{-\rho_1 - 1} = \Lambda_1 \tag{B.1}$$

$$\partial u/\partial h_0 : -\rho_1 \delta_0 h_0^{-\rho_1 - 1} = \Lambda_1 \tag{B.2}$$

$$\partial u/\partial \Lambda_2 : \sum_{c\in s(b)} h_c + h_0 = T \tag{B.3}$$

Equating (1) and (2), then substituting into (3) gives, for any $j \in s(b) \cup 0$,

$$h_j^* = \frac{\delta_j^\sigma}{\sum_c \delta_c^\sigma + \delta_0^\sigma} \cdot T$$

where $\sigma \equiv 1/(1+\rho_1)$.

B.1.2 Nested Utility

The maximization problem with the full utility function is:

$$\max_{\mathbf{h}} \tilde{u}(\mathbf{h};\boldsymbol{\theta}) = \left[\left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\rho_1/\rho_2} + \delta_0 h_0^{-\rho_1}\right]^{-1/\rho_1}$$
$$\text{s.t.} \sum_{c\in s(b)} h_c + h_0 = T$$

The first-order conditions are (for Lagrange multiplier Λ_2):

$$\partial u/\partial h_c : \left[\left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\rho_1/\rho_2} + \delta_0 h_0^{-\rho_1}\right]^{\frac{-1-\rho_1}{\rho_1}} \left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\frac{\rho_1-\rho_2}{\rho_2}} \delta_1 h_1^{-\rho_2-1} = \Lambda_2 \tag{B.4}$$

$$\partial u/\partial h_0 : \left[\left(\sum_{c\in s(b)} \delta_c h_c^{-\rho_2}\right)^{\rho_1/\rho_2} + \delta_0 h_0^{-\rho_1}\right]^{\frac{-1-\rho_1}{\rho_1}} \delta_0 h_0^{-\rho_1-1} = \Lambda_2 \tag{B.5}$$

$$\partial u/\partial \Lambda_1 : \sum_{c\in s(b)} h_c + h_0 = T \tag{B.6}$$

B.2 Subscription Bundles and Consumption Types

The choice model permits households to choose a subscription from combinations of internet access, three TV tiers (Basic, Expanded 1, Expanded 2), Netflix, Streaming TV, and the outside option. Depending on the chosen subscription, different consumption options are available. The following table indicates which consumption options are obtained with the purchase of each subscription combination.

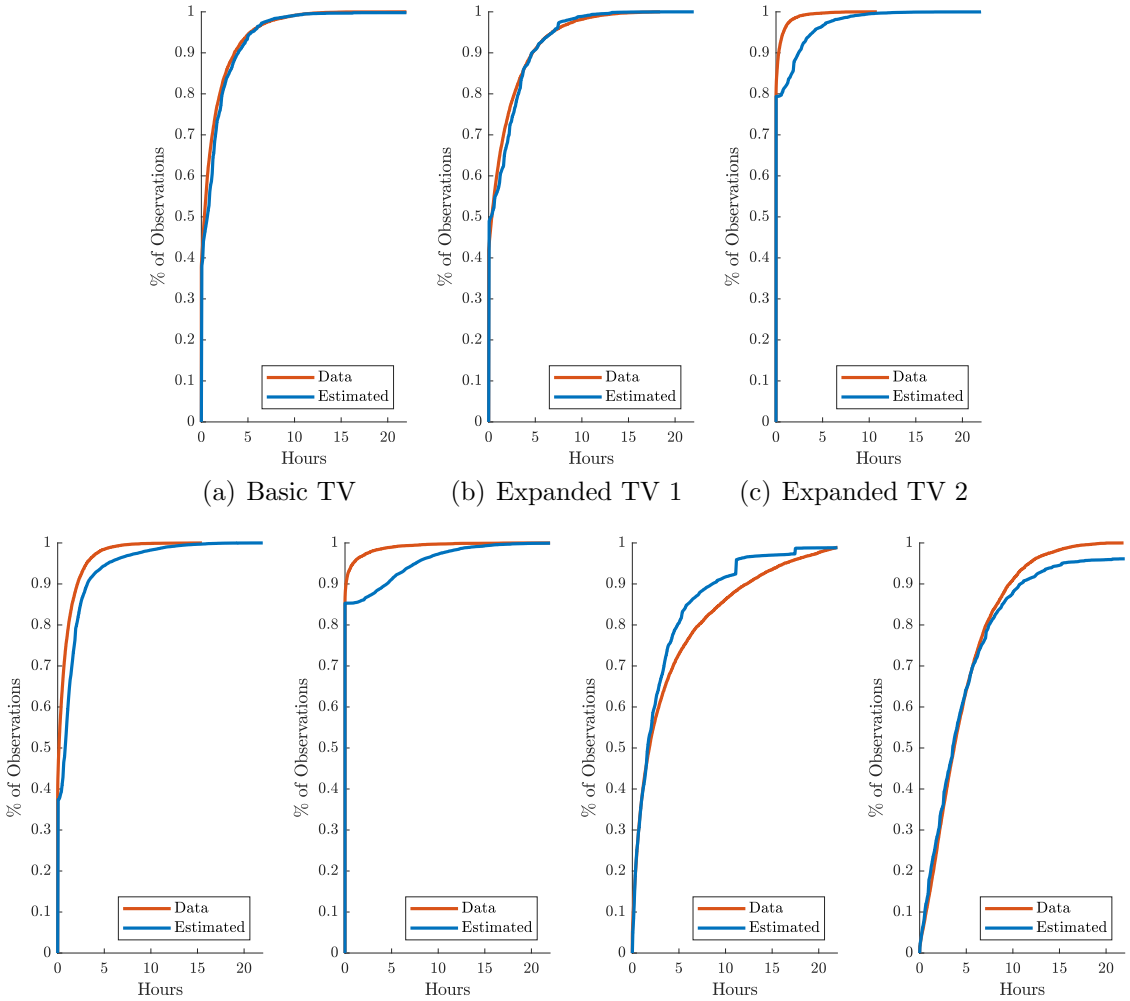
Table B.1: Subscription Bundles and Consumption Types

Bundle	Basic TV	ETV1	ETV2	Netflix	Streaming TV	Other Streaming	Other Web	O.O.
No Subscription	No	No	No	No	No	No	No	Yes
Basic TV	Yes	No	No	No	No	No	No	Yes
Expanded TV 1	Yes	Yes	No	No	No	No	No	Yes
Expanded TV 2	Yes	Yes	Yes	No	No	No	No	Yes
Internet	No	No	No	No	No	Yes	Yes	Yes
Internet, Netflix	No	No	No	Yes	No	Yes	Yes	Yes
Internet, Streaming TV	No	No	No	No	Yes	Yes	Yes	Yes
Internet, Netflix, Streaming TV	No	No	No	Yes	Yes	Yes	Yes	Yes
Internet ,Basic TV	Yes	No	No	No	No	Yes	Yes	Yes
Internet ,Basic TV ,Netflix	Yes	No	No	Yes	No	Yes	Yes	Yes
Internet ,Basic TV ,Streaming TV	Yes	No	No	No	Yes	Yes	Yes	Yes
Internet, Basic TV, Netflix, Streaming TV	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Internet, Expanded TV 1	Yes	Yes	No	No	No	Yes	Yes	Yes
Internet, Expanded TV 1, Netflix	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Internet, Expanded TV 1, Streaming TV	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Internet, Expanded TV 1, Netflix, Streaming TV	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Internet, Expanded TV 2	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Internet, Expanded TV 2, Netflix	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Internet, Expanded TV 2, Streaming TV	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Internet, Expanded TV 2, Netflix, Streaming TV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N								

Notes: This table lists the twenty subscription bundles that make up each household's choice set (left column) and shows which of the eight consumption types are provided by each bundle.

B.3 Fit of Estimated Model

Figure B.1: Model Fit of Usage Distributions



(a) Basic TV (b) Expanded TV 1 (c) Expanded TV 2

(d) Netflix (e) Streaming TV (f) Other Streaming (g) Web Browsing

Notes: This figure shows the empirical and predicted distributions of hours spent viewing each consumption type.

B.4 Counterfactual Transitions and Consumer Surplus Changes

Table B.2: Transition Frequencies from Baseline to Streaming Ban

	Streaming Ban Choice					
Baseline Choice	(0)	(1)	(2)	(3)	(4)	(5)
(0) Outside Option	0.9447	0	0.0509	0.0044	0	0
(1) TV-only	0.1581	0.0174	0.2882	0.5363	0	0
(2) Internet-only	0	0	1.0000	0	0	0
(3) Internet, TV	0.0020	0	0.0838	0.9142	0	0
(4) Internet, Streaming	0.1329	0.0062	0.8389	0.0219	0	0
(5) Internet, TV, Streaming	0.0324	0.0003	0.0610	0.9063	0	0

Notes: This table shows the frequencies of bundle transitions between the baseline pricing strategy and the "no streaming" case. Each row indicates a baseline choice and each column indicates a choice under the new strategy. The entries in each row sum to 1. All TV tiers are aggregated into "TV" and all online video subscriptions are aggregated into "Streaming".

Table B.3: Consumer Surplus Change by Transition Group Under Streaming Ban

	Streaming Ban Choice					
Baseline Choice	(0)	(1)	(2)	(3)	(4)	(5)
(0) Outside Option	0	0	0.1910	0.0266	0	0
(1) TV-only	-0.1118	-0.0490	0.0133	-0.2445	0	0
(2) Internet-only	0	0	0.5175	0	0	0
(3) Internet, TV	-0.0000	0	0.0190	0.5288	0	0
(4) Internet, Streaming	-0.7579	-0.0910	-1.6339	-0.2045	0	0
(5) Internet, TV, Streaming	-0.1907	-0.0031	-0.3668	-1.1561	0	0

Notes: This table decomposes the change in consumer surplus between the baseline and "no streaming" cases according to subscription transition groups. Each row indicates a baseline choice and each column indicates a choice under the new strategy. The entries in each row sum to 1. All TV tiers are aggregated into "TV" and all online video subscriptions are aggregated into "Streaming".

Table B.4: Transition Frequencies from Baseline to Add-on Pricing

	Add-on Pricing Choice					
Baseline Choice	(0)	(1)	(2)	(3)	(4)	(5)
(0) Outside Option	0.8705	0.0004	0	0.0643	0	0.0648
(1) TV-only	0.0788	0.0523	0	0.6724	0	0.1966
(2) Internet-only	0.0605	0.0069	0	0.8140	0	0.1186
(3) Internet, TV	0	0.0014	0	0.9421	0	0.0565
(4) Internet, Streaming	0.0306	0.0032	0	0.0902	0.0000	0.8760
(5) Internet, TV, Streaming	0	0.0001	0	0.0191	0	0.9807

Notes: This table shows the frequencies of bundle transitions between the baseline pricing strategy and the "add-on pricing" case. Each row indicates a baseline choice and each column indicates a choice under the new strategy. The entries in each row sum to 1. All TV tiers are aggregated into "TV" and all online video subscriptions are aggregated into "Streaming".

Table B.5: Consumer Surplus Change by Transition Group Under Add-on Pricing

	Add-on Pricing Choice					
Baseline Choice	(0)	(1)	(2)	(3)	(4)	(5)
(0) Outside Option	0	0.0053	0	0.8643	0	1.0358
(1) TV-only	-0.0179	-0.0151	0	0.6713	0	0.1747
(2) Internet-only	-0.0168	0.0001	0	0.7121	0	0.1240
(3) Internet, TV	0	0.0042	0	2.0311	0	0.1076
(4) Internet, Streaming	-0.0502	0.0041	0	0.2626	-0.0003	2.6919
(5) Internet, TV, Streaming	0	0.0009	0	0.1044	0	6.1012

Notes: This table decomposes the change in consumer surplus between the baseline and "add-on pricing" cases according to subscription transition groups. Each row indicates a baseline choice and each column indicates a choice under the new strategy. The entries in each row sum to 1. All TV tiers are aggregated into "TV" and all online video subscriptions are aggregated into "Streaming".

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Biography

Zachary Nolan graduated with degrees in Economics (B.A., *summa cum laude*) and Mathematics (B.S.) from the University of Florida in 2014. During his time as a graduate student at Duke University, he interned at CableLabs and received external research grants from the NET Institute in 2018 and 2019. He graduated with a Ph.D. in Economics from Duke University in 2020. He will join the Marketing faculty at the University of Delaware in Summer 2020.