Does Pricing of Internet Usage Steer Consumers or Meter Usage? Evidence from a Pricing Experiment*

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Abstract

Competition authorities have expressed concern that firms selling broadband internet and TV subscriptions may employ usage-based pricing (UBP) of internet to steer consumers toward TV over streaming video. We study this issue with household-level panel data from an internet service provider's UBP experiment, capturing the prices' effects on internet and TV subscriptions, internet usage, and firm revenue. We find that this specific UBP policy largely served to meter internet usage by high-demand households rather than steer them toward TV. Households' payments increased due to usage-related overage charges and internet subscription upgrades to avoid overages. Some households avoided internet-related payments by reducing usage rather than adding TV subscriptions.

Keywords: Usage-based Pricing, Steering, Metering, Bundling, Telecommunications Industry, Broadband Internet, Net Neutrality

JEL Codes: L11, L13, L96.

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1 Introduction

A common concern of competition authorities is whether firms with market power take action to reduce consumers' access to competitors. This issue is potentially relevant in residential broadband markets, where Internet Service Providers (ISPs) may have an incentive to disadvantage, through pricing and other means, internet-based substitutes to their own services. The Federal Communications Commission's (FCC's) 2010 Open Internet Order asserts that "broadband providers have incentives to interfere with the operation of third-party Internet-based services that compete with the providers' revenue-generating telephony and/or pay-television services." (Federal Communications Commission, 2010) To address this, the Order provides a set of rules ISPs should follow, including a ban on "unreasonable discrimination" against lawful internet traffic.[1]

A primary way in which regulators have claimed ISPs could disadvantage third parties is by implementing usage-based pricing (UBP). In the US, Comcast, AT&T, Spectrum, Cox, and numerous other ISPs have implemented UBP in the form of multi-part tariffs. These tariffs typically consist of a fixed monthly access fee, a monthly usage allowance, and an overage schedule that applies additional fees to internet usage in excess of the allowance. Regulators have raised concerns that UBP offers ISPs a mechanism to raise the cost of accessing over-the-top video (OTT) services, which currently account for the majority of internet traffic. ISPs that sell both internet access and TV service (also referred to as multiple-system operators, or MSOs) may benefit if raising the cost of accessing OTT video causes consumers to substitute to TV service.[2] On the other hand, UBP allows the ISP to meter usage and ensures that users who consume more also pay more. A marginal price for usage may also result in more efficient usage of networks by eliminating low-value traffic.[3]

[1] The FCC's approach to regulating internet service providers is still evolving. After rolling back Obama-era guidelines in 2017, in 2024 the FCC voted to reinstate the core policies of the Open Internet Order (Federal Communications Commission, 2024b)

[2] Indeed, concerns over potential harm to consumers and OTT providers motivated the restrictions on UBP in Charter's acquisition of Time Warner Cable in 2016 (Federal Communications Commission, 2016).

[3] Regulators are well aware of these tradeoffs. For example, a recent FCC Notice of Inquiry asks: (i) to what extent do data caps impact cable television subscriptions and OTT viewership?, and (ii) what effects

The contrasting arguments on UBP's effects are based on differing implicit assumptions about how consumers behave if faced with UBP. The concern over disadvantaging OTT assumes that, in response to UBP, consumers will be steered towards the MSO's own services and away from OTT. The argument that UBP meters usage and will lead to more efficient network use assumes that consumers will sort to plans and usage patterns that align with their (marginal) willingness to pay for usage. Metering's potential sorting effect suggests another motivation for an MSO to introduce UBP: to capture more of the surplus from internet usage and streaming video. The metering incentive potentially increases over time as usage and usage heterogeneity increase.

In this paper, we use a unique dataset, from one MSO's implementation of a UBP policy, to measure the impact of this particular UBP policy on consumers' subscription choices, internet usage, and payments to the MSO.[4] We find that the main impacts of this particular implementation of UBP are on consumers' internet usage and the associated payments. Consumers who opted to continue relatively high internet usage did so by increasing payments to the MSO, while those who avoided usage payments did so by reducing internet usage rather than adding TV subscriptions.

To build intuition for our empirical analysis and the interpretation of our results, we begin by offering a simple model to illustrate an MSO's incentives and consumers' potential responses to UBP. We augment the standard mixed bundling model to accommodate several relevant characteristics of the TV-internet bundles offered by MSOs. Specifically, we allow "internet-only" subscribers to receive a share of TV's video entertainment through OTT streaming services, and we account for intensive-margin decisions about internet usage. As OTT improves, internet subscriptions offer greater consumption opportunities and become closer substitutes for TV subscriptions. This provides a dual motivation for an MSO to

do data caps have on competition and consumer welfare? (Federal Communications Commission, 2024a)

[4]The implemented policy is representative of the three-part tariffs used by MSOs during this period, which include a fixed fee for access, usage allowance, and overage price schedule. We discuss the details of the experiment, including the similarity of our observed usage price to other contemporary prices, in Section 3 in as much depth as our data-use agreement permits.

introduce UBP for internet usage. To the extent consumers continue using OTT, UBP can meter usage and direct some of streaming video's surplus back to the MSO. On the other hand, UBP may also steer some consumers with internet-only subscriptions to add television subscriptions, so their video consumption occurs through traditional broadcast TV rather than OTT. Our model provides a simple framework to describe which consumers are on the margins of key subscription and usage choices, and therefore the model provides guidance for investigating UBP's effects empirically.

In the empirical analysis, we use novel household-level panel data from a pricing experiment implemented by an MSO to measure a variety of consumer responses to this particular experiment. The MSO operates in multiple North American markets. In one (treated) market, the MSO shifted its pricing model to UBP about halfway through our sample period. Before this change, internet access was provided in exchange for fixed access fees. There were multiple tiers of service, with different prices associated with different connection speeds, but none of the tiers assigned prices according to the level of usage. After UBP was introduced, each tier's price schedule included a usage allowance and overage fees. In a second (control) market that we observe contemporaneously, the MSO kept its pricing fixed throughout the sample period. Other service attributes such as connection speeds were kept constant in both markets. Our data include monthly subscription decisions and daily information on internet usage volume by category (e.g., Web Browsing, OTT, etc.) and for several large applications within the OTT category (e.g., Netflix, Hulu, etc.).

Several features of the data provide challenges and opportunities for our empirical analysis. First, the treated and control markets have non-negligible differences in the market shares of the MSO's subscription options and in the level and composition of internet usage. Second, UBP's nonlinear structure implies that consumers with different internet usage levels have different exposure to the price change, so any market-level analysis will miss the opportunity to study how households' UBP responses vary with their exposure to the policy. To overcome these challenges and provide a more precise analysis of how UBP affects households' choices and payments to MSOs, we employ the penalized synthetic control approach in Abadie and L'Hour (2021). The methodology creates a matched sample of control market households for each household in the treated market based on a specified set of pre-treatment characteristics. These control households allow us to identify which differences in post-treatment behaviors are the result of the treatment rather than differences in composition of the two markets. The technique also provides a straightforward way to measure heterogeneity in the treatment intensity. In particular, each treated household's matched control households provide a "counterfactual" distribution of usage in the absence of UBP, which we use to calculate a household-specific measure of the price increase associated with UBP's implementation. We also use the usage distribution of the matched control households to calculate the counterfactual overage fees that would have been incurred by each treated household in the absence of behavioral changes. We use this dollar-valued measure of treatment intensity like a price index to examine heterogeneity in the treatment effects. On average, treated households would pay \$2.53 more per month for their internet usage if they did not alter their behavior under UBP. The distribution of price effects is heavily skewed, however, with 85% of households incurring an expected price increase of less than \$1, 92% less than \$10, and 96% less than \$20.

We find that treated households with non-negligible predicted price increases took several actions to limit UBP's impact on their monthly bills, primarily by changing their internet subscriptions and usage patterns. Subscription changes are largely concentrated in internet tier upgrades, which have greater data allowances and speeds. For example, a \$10 expected overage corresponds to a 0.062 increase in the probability of upgrading tiers, while an expected overage of \$20 corresponds to a 0.203 increase in the probability of upgrading. We interpret these upgrades as a form of metering, in which high-demand consumers are sorted into higher-priced options for internet service. By contrast, we find little net impact on households' adoption of the MSO's TV service, implying that the UBP policy we study did not serve as an instrument to steer consumers toward TV subscriptions.

The UBP we study also had a significant impact on internet usage by some households. The average treated household's daily usage level decreases by about 0.24 Gigabytes (GB), or 6%. This decrease is concentrated among households with larger treatment intensity, who generally have much higher baseline usage levels. Among households with a predicted price increase of less than $1, the average usage reduction was less than 1%. Households with an expected price increase in the top ten percent decreased their daily internet usage by 2.5 GB, a 19% reduction. Among those households that upgraded to a higher-allowance internet tier, the policy had less effect on usage levels. Households in the top 10% of treatment intensity who upgraded their internet tier decreased their daily usage by less than 1%.

Decomposing these changes in internet usage across applications, we find reductions in usage that are generally proportional to the pre-UBP level. In particular, OTT consumption accounts for the majority of the usage and therefore the majority of the usage decline among households that did not upgrade their internet tiers. Within the online video category, we find different responses by content provider. Notably, despite Netflix's position as the most-used OTT provider by volume, reductions in Netflix usage were smaller in magnitude than YouTube and other OTT applications among households who did not upgrade their internet tier. These differences in usage effects are suggestive of differences in the value consumers place on types of content, both among third-party internet services and between OTT and conventional TV.

We conclude by documenting how the policy affected the MSO's revenue. Consumers with limited expected exposure to UBP, under our measure of treatment intensity, make payments to the MSO that were identical to their control groups' payments, on average. Consumers in the top 10% of estimated price exposure, on the other hand, pay $10.90 more (8.5%) to the MSO following the price change. Realized payments increased monotonically with our measure of treatment intensity. Consumers' increased payments were largely due to overage charges for internet usage and upgrades to internet subscriptions; treated consumers' payments for TV service fell slightly relative to their matched control households.

Our analysis contributes novel empirical findings on Net Neutrality and the telecommunication industry's pricing practices. A central focus of the Net Neutrality debate, introduced by Wu (2003), is the interaction of upstream content creators and the distribution networks that deliver content to consumers. Previous analyses of these issues, which are primarily theoretical and surveyed by Lee and Wu (2009) and Greenstein et al. (2016), generally deal with relationships between content and distribution firms.[5] Our focus, by contrast, is on how content-neutral prices paid by consumers influence choices over content type, quantity, and distribution channel. We build on this analysis in McManus et al. (2024), where we use structural estimates of subscription demand and internet usage to study an MSO's incentives to charge premium or discounted prices for OTT usage.

Content-neutral usage-based broadband prices, like those we study, are the subject of a 2013 report by the Open Internet Advisory Committee (Open Internet Advisory Committee, 2013), a 2024 Notice of Inquiry from the FCC (Federal Communications Commission, 2024a), and a growing theoretical and empirical literature. Theoretical contributions in this space include MacKie-Mason and Varian (1994), Bauer and Wildman (2012), Odlyzko et al. (2012), and Chillemi et al. (2020). Related empirical research on usage-based pricing for residential broadband, e.g., Malone et al. (2014), Nevo et al. (2016), and Malone et al. (2021), focus on how prices affect usage volume. In addition, several related studies analyze nonlinear pricing for wireless telecommunications (Lambrecht et al. (2007); Miravete (2003); Grubb (2015); Grubb and Osborne (2015)). Relative to these studies, our empirical analysis has the advantage of an experimental setting and includes richer subscription information and application-specific usage data that allows us to measure the impact of a particular implementation of UBP on TV subscriptions and third-party content providers.

In addition, our analysis contributes to the literature on demand for telecommunications

[5] The extensive theoretical literature includes contributions from Economides and Hermalin (2012), Armstrong (2006), Bourreau et al. (2015), Choi et al. (2015), Choi and Kim (2010), Economides and Tag (2012), Gans (2015), Economides and Tag (2016), Reggiani and Valletti (2016), Sidak (2006). Recent empirical work in this area includes Goetz (2019), who examines how consumer welfare is affected by bargaining between content providers and ISPs over network investment

services, including both internet and TV services.[6] Malone et al. (2023) offers some insight into the substitutability of the two services from a descriptive analysis of the behavior of a selected group of households that drop TV service. Our data includes a large representative set of households and experimental price variation, which allows for a better understanding of the trade-offs households are willing to make between the services offered by MSOs under varying degrees of price exposure. Further, we provide novel evidence on whether usage-based pricing, as empirically implemented, is likely to have a meaningful negative impact on households and third-party content producers.

In several other markets, firms employ nonlinear pricing to meter demand or provide incentives for consumers to take profit- or efficiency-enhancing actions. In electricity markets, demand exhibits substantial heterogeneity across households and intra-day variation, which makes it a natural candidate for congestion or real-time pricing. Recent empirical work in this area includes Wolak (2007, 2010, 2016), Strapp et al. (2007), Ito (2014), and Anderson et al. (2017); Newsham and Bowker (2010) and Faruqui and Sergici (2010) provide a comprehensive review of the literature. Einav et al. (2015a) and Einav et al. (2015b) study health insurance contracts featuring deductibles and caps on out-of-pocket expenditures that are similar to the multi-part tariffs in our study. Performance incentives in labor contracts often also take a nonlinear form with thresholds for bonuses (Copeland and Monnet (2009); Chung et al. (2010); Misra and Nair (2011); Duflo et al. (2012)).

2 Model

In this section we introduce a model to describe how UBP for internet service affects consumers' choices in a setting where video entertainment is available through both OTT and traditional TV. We begin with a standard mixed bundling model in which an MSO sells

[6] On internet services, see Prince and Greenstein (2017); Goolsbee and Klenow (2006); Dutz et al. (2009); Rosston et al. (2013); Greenstein and McDevitt (2011); Edell and Varaiya (2002); Varian (2002); Hitt and Tambe (2007). On TV services, see Crawford and Shum (2007); Crawford and Yurukoglu (2012); Crawford et al. (2018, 2019).

standalone TV and internet subscriptions as well as in a bundle, and we augment the model in a few ways. First, we allow consumers to make usage decisions in addition to subscription choices, so we capture activity at both the intensive and extensive margins. Second, we allow consumers with internet subscriptions to access some TV video content through the internet. This increases the value that consumers receive from the MSO's internet service, which affects consumers' subscription and usage decisions. We demonstrate that OTT's availability may create incentives for an MSO to introduce UBP or similar nonlinear prices for internet service. UBP can serve as a metering instrument, capturing some of the surplus consumers receive from OTT, and it can affect both the total amount, and composition, of internet data usage. In raising the price of OTT and other internet content, UBP may also steer some consumers toward TV subscriptions. We use our model to develop intuition on how metering and steering effects may be generated by the properties of consumers' utility and demand as well as the structure of a UBP policy.

2.1 The Setup

Consider a market in which a monopolist MSO offers consumers access to two types of content. Type 1 is available on the internet only and type 2 is video entertainment available through TV.[7] An individual consumer's taste for "units" (e.g. hours) of content 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 on $[0, 1] \times [0, 1]$.

The MSO offers subscription plans that allow consumers to access content. We begin by assuming that the MSO offers three plans: broadband internet access (INT), TV (TV), and a bundle (BUN) that includes both INT and TV. The firm's (mixed bundling) pricing strategy includes prices for the stand-alone plans (p_{INT} and p_{TV}) and a price for the bundle (p_{BUN}). A consumer can subscribe to one of the firm's three plans, $\{INT, TV, BUN\}$, or

[7] In this stylized model video content available only through the internet and not TV, e.g. some of the content available on Netflix, is part of type 1 content. In practice, different varieties of video content may have complex substitution relationships with each other. In our empirical analysis, we highlight some of these relationships.

an outside option denoted by 0 that provides utility normalized to zero. To capture the presence of OTT, we assume that consumers can access some fixed fraction, $\delta \in [0,1]$, of type 2 content through an internet-only plan (INT) by subscribing to a OTT provider. We abstract away from the fee to subscribe to the OTT service and assume it is available at no additional expense to the consumer. The restriction $\delta \leq 1$ has several possible interpretations, including limited available OTT content or diminished video quality, which could be due to transmission (e.g. congestion and buffering) or hardware limitations.

An individual consumer receives utility from consuming q_1 units of content type 1 and q_2 units of content type 2. The quantity choice for type 2 content, q_2, can include both traditional TV, $q_{2,TV}$, and OTT, $q_{2,INT}$, with $q_2 = q_{2,TV} + q_{2,INT}$. The consumer decides on consumption based on his tastes (v) and subscription plan. For simplicity, we assume that a consumer has marginal utility equal to one for content j up to a satiation level equal to the taste parameter v_j, and then marginal utility is zero for any greater quantity. For example, a consumer with taste v_2 and a TV-only subscription consumes $q_{2,TV} = v_2$ units of video entertainment through his TV and receives surplus of v_2 from this activity. We integrate OTT into this framework by assuming that when the consumer uses OTT, his 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 OTT. To simplify our descriptions of bundle subscribers' consumption choices, we assume that bundle subscribers receive all of type 2 content through TV, with $q_{2,TV} = v_2$ and $q_{2,INT} = 0$.

Putting this all together, subscribers in internet-only plans receive utility of $U_{INT} = v_1 + \delta v_2 - p_{INT}$, where the first and second terms capture utility (and quantities) from consuming internet content and OTT applications, respectively. A subscription to the TV service, TV, results in TV content consumption of $q_{2,TV} = v_2$, zero internet usage given the lack of access, and net utility equal to $U_{TV} = v_2 - p_{TV}$. Bundle subscribers consume quantities of content types 1 and 2 up to their satiation levels and receive utility equal to

$U_{BUN} = v_1 + v_2 - p_{BUN}$. Finally, if the consumer selects the outside option, 0, quantities are zero for both content types and utility is zero.

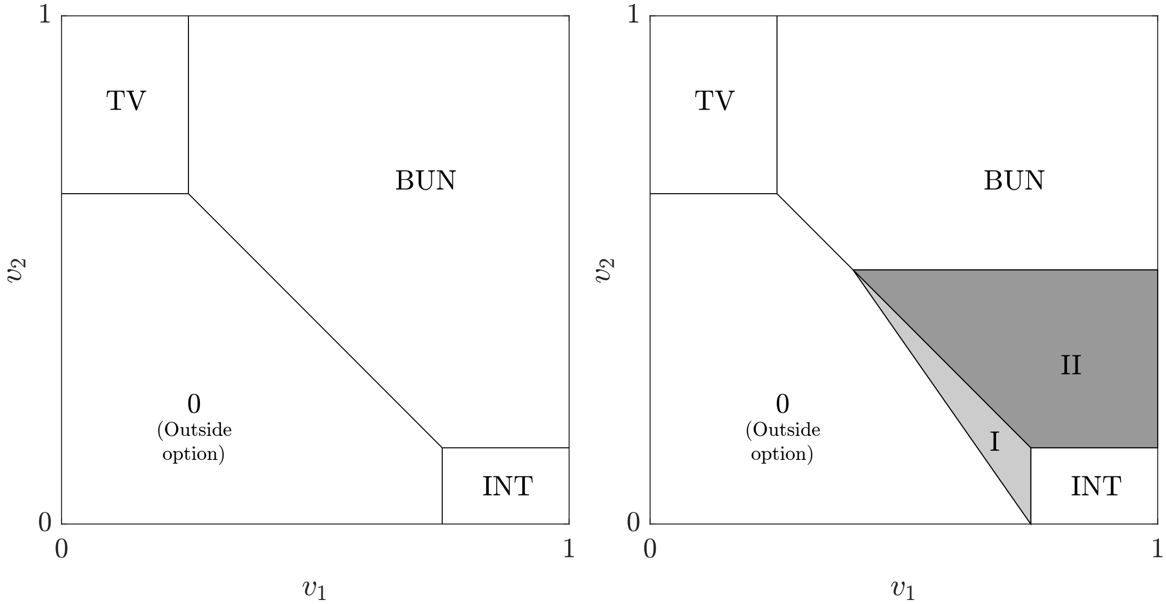
We abstract away from specifying the MSO's cost structure and profit function. While the firm's costs are an important part of how it sets prices with and without OTT, along with its incentive to introduce UBP, in this paper we focus on tracking consumers' responses to UBP. For related discussion of the MSO's incentives see McManus et al. (2024).

2.2 Consumer Choice

We now turn to the choices consumers make in this setup. In Figure 1 we present choices different consumers make for a fixed set of prices. In panel (a), we show the choices when no OTT is available, or if OTT does not substitute at all for TV service, (i.e., $\delta = 0$), consumers in the area labeled '0' select the outside option, and those in area labeled 'BUN' select the bundle. Consumers in areas INT and TV select the stand-alone internet and TV subscription plans. The split is intuitive: consumers with high valuations for both content types choose the bundle, and consumers with high valuation for one content type and not the other choose the plan with just the appropriate stand-alone subscription. Consumers with low valuations of both content types choose the outside option. The locations of the margins between the regions depend on the prices of the various options.

Next, we consider the effect of OTT becoming more attractive, or a better substitute for TV, (i.e., the effect of an increase in δ) on subscription choices. In Figure 1(b) we show the effect of δ increasing to 0.7, holding prices fixed at their original levels. Two types of consumers change their choices. First, some consumers (in area I) who did not purchase, despite moderately high valuation for content 1 or 2, will subscribe to INT because it became more attractive. These new consumers increase the MSO's revenue and are one reason the MSO has an incentive to encourage OTT. Second, some consumers (in area II) decide to "cut the cord." These consumers choose a bundle when $\delta = 0$ but have relatively low taste for TV content among bundle subscribers. As δ increases, they prefer stand-alone internet

Figure 1: Consumer Choices in Simplified Model



(a) $\delta = 0$ (b) $\delta = 0.7$

Notes: This figure shows consumer subscription choices for $\delta = 0$ (left panel) and $\delta = 0.7$ (right panel), holding prices fixed. At $\delta = 0$, consumers with v values in INT choose internet-only subscriptions, those in TV choose TV subscriptions, and those in BUN select the bundle. Consumers with v values in region 0 do not purchase from the MSO. At $\delta = 0.7$, consumers with v values in region I switch from 0 to INT, and those in region II switch from BUN to INT. Unshaded regions maintain the same choices.

service because they can consume OTT using the internet service. The cord-cutting by these consumers diminishes the MSO's revenue, as the bundle price is higher than the internet-only price. Whether the consumers in area II reduce the firm's profit, however, depends on several factors which may work in opposite directions. The relative costs of providing TV and internet affect the bundle and internet-only profit margins, and consumers in area II may be moving to a higher- or lower-margin service.

2.3 UBP's Impact

We illustrate the impact of introducing UBP with a stylized tiered internet service in which consumers must pay a premium for greater usage. As in the UBP policy we observe empirically, consumers have the option to upgrade to a higher internet tier if they desire more content than is permitted in their initial tier's allowance.[8] We illustrate this strategy with a simple menu of two internet plans, with the low-usage plan (INT_L) available for price p_{INT_L} and usage cap κ, plus a high-usage plan (INT_H) with unlimited usage. The usage cap and tiers serve two purposes. First, the high-usage tier allows the MSO to extract a premium from high-demand individuals who are willing to pay a premium $(p_{INT_H} - p_{INT_L})$ for extra usage $((v_1 + \delta v_2) - \kappa)$. Second, the usage cap prevents additional internet usage by inframarginal consumers on the low tier whose tastes would lead them to consume in excess of the cap; this may be valuable to the MSO if internet costs increase with usage. To the extent that the cap and tiers limit OTT usage in some cases while charging a premium for it in others, they act as metering instruments for the MSO. In a setting with $\delta > 0$, the caps and tiers reduce consumers' net benefit from video entertainment over the internet and, therefore, may steer consumers from INT to BUN.

To illustrate the impact of tiers on consumers' choices, we consider a case in which the MSO introduces tiers to internet service while keeping other prices fixed. This scenario resembles the situation we see in our data, in which the MSO introduced tier allowances and overage charges without adjusting other subscription prices. When the MSO introduces caps and tiers to a setting that had neither, consumers are affected in distinct ways, as we illustrate in Figure 2. We impose a set of prices that facilitate reading the different regions of Figure 2, including setting p_{INT_L} equal to the initial p_{INT}.[9]

Panel (a) of Figure 2 provides an initial distribution of consumers across subscription options with $\delta = 0.70$, before any tiers or cap are offered. The introduction of usage tiers has both metering and steering effects, as we illustrate in Figure 2 Panel (b). First, consider the metering effect. Some consumers accept the usage cap κ and remain internet-only with a low allowance (INT_L), denoted by area I in Figure 2 Panel (b). This tier's usage cap

[8] Unlike the empirical UBP in our data, the stylized example does not allow the consumer to pay an overage charge for extra internet usage while remaining on his initial tier.

[9] In panel (a), we plot market shares for prices $(p_{INT}, p_{TV}, p_{BUN}) = (0.75, 0.65, 0.9)$. In panel (b), the MSO places a usage allowance $\kappa = 0.8$ on the original internet tier, now INT_L, and a new premium internet tier, INT_H is introduced with no allowance. The new prices are $(p_{INT_L}, p_{INT_H}, p_{TV}, p_{BUN_L}, p_{BUN_H}) = (0.75, 0.85, 0.65, 0.9, 1.0)$.

will cause some subscribers to reduce their internet usage relative to their pre-UBP levels. On the other hand, consumers with a stronger taste for internet usage, whether for video- or non-video content, may "upgrade" their internet subscription to INT_H; these consumers are denoted by Area II in Panel (b). This sorting of consumers across plans is the central metering channel. From the MSO's perspective, offering the two tiers with UBP allows it to collect more revenue from consumers who use the internet more.

To see the steering effect, note that consumers with relatively strong values of v_2 switch from INT into the bundle (Areas III and IV) when the MSO introduces UBP. 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 OTT usage falls.

In addition, some of the initial INT subscribers cancel their subscriptions completely (Area V) because they value the outside option more than the capped internet service at the current price. Finally, some bundle subscribers with strong internet tastes (in Area VI) opt for BUN_H so that they can consume internet without a usage limit.[10]

Whether the metering or steering effect dominates depends on several factors. First, it depends on the relative sizes of Areas I-VI in Figure 2 Panel (b). The exact size of each Area depends of the model's parameters. For example, as noted above, the demand parameter δ captures the degree of substitution between INT and BUN. The larger the value of δ, the greater the similarity in sources of utility to consumers from INT and BUN, and therefore a larger δ is associated with more steering from INT to BUN when the price of internet usage increases. This is reflected in the sizes of areas III and IV in Figure 2. However, a larger δ also increases the value of internet usage for those who remain with INT, which is associated with a greater willingness to pay for upgraded internet to accommodate more

[10]We note that one potential outcome of UBP's introduction that does not arise from this simple example is substitution from BUN to INT, i.e., cord-cutting. Cord cutting can arise in our model by a change that affects the difference in utility between internet-only and bundle plans (e.g., an increase in δ or an increase in the gap between p_{BUN} and p_{INT}). Other possible explanations that are outside of our framework might include income effects for budget-constrained households or the reduction in behavioral frictions and choice inertia due to the policy roll-out.

usage, i.e., metering. This contributes to the size and shape of region II. In addition to these considerations of the Areas' sizes and shapes, obviously the effects' magnitudes are also determined by the mass of consumers in each Area.

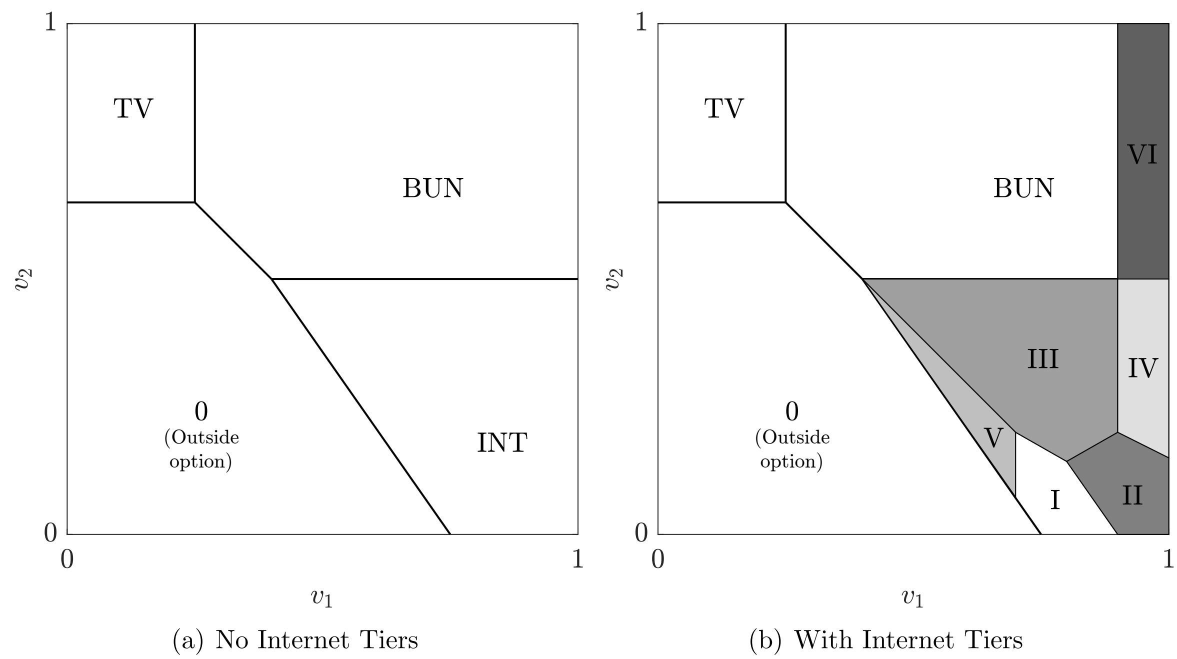
The relative impacts of metering or steering effects are also determined by the UBP policy and structure. In our simple model, the UBP structure is captured by κ and the price differences between low- and high-usage internet subscriptions. These determine how many consumers have usage levels that would be impacted by the introduction of UBP, and the prices of internet tier upgrades and bundle subscriptions influence what type of response the consumer finds most beneficial. Like the demand parameters, these policy values also affect the sizes of Areas I-VI, and differently structured UBP policies will have different metering and steering effects.

In practice, UBP policies are not exogenous and are chosen by MSOs to maximize the firms' objectives, subject to constraints they face, including regulatory oversight. As is usually the case, an MSO's optimal design of a product menu, including whether it has incentive to introduce UBP, depends on the same demand responses discussed above. However, an optimal policy that includes UBP should also be considered jointly with subscription prices. With UBP in place to meter the usage of higher-demand consumers, the MSO may select lower subscription prices because a reduction on this margin sacrifices less revenue from inframarginal consumers. Therefore, simply adding UBP to existing prices, as we do in the simple model above and observe as an experiment in the data, is unlikely to be optimal for a profit-maximizing MSO.

If the MSO wants to maximize the steering impact of its UBP, it could consider discriminatory usage prices that distinguish between video content available through TV versus other internet content. Alternatively, it could apply usage prices to INT subscribers only, exempting those who already purchase the bundle. Different usage prices might also be motivated by differences in marginal utilities across content types, which is not present in the current demand model.

Finally, the MSO's distinct costs of providing TV and internet service each influence whether the firm has a greater incentive to steer consumers toward TV or allow them to remain with more easily-metered internet usage. We study some of these issues in a related paper, McManus et al. (2024).

Figure 2: Consumer Choices with Tiers and Allowances



Notes: This figure shows the effect of the introduction of internet tiers on subscription choices. Throughout, δ is fixed at 0.7. In panel (a), the MSO offers a single internet tier with unlimited usage. Consumers with v values in region INT choose internet-only subscriptions, those in TV choose TV subscriptions, and those in BUN select the bundle. In panel (b), consumers must select a high-usage internet-only or bundle tier for internet usage greater than κ. Region I selects INT_L, region II selects INT_H, regions BUN and III select BUN_L, and regions IV and VI select BUN_H. Regions V and 0 select the outside option.

3 Data and Descriptive Analysis

In this section, we describe our data sources and discuss the implementation of the MSO's UBP experiment. We next present summary statistics on households' subscription choices and internet usage. Finally, we provide a descriptive analysis of how household behavior changed following the introduction of UBP.

3.1 Data Sources and the Usage-Based Pricing Experiment

Our data come from a North American MSO; our data use agreement with the MSO prevents us from identifying the firm or any details that could be used to infer its identity.[11] We observe nine months of billing information, subscriptions, and application-specific internet usage data for a random sample of 70,500 households that subscribe to internet service from the MSO in two large markets. The data were collected during the latter half of the 2010s. The MSO that provided this sample, like most other MSOs during this period, offered a menu of internet tiers and TV service. These services could be purchased as standalone subscriptions or as bundles including both an internet tier and TV service.[12] Subscription contracts and billing periods were about one month long, so we use the terms "month" and "billing period" interchangeably below. The internet tiers are differentiated by speed, while TV service was available in several tiered channel packages (basic, premium, etc.). Adding a TV plan to an existing internet subscription increased a household's bill by about \$100, on average. For each household, we observe the internet tier chosen, the presence or absence of a TV-service subscription (but not consumption or the set of available channels), and monthly payments to the MSO. We also observe internet usage in several distinct categories, including real-time entertainment (RTE), web browsing, gaming, and peer-to-peer traffic. The RTE category contains online/streaming video, and within the RTE category we can identify usage of some major applications like Netflix.[13]

One important feature of our data is that the MSO introduced UBP in one of the two markets during our sample period. Prior to introducing UBP in the "treated" market, the

[11] To maintain the MSO's anonymity, we cannot provide details on the specific markets served, the exact dates and details of the implementation of UBP, and the detailed characteristics of the MSO's product menus.

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

[13] Information on internet usage comes from two sources: internet protocol data records (IPDR) and a deep packet inspection (DPI) platform. IPDR is considered the most reliable source for high-frequency customer-specific upload and download byte counts and is used by MSOs for usage-based billing purposes. The DPI platform (e.g., Sandvine) provides detailed information on the composition of bytes used by a household. In these DPI data, we observe household-specific byte counts at an hourly frequency for each traffic category.

MSO offered identical product menus in the treated and control markets, with the control market's menu remaining unchanged throughout the sample period. Under the original product menu, internet tiers were differentiated by price and connection speed, with faster connection speeds associated with higher prices. Under UBP, each internet tier received a monthly usage allowance, with more expensive tiers associated with higher allowances, while the baseline access fees and connection speeds associated with each tier remained the same. Internet usage in excess of the UBP allowance triggered the automatic purchase of a "top-up" quantity of additional data. The top-up quantity was smaller than the allowance difference between any two adjacent tiers, and its price was approximately equal to the subscription price difference between adjacent tiers. Households could purchase an unlimited number of top-ups.[14]

The MSO introduced UBP in two phases. First, during an "announcement period" that began several months prior to UBP implementation, the MSO publicized the details of the new policy to its customers in the treated market. The MSO provided the UBP starting date, the menu of tier usage allowances, and the price and quantity of an allowance top-up. During each billing period in the announcement period, the MSO also informed treated subscribers about how their monthly usage compared to the data allowance that would be associated with their current tier under UBP. In the second phase, which we call the "treatment period," the MSO enforced its UBP policy, including assessing overage charges on households with internet usage greater than their monthly allowance. In all, our sample period includes multiple months of the "pre-policy period" prior to UBP's announcement, the full announcement period, and several months of the treatment period. To our knowl-

[14] The MSO's offerings, including its base subscription prices, internet speeds, and usage allowances and overage prices, are representative for the late 2010s in North America. During this period, the range of observed subscription prices was between \$30 and \$180, with the less expensive plans typically having both a lower download speed and usage allowance. The range of download speeds was between 1Mbps (low DSL tiers) and 1 Gbps (high cable tiers). Most operators had usage allowances, which ranged from 30 GB to 2,000 GB. The structure of overage price schedules for usage in excess of the allowances had some variation across MSOs. Most were a "top-up" structure that increased the allowance by a fixed amount for a fixed fee (e.g., \$10 per 50 GB for many plans in the US), while some had a linear tariff (e.g., up to \$4 per GB for some Canadian MSOs). The UBP policy we observe included usage prices similar to the US rates.

edge, the MSO selected the treated market for UBP based on its technological capability to charge subscribers for usage there. In both the treated and control markets, the MSO offered internet service on a substantially higher-speed and higher-capacity network than its competitors. Internet service via DSL was available in each market, as was satellite TV. MSO's competitors did not change their subscription menus meaningfully during the sample period, including in response to UBP's introduction in the treated market.

3.2 Descriptive Statistics

In Table 1, we describe household-level monthly internet usage and plan choices in each market during the pre-policy period. Table 1's left side contains statistics on internet-only households who had no TV subscription, and the right side describes households with an internet-TV bundle. The distributions of internet usage are displayed in Panel 1. Among internet-only subscribers, the treated and control distributions are quite similar. For bundle subscribers, internet usage is greater in the control market. These differences motivate our empirical approach, which constructs household-specific control groups to aid in measuring treatment effects. In both the treated and control markets, internet-only households use more internet data than bundle subscribers.[15]

Table 1's Panel 2 provides a breakdown of subscription choices. About 28% of the MSO's customers have internet-only subscriptions, and the remaining 72% subscribe to an internet-TV bundle; no MSO customers in our sample subscribe to TV alone. We aggregate the internet tiers into three categories by speed: low, medium and high. There are some minor differences across subscription choices, but in general the medium-speed tiers are the most popular, followed by the low-speed tiers.

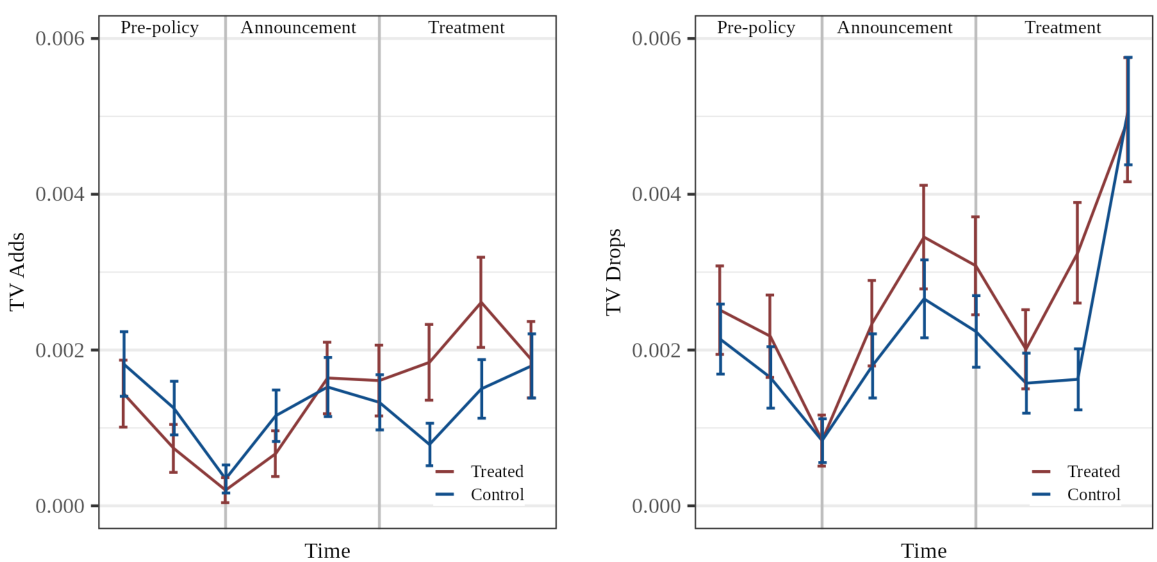
Panels 3 and 4 of Table 1 provide a breakdown of internet usage by category, including several major streaming video applications. More than half of the internet usage we observe

[15] 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. (2021) for a study of the impact of congestion on broadband networks.

is OTT consumption. Netflix, which offers a variety of original programming along with a library of previously distributed movies and television programs, is the most-used subscription service. Engagement with YouTube generates the second-largest level of network usage. Other observable applications include Hulu, which emphasizes opportunities to stream on-demand TV shows currently airing on network TV, and Sling TV, which offers live TV over the internet. Internet-only households use each of these applications more intensely than bundle households.

3.3 Descriptive Analysis of Responses to UBP

Figure 3: UBP Response: TV Adds and Drops



(a) Additions (b) Drops

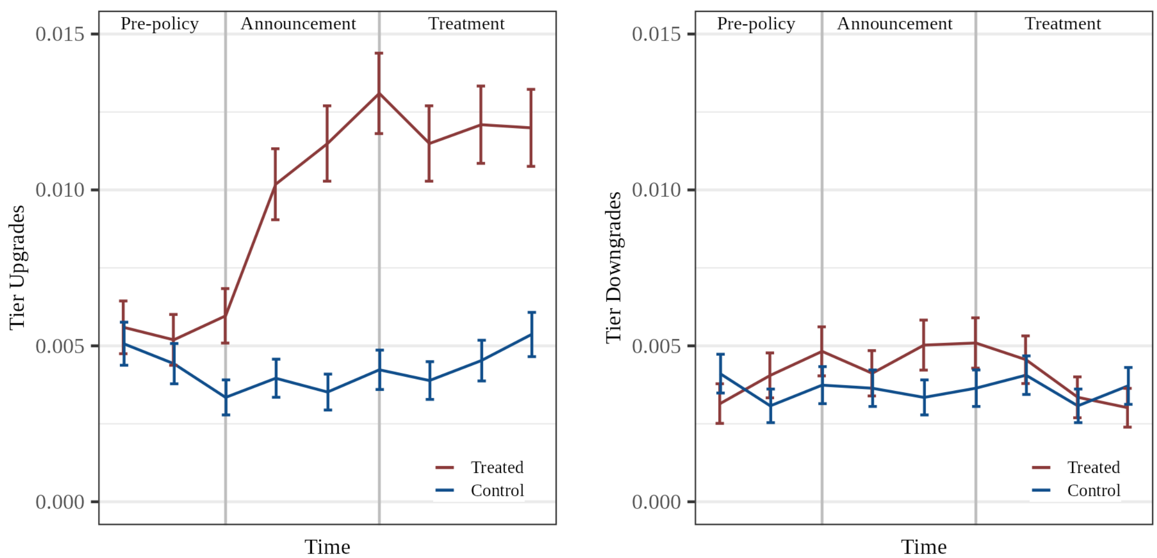
Notes: Share of households that add (panel a) and drop (panel b) TV subscriptions in the treated and control markets. Monthly level of aggregation coincides with bill frequency. Error bars denote 95% pointwise confidence intervals.

The MSO's UBP policy, if relevant to households' choices, would create differences in subscription patterns between the treated and control markets. In Figure 3, we report how the propensities to add and drop TV service (panels (a) and (b), respectively), changed in the treatment and control markets during our panel.[16] Panel (a) shows that, prior to

[16]To construct Figure 3 and similar figures below, we use all households in the sample, i.e., without

UBP's introduction, the flows of households from internet-only to bundle subscriptions were virtually identical in the treated and control markets. After UBP was introduced, treated households were more likely to add TV subscriptions in some months. While this difference in new TV subscriptions is consistent with arguments about UBP's potential steering effects, in panel (b) we show that the treated market also experienced a slightly greater cord-cutting rate than the control market throughout the sample period. The two offsetting effects are small and have limited statistical significance. Overall, the share of households with TV subscriptions fell by slightly more in the treated market compared to the control market.

Figure 4: UBP Response: Tier Upgrades and Downgrades



(a) Upgrades (b) Downgrades

Notes: Share of households that upgrade (panel a) and downgrade (panel b) internet tiers in the treated and control markets. When households make multiple changes during the sample period, only the first change is shown. Monthly level of aggregation coincides with bill frequency. Error bars denote 95% pointwise confidence intervals.

In Figure 4 we display the shares of households upgrading and downgrading their internet tiers. In panel (a) we show that the upgrade rates were approximately equal during the pre-policy months of the sample period, and then they diverged substantially. Treated households upgraded their internet tiers more frequently than control households starting

matching on households' pre-policy characteristics as in our main empirical results.

during the announcement period, and this continued after UBP's full introduction. In panel (b) we show that the treated market also had a greater rate of internet downgrades than the control market, but the difference is relatively small in magnitude. As we discuss below, this may be due to UBP informing some low-usage households that their consumption could fit within a lower tier's allowance.

In addition to UBP's impact on subscriptions, we investigate how it affected internet usage. In Table 2, we provide a summary of the difference-in-differences impact of UBP on usage. Internet usage grew in both markets during the sample period, but growth was substantially slower under UBP. In the control market, average GB per household per month grew by 36% (from 119.68 GB to 162.09 GB) during the sample period, but growth in the treated market was only 20% (from 91.77 GB to 110.21 GB). Just under half of the difference between the two markets is due to slower growth in video usage, and a similar share is due to reduced growth in browsing, which itself includes embedded video. The major video streaming services we highlight in Table 2 account for considerably more than half of all pre-UBP video usage, but, in relative terms, video usage reductions occurred primarily outside of these services in the treated market.

To provide some preliminary context on UBP's incidence in the treated markets, we describe briefly how pre-announcement internet usage levels compared to the allowances that were eventually introduced to a household's tier. In the most popular internet tier, 5% of households had average pre-UBP monthly usage that exceeded the tier's allowance under UBP. Average usage in excess of the allowance was more common in lower tiers than higher tiers. Across all household-month pre-UBP observations in the treated market, 3.9% would have generated an overage charge, had UBP been in place. Overall, 5.2% of all treated households would have received at least one bill with a positive overage charge. Secular growth in internet usage, in addition to increasing overage incidence within the sample period, could result in UBP affecting more households and at a greater intensity over time.

Table 1: Usage and Plan Choice during the Pre-Policy Period

Household Type	Has TV: NO		Has TV: YES	
	Treated	Control	Treated	Control
Panel 1: GB Total Monthly Usage				
Mean	154.47	156.48	73.62	102.94
Standard Deviation	169.49	170.57	114.27	122.40
1st Percentile	1.49	1.90	0.21	0.34
25th Percentile	43.31	60.10	9.08	22.57
Median	105.50	117.76	30.66	65.65
75th Percentile	211.27	208.62	93.38	139.79
99th Percentile	732.85	655.40	515.91	560.41
Panel 2: Subscription Choices				
Households (N)	7,330	13,374	23,439	28,278
Total Bill ($)	74.92	78.56	175.46	181.47
Low Speed Internet	0.32	0.23	0.25	0.12
Median Speed Internet	0.53	0.56	0.66	0.63
High Speed Internet	0.15	0.21	0.10	0.25
Panel 3: Mean Usage by Category				
Video	100.14	98.11	43.19	61.58
Browsing	39.43	42.30	22.05	29.79
Other	14.91	16.06	8.38	11.57
Panel 4: Mean Usage of OTT Services				
Netflix	54.82	40.27	22.59	27.83
YouTube	20.64	29.64	12.25	18.28
Hulu	4.38	3.08	0.86	1.11
Sling TV	0.66	0.40	0.04	0.06

Notes: Summary statistics at a household-month level of observation. Usage levels are totals within monthly billing cycles. Tier choice shares are the share of households that choose each speed tier group.

Table 2: UBP Response: Usage

	Treated: YES		Treated: NO		Diff-in-Diff
	Pre-UBP	UBP	Pre-UBP	UBP	
Video	55.98	64.17	73.01	92.53	-11.33
Netflix	29.83	34.97	31.72	40.60	-3.74
YouTube	14.13	16.46	21.83	25.39	-1.24
Hulu	1.65	2.70	1.73	2.73	0.04
Sling TV	0.18	0.70	0.17	1.19	-0.51
Browsing	25.95	32.48	33.71	51.32	-11.09
Other	9.85	13.56	12.97	18.24	-1.55
Total	91.77	110.21	119.68	162.09	-23.97

Notes: Average monthly internet usage by category, treatment period, and treatment status.

4 Measuring the Impact of Usage-Based Pricing

In this section, we describe our empirical approach, which adapts the penalized synthetic control (PSC) framework of Abadie and L'Hour (2021). We construct a household-specific measure of treatment intensity that as a result of the UBP policy we observe. We then relate the treatment intensity to household usage and subscription decisions.

4.1 Empirical Strategy

Our data exhibit both market-level and intertemporal variation in exposure to treatment. The PSC estimator provides a powerful tool to identify household-specific measures of treatment intensities and effects while controlling for observable differences between treated and control households. Specifically, the PSC estimator yields two useful objects for each household: weights for a matched sample of control households and an estimate of the treatment effect for each outcome of interest, in our case UBP's impact on usage and subscriptions. In a treated household's matched sample, the control households' usage distribution provides a measure of treatment intensity in the absence of behavioral changes brought on by treatment. The treatment intensity is the expected price change from UBP given the synthetic control's usage distribution in the treatment period. This measure captures the relative cost of inaction for treated households in response to UBP. We relate this treatment intensity measure to the treatment effect estimates to characterize the heterogeneity in households' subscription and usage responses to UBP.

The PSC approach has particular advantages for constructing the measure of treatment intensity. In particular, it explicitly accounts for the trade-off between (a) minimizing behavioral discrepancies between a given treated household and its synthetic control, and (b) minimizing discrepancies between a given treated household and each of the individual control households included in its synthetic control. Favoring option (a) will lead to the best overall fit between treated households and their corresponding synthetic control, but accounting for option (b) can reduce bias by ensuring that each treated household's matched sample includes only control households with similar observable characteristics. Given that our measure of treatment intensity relies on the synthetic control's distribution of usage in the treatment period, it is important that each matched control household have similar usage patterns to the treated household in the pre-treatment period. The large number of control households and disaggregated nature of our data is ideal for this purpose, because it allows us to account for (b) with little to no impact on (a).

We index treated households by $i \in \{1, \ldots, n_1\}$, and control households by $j \in \{1, \ldots, n_0\}$. Formally, for each treated household i, the PSC framework solves the following quadratic program:

$$\min_{W_i \in \mathbb{R}^{n_0}} \|X_i - \sum_{j=1}^{n_0} W_{i,j} X_j\|^2 + \lambda \sum_{j=1}^{n_0} W_{i,j} \|X_i - X_j\|^2 \tag{1}$$

$$\text{s.t. } W_{i,j} \geq 0 \ \ \forall j = 1, \ldots, n_0$$

$$\sum_{j=1}^{n_0} W_{i,j} = 1.$$

The solution, $W_i^*(\lambda)$, is a set of weights that describe the matched sample among the n_0 control households for each treated household i. The tuning parameter, λ, balances the trade-off described above between considerations (a) and (b), described above. Larger values of λ correspond to more weight on ensuring that the characteristics of treated household i (X_i) are similar to the characteristics of each matched control household (X_j). We include eleven covariates that describe the level, variance, and composition of internet usage during the M_0 months in the pre-UBP period, as well as plan choice. Specifically, X includes: total internet usage in each of three pre-UBP months, variance in daily usage during the pre-UBP months, share of total pre-UBP usage in each of four categories (online video, web browsing, Netflix, and YouTube), whether the household subscribed to TV service, and which internet tier they chose at the start of the pre-UBP period.

We follow the leave-one-out cross-validation of post-intervention outcomes for the untreated approach of Abadie and L'Hour (2021) to identify the λ penalty values that minimize mean squared prediction error and bias. We find a value of $\lambda = 0.1$ is optimal, so this is our focus in the discussion of our results presented in section 5. We describe in greater detail the λ selection procedure in Appendix A. In Appendix B, we explore the robustness of our main results to the λ parameter. We find that results generated using alternative λ parameters are qualitatively similar to the case $\lambda = 0.1$.

4.2 Measuring Treatment Intensity and Effect

We use the solution to Equation (1) to estimate household-specific measures of treatment intensity for each treated household, which we relate to treatment effect estimates for a variety of household behaviors.

To construct the measure of treatment intensity, we first calculate a counterfactual cumulative distribution function describing usage in the absence of treatment. For each treated household ($i = 1, \ldots, n_1$), we calculate

$$\hat{F}_i (z; \lambda) = \frac{1}{M_1 n_0} \sum_{j=1}^{n_0} \sum_{m=1}^{M_1} \mathbb{1} \left[c_{jm} < z \right] W^*_{i,j}(\lambda), \tag{2}$$

where c_{jm} refers to the realized monthly usage of control household j during month m of the treatment period ($m = 1, \ldots, M_1$) and z is an arbitrary usage level. The expected monthly price increase from UBP in the absence of behavioral changes for household i, our measure of treatment intensity, is then

$$\hat{\rho}_i(\lambda) = \int_0^\infty \mathcal{O}(z) d\hat{F}_i(z; \lambda) \tag{3}$$

where $\mathcal{O}(z)$ are the overages associated with z GB of usage on household i's internet tier. Note that $\mathcal{O}(z)$ is the UBP billing schedule set by the MSO. In practice, this schedule is internet tier-specific. For treated household i, we use the billing schedule attached to the tier i selected in the pre-policy period. The resulting measure $\hat{\rho}_i(\lambda)$ can be interpreted like a price index because it places (probability) weights on the prices associated with different quantities, conditional on choices remaining fixed.

We define the effect of UBP on the subscription decisions of household i as

$$\hat{\tau}_i(\lambda) = y_i - \sum_{j=1}^{n_0} y_j W^*_{i,j}(\lambda) \tag{4}$$

where y_i is the outcome of interest. For example, for tier upgrades (downgrades), y_i equals 1 if household i upgrades (downgrades) during the treatment period and zero otherwise. Similarly, for TV adds (drops), y_i equals 1 if household i adds (drops) TV during the treatment period and zero otherwise. The resulting $\hat{\tau}_i(\lambda)$ measure captures the deviation in subscription decisions of household i from its synthetic control between the end of the pre-treatment period and the end of the sample. For outcomes like monthly usage and payments, we define the treatment effect similarly as,

$$\hat{\tau}_i(\lambda) = \frac{1}{M_1} \sum_{m=1}^{M_1} \left(y_{im} - \sum_{j=1}^{n_0} y_{jm} W^*_{i,j}(\lambda) \right), \tag{5}$$

to capture the average deviation of household i from its synthetic control across all months of the treatment period.

In Section 5, we examine the relationship between the household-specific measures of treatment intensity and effect, $\hat{\rho}_i(\lambda)$ and $\hat{\tau}_i(\lambda)$, respectively. This offers a systematic way of providing insight into the heterogeneous actions taken by households in response to the market-level introduction of UBP. To calculate standard errors for these measures and the relationships between them, we use block resampling with 200 repetitions. In particular, for each repetition we sample with replacement n_1 treated households (the entire block of each household's data), and similarly n_0 control households.[17]

[17]We use the entire population of treated households in this process, but each resampling of size n_0

5 Results

In this section, we describe our estimates of treatment intensity from the MSO's UBP policy ($\hat{\rho}_i(\lambda)$), and then we relate these measures to changes in treated households' subscription and usage choices under the UBP policy ($\hat{\tau}_i(\lambda)$). The relative magnitudes of households' subscription and usage responses allows us to break down the potential steering and metering effects caused by the MSO's UBP policy.

5.1 UBP Treatment Intensity

The average expected overage charge, calculated using Equation (3), is \$2.62. The distribution of $\hat{\rho}_i(\lambda)$ is highly skewed, with 85% of treated households with expected charges of less than \$1 if they remain on their pre-UBP subscriptions and usage trends. At the 95$^{\text{th}}$ percentile, the expected overage charge is \$16.76. We display the distribution of expected overages, conditional on the charge being greater than \$0 (17% of households), in Figure 5. While most households can meaningfully reduce overages by upgrading, the top few percentiles would incur overages even after upgrading if usage does not decrease.[18]

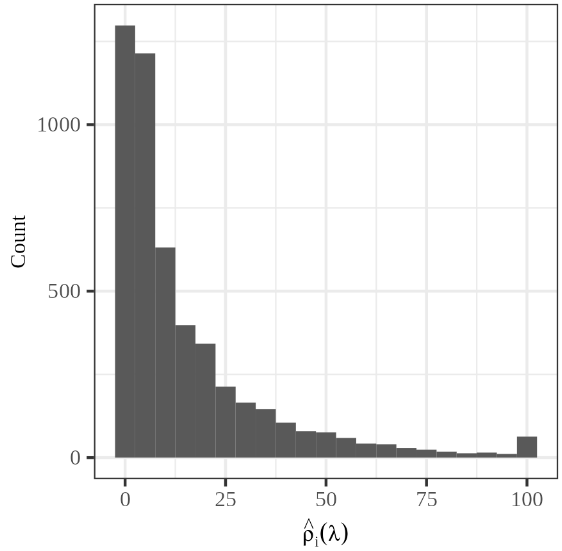
Our measure of treatment intensity is not a price that is actually paid by a household, but rather it is the additional cost associated with maintaining current behaviors in the post-UBP period as captured by the household's synthetic control. For example, two high-usage households may have substantially different expected overage charges, but each could avoid its charge by paying the same fee to upgrade to the next-highest internet tier or decreasing usage. For our purposes, it is worthwhile to describe the two households as ex-ante different (in expected overage, conditional on no upgrades or changes to usage behavior) rather as equivalent through realized payments under UBP.

In the remainder of this section, we examine the relationship between household-level

contains 20% of the control households. This has no measurable impact on the estimates, but makes the PSC calculations computationally tractable.

[18] If we calculate $\hat{\rho}_i(\lambda)$ using the allowance on the next highest tier instead of on the chosen tier, the 95$^{\text{th}}$ percentile is \$0.01, the 96$^{\text{th}}$ percentile is \$1.39, the 97$^{\text{th}}$ percentile is \$3.89, the 98$^{\text{th}}$ percentile is \$7.58, and the 99$^{\text{th}}$ percentile is \$17.47.

Figure 5: Distribution of Expected Overages



Notes: Histogram of household-level estimated expected overages, $\hat{\rho}_i(\lambda)$. The 83% of households with zero expected overage are not included in the figure.

treatment effects of interest and the expected overage distribution. Since the distribution of expected overages is continuous, it is helpful to describe this heterogeneity by taking local averages across households with similar expected overage levels. To this end, we construct visualizations using a kernel smoothing approach.

5.2 The Policy's Impact on Subscriptions

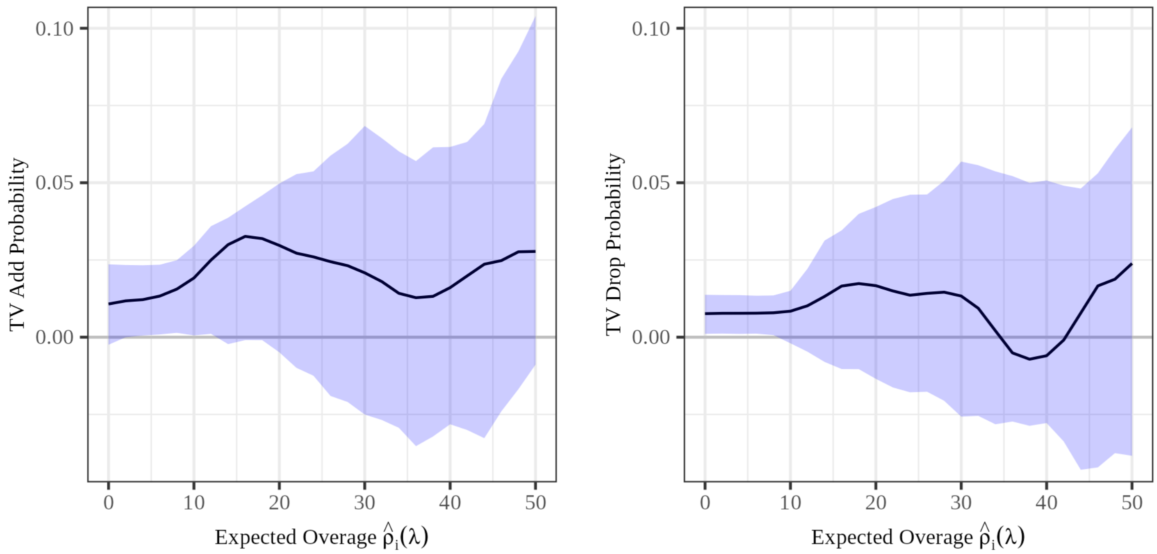
A prominent concern about UBP is that it may steer consumers toward bundles that include TV subscriptions, which might be more profitable for the MSO than internet-only subscriptions. In particular, the TV subscription may allow the MSO to capture consumers' surplus from content delivered through their TV service, while similar OTT content generates surplus that is captured, in part, by third-party OTT providers. If UBP is successful at steering consumers toward TV subscriptions, it would come at the cost of the otherwise-preferred OTT delivery and potentially harm third-party OTT providers.

The average treatment effect of the MSO's UBP implementation across all treated households without a TV subscription is a 0.014 (Std. Err.: 0.005) increase in the probability of adding TV during the treatment period, relative to the synthetic control. In Figure 6 panel (a) we describe heterogeneity in this effect, where the x-axis indicates the degree of exposure to the price change. The black curve is the local estimate of the treatment effect, $\hat{\tau}_i(\lambda)$, and the shaded area is a 95% confidence band. Consumers with zero or very small expected overages have a small and marginally significant response in TV subscriptions. This response increases slightly in magnitude and is statistically significant for households with expected overages in the range of about $5 to $20. This positive effect may be due to increased salience of prices for internet usage, or households perceiving greater risk of encountering future charges under UBP than we are able to capture with our approach to expected overages. While treated households with high expected charges under UBP have no statistically significant difference from matched control households, we note that the precision of these estimates decreases at higher expected overage levels, so we cannot rule out moderate effects.

For treated households who began the sample period with a TV subscription, the average effect of the observed UBP implementation is a 0.008 (Std. Err.: 0.003) increase in the probability of dropping TV during the treatment period. In Figure 6 panel (b), we show how decisions to drop TV subscriptions vary with $\hat{\rho}_i(\lambda)$. Among households with near-zero UBP exposure, treated households are significantly more likely to drop their TV subscriptions than control households, but this difference is quantitatively small. Per household, this effect is similar in magnitude to the corresponding difference in TV additions among internet-only treated households with nearly zero price exposure. For treated households with greater expected overage charges, there is generally no significant difference from the control market.

Although the introduction of UBP led treated households to change their TV subscription decisions, taken together, the countervailing effects resulted in little net effect on the MSO. After weighting the two effects by the share of households with a TV subscription, the net effect is approximately zero change in the TV share relative to the synthetic control baseline.

Figure 6: TV Subscription Changes by Expected Overage Level



(a) New Subscriptions

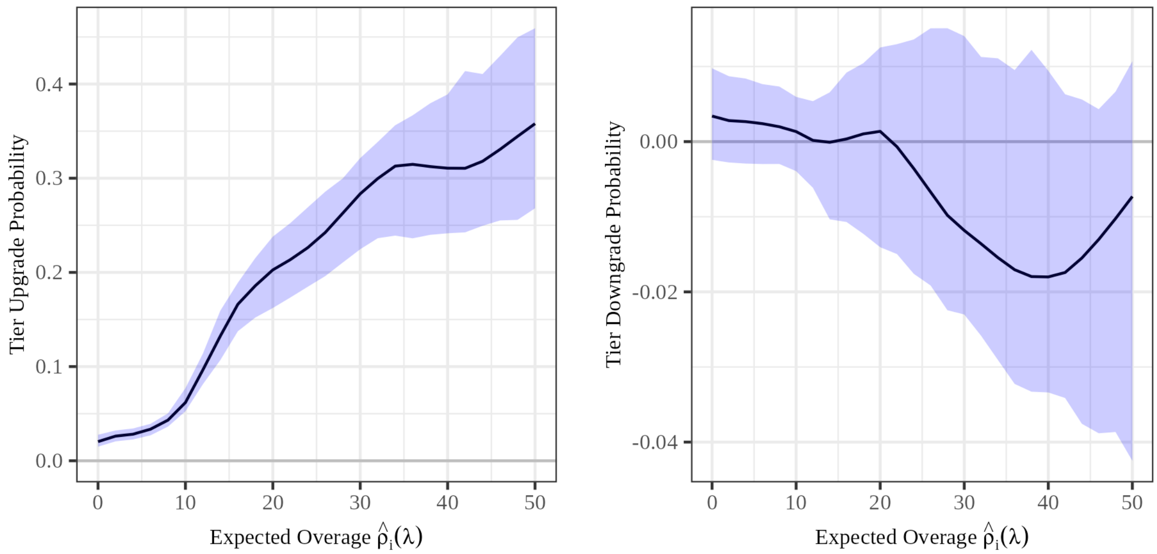
(b) Cancelled Subscriptions

Notes: Heterogeneity in the effect of the MSO's UBP policy on the take-up of TV subscriptions. Households that began the sample without a TV subscription are in panel (a); households with a TV subscription are in panel (b). The curves are smooth treatment effects, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block resampling with 200 permutations.

This net effect is inconsistent with concerns that commonly-implemented forms of UBP in the US have significant impacts as steering mechanisms.

While the implemented UBP had minimal effects on TV subscription choices, it had an economically meaningful impact on internet tier subscription decisions. The average household had a 0.043 (Std. Err.: 0.003) increase in probability of shifting to a higher-allowance tier during the treatment period. In Figure 7, we display the changes in the propensity to upgrade and downgrade tier for different levels of UBP price exposure. Panel (a) shows that the implemented UBP had a positive but small impact on upgrading decisions for treated households with near-zero price exposure, and as exposure increased the propensity to upgrade did as well. Where expected overage charges were nontrivial, treated households responded meaningfully. A \$10 expected overage corresponded to a 0.062 increase in the probability of upgrading tiers. In the higher range of expected UBP exposure, the effects were substantially larger. A \$20 expected overage corresponded to a 0.203 increase in prob-

Figure 7: Internet Tier Changes by Expected Overage Level



(a) Tier Upgrades (b) Tier Downgrades

Notes: Heterogeneity in the effect of UBP on the internet tier choice decision. Households that began the sample on the highest internet tier are omitted from panel (a); households on the lowest internet tier are omitted from panel (b). The curves are smooth treatment effects, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block resampling with 200 permutations.

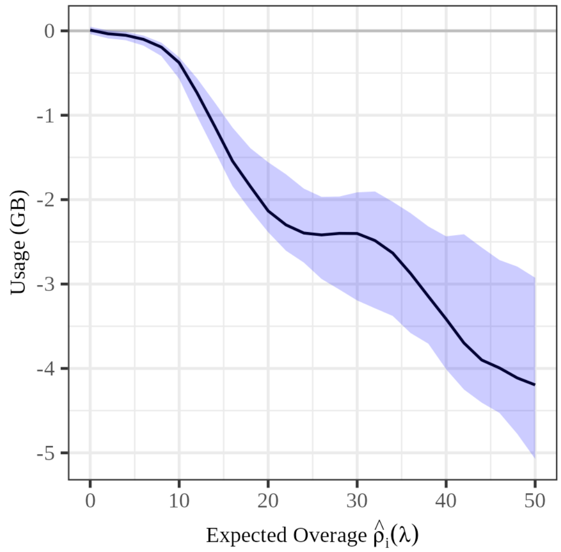
ability of upgrading, while a $30 expected overage increased the probability of upgrading by 0.283. These outcomes are evidence that the MSO's UBP policy acted as a form of metering, sorting higher-demand households into higher-priced tiers.

We also examine tier-downgrade decisions in response to UBP. The average effect across all households was indistinguishable from zero, and in Figure 7 panel (b) we show that there was generally no economically or statistically significant response heterogeneity.

5.3 The Policy's Impact on Internet Usage

In addition to impacts on subscription choices, UBP may affect households' internet usage in several ways. If a household with relatively high usage stays with its initial internet tier under UBP, it may decrease usage so it does not incur overage charges. This would imply some (perhaps modest) utility loss for the household, and a traffic reduction for third-party

Figure 8: Internet Usage by Expected Overage Level

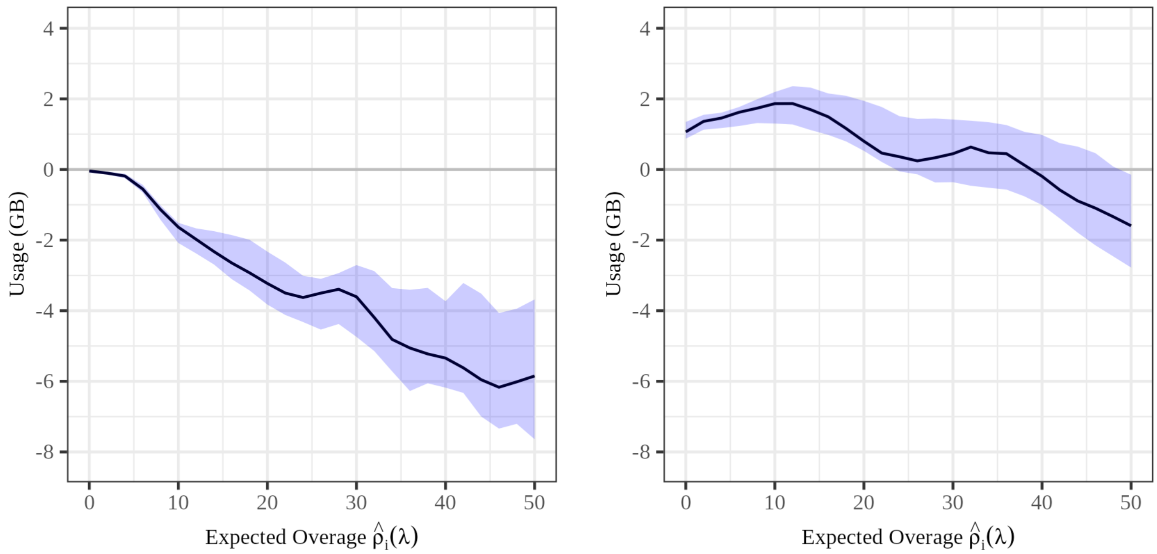


Notes: Heterogeneity in the effect of UBP on overall daily internet usage. The curve is a smooth treatment effect, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block resampling with 200 permutations.

firms. If a similar household upgrades its tier to maintain its existing usage, this represents a transfer from the household to the MSO, but the household and third-parties may benefit from a greater speed. We display the overall effect of the price change on usage levels in Figure 8, then decompose the overall effect in the two panels of Figure 9, which displays usage changes separately for households that did not (panel a) or did (panel b) upgrade their internet tier.

The average treatment effect across all households is a 0.24 GB (Std. Err.: 0.032) reduction in daily usage, a 6% reduction from the synthetic control baseline. For households that did not upgrade their internet tier, responses to UBP are zero or significantly negative, as would be expected. For example, households with a \$10 expected overage level reduced their internet usage by 0.6 GB (12%) if they did not upgrade. Households with expected overages of \$20 reduced their internet usage by 3.1 GB (25%) on average if they did not upgrade.

Figure 9: Internet Usage by Expected Overage Level and Upgrade Decision



(a) No Tier Upgrade

(b) Tier Upgrade

Notes: Heterogeneity in the effect of the implemented UBP on overall daily internet usage. Households that did not upgrade to a higher internet tier are described in panel (a); households that upgraded their internet tier are described in panel (b). The curves are smooth treatment effects, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block resampling with 200 permutations.

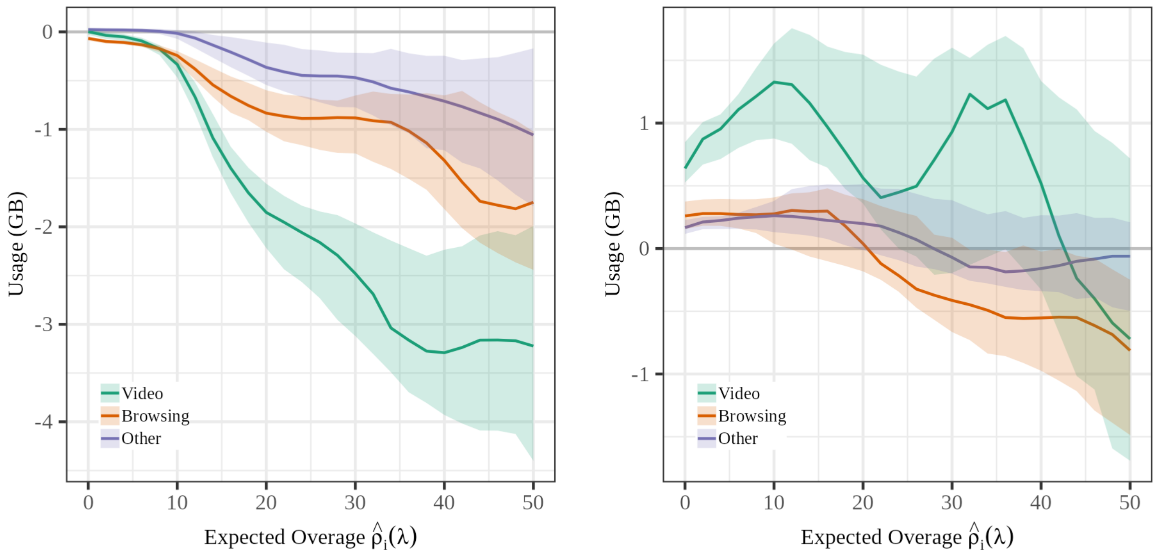
In panel (b), we show the usage responses of households that move to a higher-allowance tier. These households valued continuing their internet usage above the incremental price of increasing their tier, and most households display a significant increase in total GB used. A prominent mechanism for usage increases is the greater speed of a higher tier, which typically generates an automated response from bandwidth-adaptive applications. This can increase usage in GB even if the household spends no additional time using the internet. In addition, the increased bit rate may be valued by households because of increased video resolution or reduced download times. For households with the greatest price exposure, we find a usage reduction for households that upgrade. These households have predicted usage so great that, without further reduction, they risk exceeding the usage allowance of their new internet tier.

Overall, the 0.24 GB reduction in daily usage can be decomposed to a 0.093 GB (Std. Err.: 0.022) reduction in video usage, a 0.148 GB (Std. Err.: 0.015) reduction in web browsing, and a 0.003 (Std. Err.: 0.015) GB reduction in other traffic. We show this usage change decomposition by application in Figures 10 and 11. In Figure 10, we display usage changes, again separated by tier upgrading choices, for video, browsing, and other internet usage. In panel (a), we show that video usage reductions accounted for most of the usage declines among households that did not upgrade their internet tiers. These impacts of the implemented UBP, measured as daily GB changes, reflect both the pre-policy usage levels and magnitudes of reduction. In percentage terms, the reductions in usage types are quite similar to each other. The reduction in video usage is consistent with some concerns about how an MSO may use UBP to steer consumers toward its TV service, but our results in Figure 6 suggest that consumers were not responsive on the extensive margin of TV subscriptions.[19] Our results in Figure 10 panel (b) show that the usage increases in Figure 9 panel (b) were largely concentrated in video applications. This is consistent with a mechanism for increased usage we described above, as video applications have both greater benefits from increased bit rates (through higher-definition video) and are likely to be bandwidth-adaptive.

In Figure 11, we provide a further decomposition of usage changes. We separate video usage into four categories: Netflix, YouTube, Hulu or Sling TV (combined), and all other video. Despite Netflix's position as the largest category of video usage (see Table 1), its usage reductions are smaller in magnitude than YouTube or other video among households that did not upgrade their internet tier. This suggests that Netflix has a relatively high value among video categories: when treated households perceived a need to reduce video usage, they chose to focus their reductions on video categories other than Netflix. Changes to Hulu and Sling TV, which are near zero in Figure 11 panel (a), are partially due to their small average usage in the population, but households' utility for the services may play a role, as in the case of Netflix.

[19] We do not observe households' TV viewing activity. If households substitute on the intensive margin from streaming video to the MSO's TV service, this could raise the value of MSOs' TV offerings. For example, a sustained increase in TV viewing may allow an MSO to receive more revenue from the local ad slots it fills in network programming, contributing to both the metering and steering effects of UBP. Back of the envelope calculations that convert the observed decrease in internet usage to a potential increase in TV ad revenue suggest a modest increase in TV revenue, in the range of \$0.02-\$0.37 per household-month. Alternatively, households may also choose to reduce bit rates for video applications to reduce the usage required for a given viewing period. We defer this issue to future research.

Figure 10: Composition of Internet Usage by Expected Overage Level and Upgrade Decision



(a) No Tier Upgrade

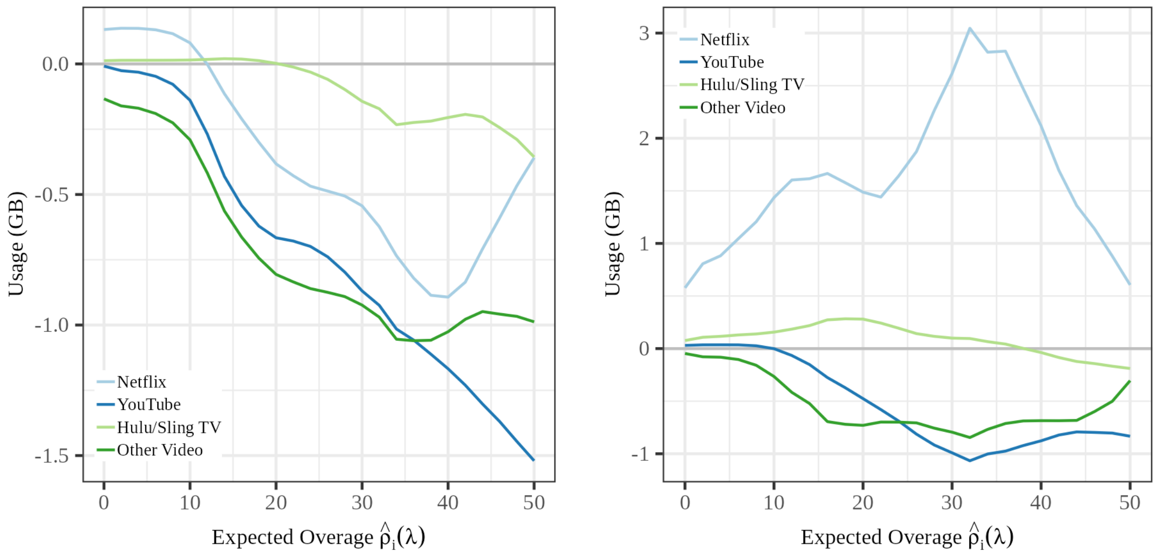
(b) Tier Upgrade

Notes: Heterogeneity in the effect of the implemented UBP on daily internet usage by category. The 3 categories are mutually exclusive and collectively exhaustive. Households that did not upgrade to a higher internet tier are described in panel (a); households that upgraded their internet tier are described in panel (b). The curves are smooth treatment effects, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block resampling with 200 permutations.

In Figure 11 panel (b), we display usage changes by video category for households that upgraded their internet tiers. Netflix usage increased significantly for households at all expected overage levels, including those with near-zero price exposure. Netflix's applications automatically adapt their data usage to provisioned speeds, so this channel is one likely explanation for increased Netflix usage. In addition, improved video resolution may increase Netflix's appeal relative to YouTube and applications in the 'other video' category, which each have usage decreases for high levels of expected overages.

Averaging across all households, the implemented UBP led to a 0.171 GB (Std. Err.: 0.020) increase in daily Netflix consumption, a 0.075 GB (Std. Err.: 0.011) decrease in YouTube consumption, a 0.015 GB (Std. Err.: 0.006) increase in Hulu/Sling TV consumption, and a 0.204 GB (Std. Err.: 0.010) decrease in the consumption of all other online video applications.

Figure 11: Online Video Usage by Expected Overage Level and Upgrade Decision



(a) No Tier Upgrade

(b) Tier Upgrade

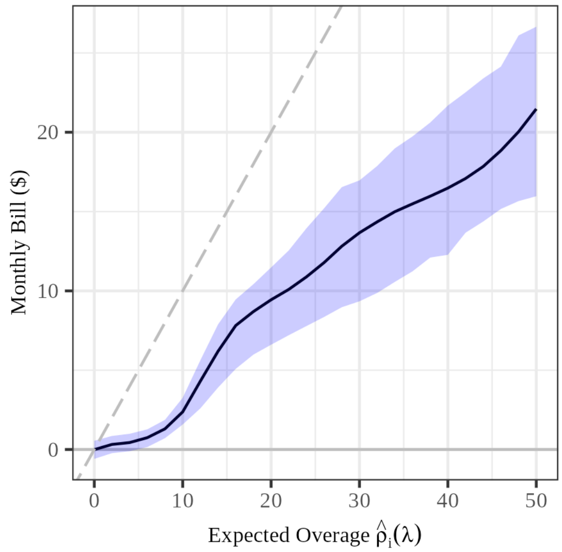
Notes: Heterogeneity in the effect of the implemented UBP on daily online video usage. The 4 categories are mutually exclusive and collectively exhaustive. Households that did not upgrade to a higher internet tier are described in panel (a); households that upgraded their internet tier are described in panel (b). The curves are smooth treatment effects, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. We omit confidence bands for readability.

5.4 The Policy's Impact on Payments to the MSO

Several of the responses to the introduction of UBP, such as subscription changes and overage charges, affect households' payments to the MSO. We conclude our analysis by describing the distribution and magnitudes of changes to subscribers' payments due to the MSO's UBP policy.

The average household's monthly bill increased by \$1.28 (Std. Err.: 0.27) on top of an average bill of \$152.89. In Figure 12, we show how treated households with varying exposure to UBP changed their payments to the MSO, relative to control households. We find that the 83% of households with near-zero expected overages had no change in their payments to the MSO. For greater levels of $\hat{\rho}_i(\lambda)$, additional payments to the MSO increase monotonically. Households with \$10 in expected overage make additional payments of \$2.37, while those with \$20 and \$30 in expected overages pay \$9.44 and \$13.66 more per month, respectively.

Figure 12: Change in Payments by Expected Overage Level

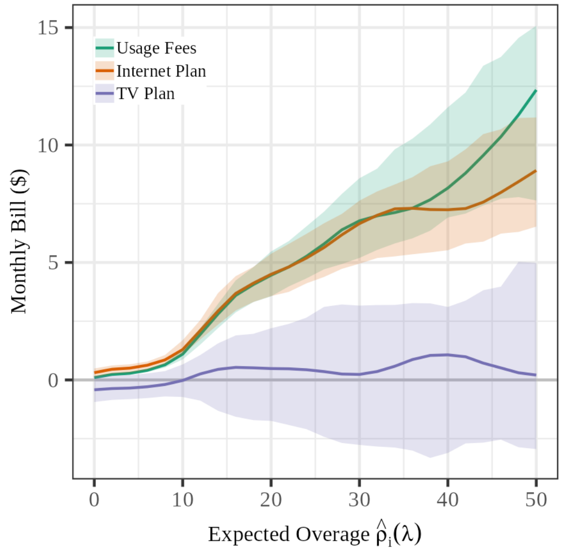


Notes: Heterogeneity in the effect of the implemented UBP on monthly bill level. The curve is a smooth treatment effect, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block re-sampling with 200 permutations. The dashed line identifies where the expected overage charges and the realized monthly bill increase would be equal.

Payments to the MSO are increasing in the expected overage estimates, but actual payments are much less than our estimated cost without behavioral changes, i.e., $\hat{\rho}_i(\lambda)$. This is because treated households' actual payments allow for re-optimization, which can include upgrading the internet tier or reducing usage, while the expected overage values assume that behavior continues according to their matched sample of control households.

In Figure 13, we show how treated households' additional payments are divided among realized overage charges, internet tier upgrades, and changes to TV subscriptions. At all levels of the expected overage distribution, overage charges and upgrade fees each contribute similar amounts to the overall change in payments reported in Figure 12. Changes to TV subscription payments are indistinguishable from zero, which is in line with the estimates of subscription changes reported in Figure 6. Households with the greatest values of $\hat{\rho}_i(\lambda)$ are the exception to the patterns described above. We find that these households pay more in

Figure 13: Change in Payments by Expected Overage Level

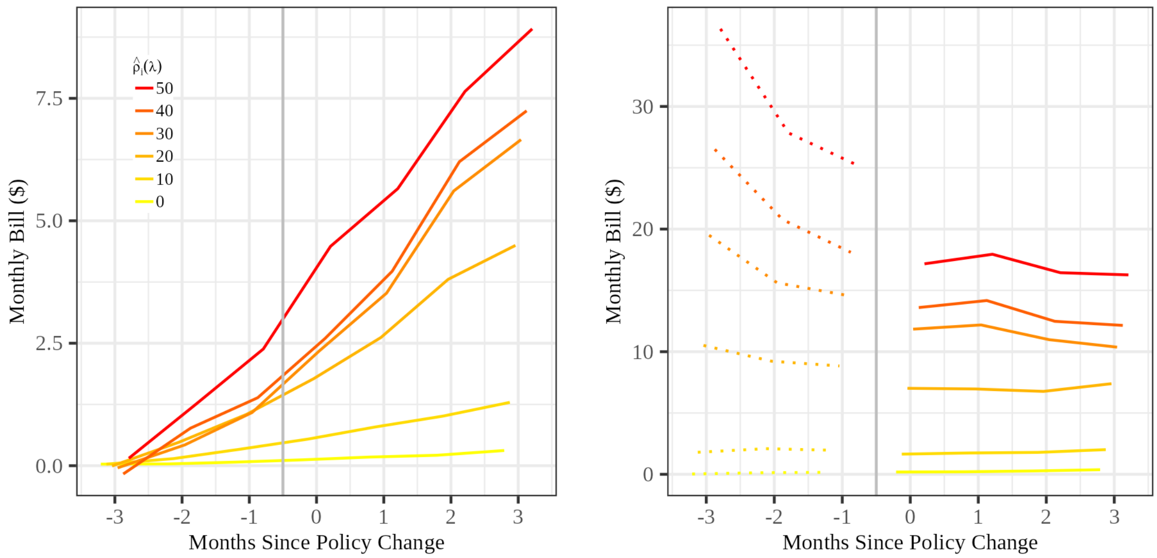


Notes: Heterogeneity in the effect of the implemented UBP on monthly bill level. The curves are smooth treatment effects, computed using the kernel-weighted average of $\hat{\tau}_i$ across households. 95% confidence bands are calculated using block resampling with 200 permutations.

additional usage fees versus internet tier upgrades. This could be due to especially heavy internet usage being a transient phenomenon for households. In these cases, it may be worthwhile to pay overage charges while demand is high rather than making a commitment to an internet tier that would accommodate all of their usage. Other households in this situation may already be on the tier with the greatest allowance.

During the initial implementation of UBP, we observe some notable changes to the composition of the additional revenue. In Figure 14, we show initial trends in payments of the two types of internet charges we highlight above. Additional payments by treated households for internet tier upgrades, displayed on the left, rise steadily through the announcement and treatment periods. Households with greater expected overages make greater additional payments for tier upgrades throughout this portion of the sample period. Overage charges, displayed on the right, fall slightly over time for households with the highest expected overages, while charges for treated households with lower expected overages rise slightly over time

Figure 14: Change in Payments by Month



(a) Internet Plan

(b) Usage Fees

Notes: Change in internet subscription fees and usage fees during the sample. Each line is a slice of the expected overage distribution across households. Pre-policy change usage fees (dotted line) are the implied usage fees had the policy change been in effect. No usage fees were billed until month 0.

or remain flat. Differences in levels and changes are generally small among these households. In general, consistent with optimizing behavior by consumers, overage charges are less than the typical price to upgrade the internet tier.

6 Conclusion

Usage-based pricing of internet access has attracted scrutiny because of its potential to shift consumers' choices on several margins and reallocate surplus from consumers and third-party content providers to MSOs. Despite attention from policymakers and other interested parties, there has been little prior empirical research to evaluate UBP's steering and metering impacts. We use novel panel data on an MSO's introduction of UBP to measure its effects on consumers, third-party content sources, and MSO revenue. We exploit highly detailed subscription and usage data on treated households, to whom UBP was introduced, and matched control households to construct measures of heterogeneous treatment intensity and effects.

We find that consumers facing nontrivial charges under UBP responded meaningfully to the policy, largely through their internet subscriptions and usage. A significant share of consumers facing a high cost of inaction upgraded their internet tiers to accommodate their internet usage, while other "in the money" consumers reduced their usage in order to limit overage charges while remaining in their original tiers. Thus, the UBP implementation we observed served as an effective instrument for metering households' internet demand, prompting greater payments to the MSO from households that value usage most. Notably, we uncover two results in our setting that are contrary to some warnings about UBP. First, despite concerns that UBP will disproportionately affect OTT, we find no meaningful difference between OTT and other internet content when consumers reduced usage under UBP. Second, under the observed policy design, UBP was ineffective in steering consumers toward the MSO's TV service. In total, the UBP implementation we study primarily served to transfer surplus from consumers to the firm, which we observe through increases in the MSO's revenue from overage fees and tier upgrades. A different UBP implemention – for example, one with higher overage charges or one that only applies to internet-only plans – might yield a different conclusion. We study issues related to MSO incentives and alternative UBP policy design in McManus et al. (2024).

There are a number of issues that remain for future research. Despite the richness of our data, more detail is required to understand how the increasingly complex relationships between MSOs and content providers impact their pricing and steering incentives. MSOs that are vertically integrated with content producers may have a greater incentive to use pricing to steer customers towards their TV service, or they may implement non-neutral pricing that favors their content. The recent growth of stand-alone streaming services has also altered MSOs' incentives. Given OTT's popularity, MSOs may focus on strategies to capture surplus from these services rather than steer customers toward their TV services.

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Appendix A Penalty Selection

To select an appropriate value of the tuning parameter λ, we follow the leave-one-out cross-validation approach of post-intervention outcomes for the untreated approach described in Abadie and L'Hour (2021). Specifically, for each candidate λ and each control household j, we implement the PSC procedure to construct a synthetic control for household j from a donor pool comprised of all other control households (i.e., the donor pool for household j is $\{1, \ldots, n_0) \setminus j)$. We then calculate the "treatment effect,"

$$\tilde{\tau}_j(\lambda) = \sum_{k \neq j,\, k=1}^{n_0} \left[\frac{1}{M_1} \sum_{m=1}^{M_1} \left(y_{jm} - y_{km} W^*_{j,k}(\lambda) \right) \right],$$

where the outcome of interest y_{im} is the monthly usage of household i during UBP period month m.

We use these estimates to identify the values of λ that minimize mean squared prediction error and bias, where prediction error and bias are defined as follows:

$$\text{RMSE}(\lambda) = \left(\frac{1}{n_0} \sum_{j=1}^{n_0} \tilde{\tau}_j(\lambda)^2 \right)^{1/2}$$

$$\text{Bias}(\lambda) = \left| \frac{1}{n_0} \sum_{j=1}^{n_0} \tilde{\tau}_j(\lambda) \right|.$$

In Table 3, we describe the results of the exercise for 6 values of λ, including prediction error, bias, and the density of the estimated synthetic control weights. For a given λ, each density statistic describes the distribution across synthetic controls of the count of units in the donor pool that receive positive (non-zero) weight.

Table 3: Cross-Validation Results

			Density		
λ	$\lvert\text{Bias}(\lambda)\rvert$	RMSE(λ)	Min	Median	Max
$\to 0$	29.77	106.91	1	1130	3474
0.001	1.05	95.65	1	7	11
0.01	1.19	95.37	1	7	10
0.1	0.26	95.97	1	5	9
1	0.02	103.32	1	3	7
10	0.93	113.52	1	1	4

Appendix B Robustness

The estimates reported in the main text are obtained by fixing the λ parameter at 0.1. In this section, we describe the sensitivity of pre-treatment fit and the robustness of the estimates reported in the main text to alternative values of λ.

B.1 Fit and Treatment Effects

In Panel I of Table 4, we report the mean levels of the 11 pre-treatment covariates used in the construction of the synthetic controls across treated households, untreated households, and five alternative synthetic controls.

In Panel II of Table 4, we report the distribution of household-level usage treatment effects ($\hat{\tau}_i(\lambda)$) and expected overages $\hat{\rho}_i(\lambda)$ for each set of alternative synthetic controls.

Table 4: Fit and Estimates for Alternative λ Penalties

Panel I: Pre-treatment Fit

			Synthetic Control				
	Treated	Untreated	$\lambda = 0.001$	$\lambda = 0.01$	$\lambda = 0.1$	$\lambda = 1$	$\lambda = 10$
Usage Month 1	92.26	130.36	92.38	92.39	92.18	91.28	91.00
Usage Month 2	90.90	130.84	91.19	91.27	91.37	90.70	90.39
Usage Month 3	101.90	140.55	102.42	102.39	101.75	100.01	99.56
Share Video	0.45	0.52	0.45	0.45	0.45	0.45	0.45
Share Browsing	0.43	0.36	0.43	0.43	0.43	0.43	0.43
Share Netflix	12.20	5.37	10.36	10.33	9.98	9.47	9.31
Share YouTube	8.30	3.65	7.05	7.03	6.79	6.44	6.34
Share Linear OTT	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Usage Variance	17.40	23.07	17.27	17.30	16.36	14.39	13.75
Has TV	0.78	0.70	0.78	0.78	0.78	0.78	0.78
Internet Tier	2.82	3.07	2.82	2.82	2.82	2.82	2.82

Panel II: Estimates

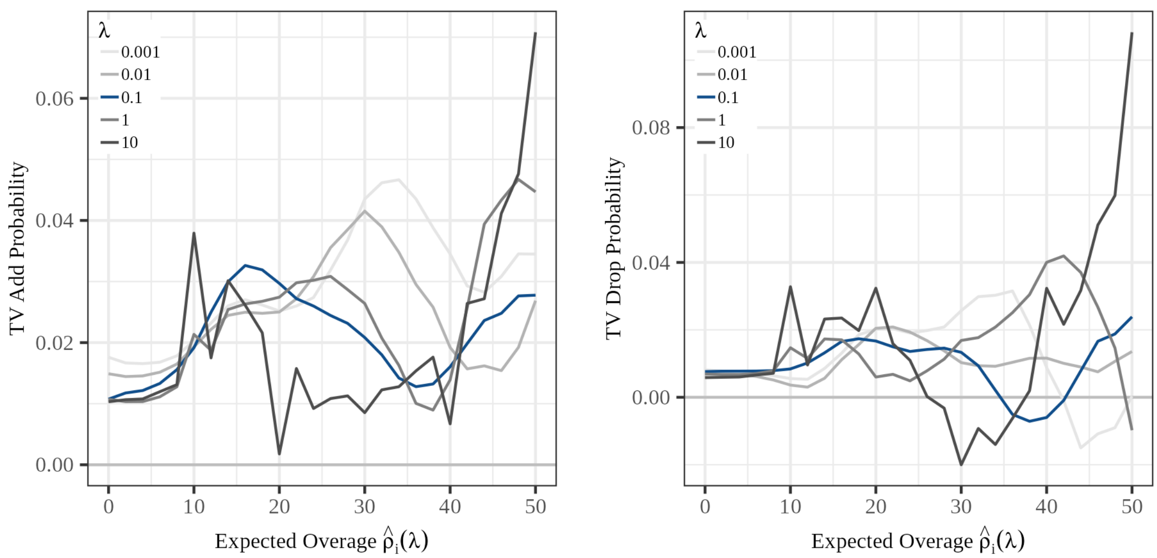
			Synthetic Control				
	Treated	Untreated	$\lambda = 0.001$	$\lambda = 0.01$	$\lambda = 0.1$	$\lambda = 1$	$\lambda = 10$
Usage Treatment Effect							
Mean	.	-53.60	-0.24	-0.24	-0.24	-0.22	-0.21
SD	.	.	2.77	2.74	2.73	2.82	3.11
5th Ptile	.	.	-3.87	-3.92	-3.96	-4.31	-4.91
10th Ptile	.	.	-2.41	-2.45	-2.51	-2.71	-3.05
Median	.	.	-0.10	-0.11	-0.11	-0.09	-0.05
90th Ptile	.	.	1.88	1.90	1.93	2.07	2.34
95th Ptile	.	.	3.34	3.37	3.44	3.64	3.99
Expected Overages							
Mean	.	.	3.33	3.04	2.65	2.25	2.16
SD	.	.	13.97	12.74	11.43	10.13	10.85
Median	.	.	0.00	0.00	0.00	0.00	0.00
90th Ptile	.	.	7.23	6.45	4.89	2.01	0.00
95th Ptile	.	.	20.14	19.03	16.76	13.70	10.00

Notes: Panel I: household-level averages of pre-treatment matching variables for treated households, untreated households, and five sets of synthetic controls. Panel II: distribution of household-level estimated usage treatment effects and expected overages for five sets of synthetic control. Untreated treatment effect is a simple average difference between treated and untreated households.

B.2 Main Results

In the figures below, we show how the main results change when the λ parameter is set to different levels. We first re-estimate expected overages and treatment effects using alternative values of λ, then replicate the main results figures using these new estimates. Figure 15 corresponds to Figure 6 of the main text, Figure 16 corresponds to Figure 7 of the main text, Figure 17 corresponds to Figure 8 of the main text, and Figure 18 corresponds to Figure 12 of the main text.

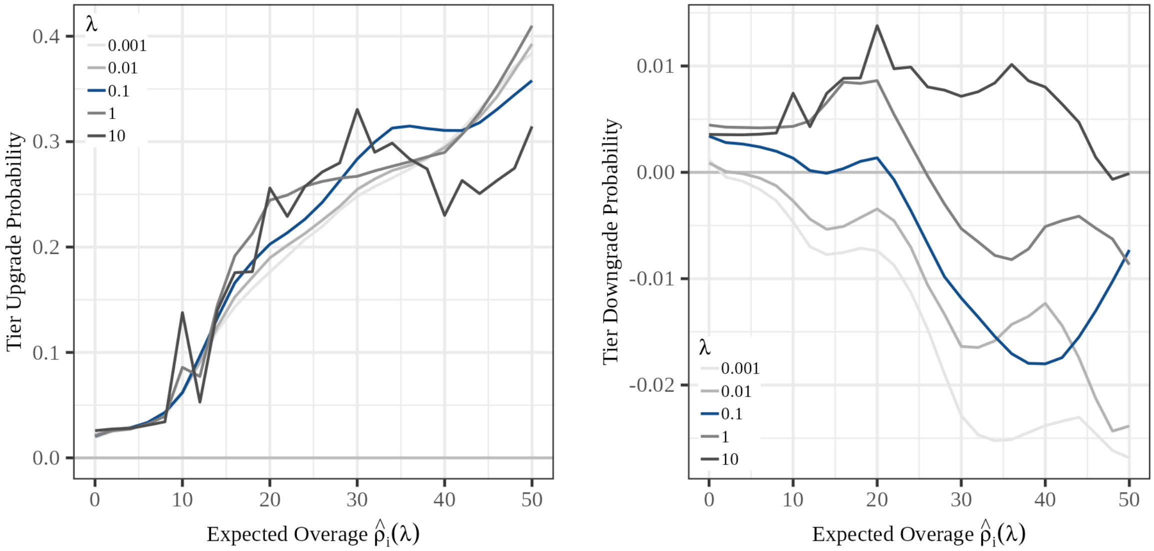
Figure 15: TV Subscription Changes by Expected Overage Level



(a) New Subscriptions (b) Cancelled Subscriptions

Notes: Heterogeneity in the effect of UBP on the take-up of TV subscriptions. Households that began the sample without a TV subscription are in panel (a); households with a TV subscription are in panel (b). Each curve is a smooth treatment effect, computed using the kernel-weighted average of $\hat{\tau}_i(\lambda)$ across households.

Figure 16: Internet Tier Changes by Expected Overage Level

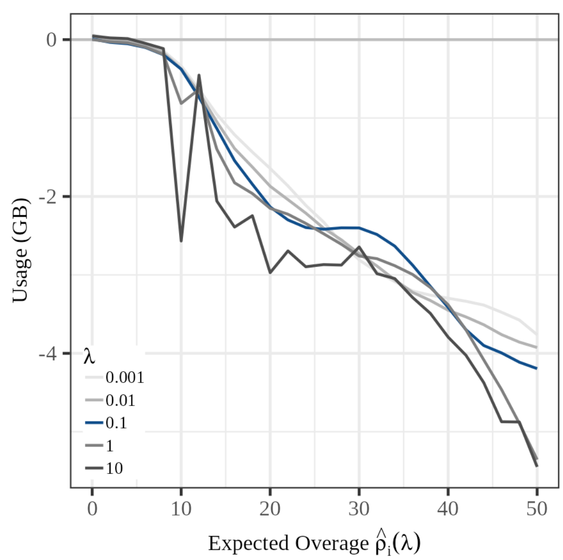


(a) Tier Upgrades

(b) Tier Downgrades

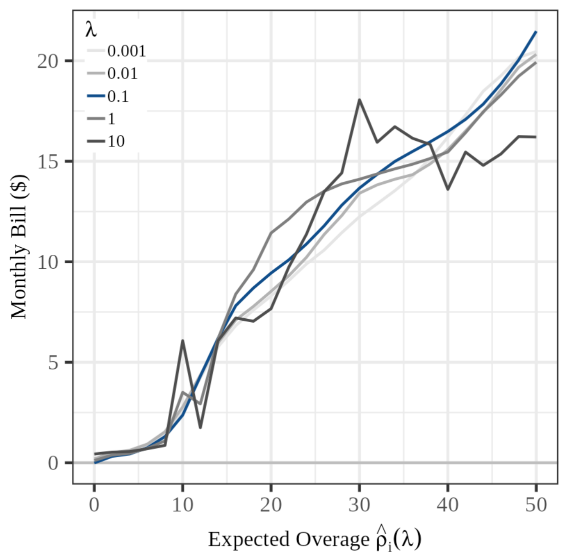
Notes: Heterogeneity in the effect of UBP on the internet tier choice decision. Households that began the sample on the highest internet tier are omitted from panel (a); households on the lowest internet tier are omitted from panel (b). Each curve is a smooth treatment effect, computed using the kernel-weighted average of $\hat{\tau}_i(\lambda)$ across households.

Figure 17: Internet Usage by Expected Overage Level



Notes: Heterogeneity in the effect of UBP on overall daily internet usage. Each curve is a smooth treatment effect, computed using the kernel-weighted average of $\hat{\tau}_i(\lambda)$ across households.

Figure 18: Change in Payments by Expected Overage Level



Notes: Heterogeneity in the effect of UBP on monthly bill level. Each curve is a smooth treatment effect, computed using the kernel-weighted average of $\hat{\tau}_i(\lambda)$ across households.