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A CRITICAL SURVEY OF THE LITERATURE ON BROADBAND DATA CAPS

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Abstract

Proponents and opponents of data caps make conflicting claims about the effect of data caps on prices, network capacity and speeds, subscription, congestion, and consumer surplus. In this paper, we survey the academic literature on data caps and analyze the relationship between the characteristics of each paper's model or data and the paper's results. We find that model or data assumptions about service differentiation, purpose of the data cap, and amount of competition strongly influence each paper's results. Consequently, conclusions about the effect of data caps are often limited to certain types of service providers (fixed or mobile) and/or to certain types of data caps (heavy-users or profit-maximizing). We find that most proponents' claims about data caps in fixed broadband service are incorrect, and that most proponents' claims about data caps in mobile broadband service are likely to be correct if and only if data caps increase competition. We also discuss how data caps may be evaluated under the FCC's 2015 Open Internet Order. We find that heavy-users caps on mobile broadband service are likely to satisfy the Order's rules, that profit-maximizing caps on mobile broadband service may or may not satisfy the rules, and that caps on fixed broadband service are unlikely to satisfy the rules.

Keywords: Broadband Internet access service; data caps; usage-based pricing; network management; Open Internet.

1. Introduction

Starting in 2010, most mobile broadband Internet access service providers in the United States instituted monthly data caps in most of their service plans. In addition, many fixed broadband Internet access service providers (often referred to as Internet Service Providers) have instituted monthly data caps in many of their service plans. The United States Government Accountability Office (GAO) found in 2014 that the four largest mobile broadband providers and seven of the thirteen largest fixed broadband providers used monthly data caps (GAO Report, 2014). Subscribers whose usage exceeds a data cap are typically either subjected to overage charges or reduced speeds. Recently, many mobile broadband providers re-introduced plans that they brand as "unlimited". However, those "unlimited" plans usually throttle users whose monthly usage exceeds a threshold.[1]

The use of monthly data caps by broadband Internet access service providers has been an issue of public policy debate ever since their introduction. The Federal Communications Commission's Open Internet Advisory Committee (FCC OIAC) reported in 2013 on policy issues that arise from data caps (FCC OIAC Report, 2013). The Committee's report discussed often conflicting perceptions of various stakeholders over fairness between light and heavy users; correlation between monthly usage and peak period usage; the role of data caps in managing congestion, managing network growth, and as a price discrimination tool; and competition issues.

Proponents and opponents of data caps make claims that appear to conflict with each other about almost every aspect of data caps, as summarized in Table 1:

- Purposes: Proponents of data caps, including the broadband providers, usually claim that their purpose is to manage congestion, to increase fairness, and to recover the cost associated with heavy users. Opponents of data caps often express skepticism that data caps effectively manage congestion, doubt that broadband

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[1] Since the frequency, duration, and effect of this throttling remains largely unknown to the public, it remains unclear whether such "unlimited" plans bear a closer resemblance to plans with data caps than to unlimited plans without throttling.

providers are using data caps to recover the cost associated with heavy users, and claim that broadband providers are using data caps to increase profit and to protect incumbent pay-television services.

- Prices: Proponents of data caps often claim that the use of data caps results in lower service prices, at least for entry level plans. Opponents often claim that the use of data caps monetizes scarcity and does not result in lower service prices.
- Capacity and speeds: Proponents of data caps often claim that the use of data caps results in greater network capacity than would exist without the use of data caps, and that the increased capacity and lower usage by heavy users results in higher download and upload speeds. Opponents often claim that the use of data caps either does not impact network capacity or incentivizes broadband providers to lower network capacity to further monetize scarcity.
- Subscription: Proponents of data caps often claim that data caps increase broadband Internet subscription. Opponents generally disagree.
- Congestion: Proponents of data caps often assert that data caps affect a small proportion of users, that data caps are high enough so that they don't affect typical consumer use, and that regulating monthly usage reduces congestion. Opponents worry that over time data caps will affect a large proportion of users, that data caps are low enough to discourage subscribers of cable television services from discontinuing that service in favor of over-the-top video, and that monthly data caps do not reduce congestion.

After making various claims about the effect of data caps on service prices, speeds, capacity, subscriptions, usage, and congestion, proponents and opponents ultimately disagree about whether data caps are in the public interest. Proponents often believe that data caps increase consumer surplus, or if not then at least increase social welfare. Opponents invariably believe data caps decrease consumer surplus.

Table 1. Claims about the effects of data caps.

	Proponents	**Opponents**
Purpose	Manage congestion, increase fairness, recover cost associated with heavy users.	Increase profit, protect incumbent pay-television services.
Prices	Lower service prices, at least for entry level plans.	No change in service prices.
Capacity and speeds	Greater network capacity, higher download and upload speeds.	No change, or lower, network capacity.
Subscriptions	Increased broadband subscription.	No change or decrease in broadband subscription.
Usage, congestion, and fairness	Reduced congestion, increased fairness.	No reduction in congestion, unfairly discourages discontinuing pay-television service.
Consumer surplus	Increased consumer surplus, or at least increased social welfare.	Decreased consumer surplus.

After the better part of a decade of conflicting claims, the academic literature should be able to lend some light on most of the apparent discrepancies. The goal of this paper is to provide a critical survey of both the claims and the academic literature on the use of data caps in broadband Internet access service. Our survey includes:

- Papers that draw from the general economics literature to predict the impact of data caps: Bauer and Wildman 2012, Economides and Hermalin 2015, Howell and Layton 2016, Lyons 2013, Odlyzko et al. 2012, and Rogerson 2016.
- Papers that have presented empirical results from the use of data caps by various fixed and mobile broadband providers: Blackburn et al. 2013, Chetty et al. 2012, Felten 2011, Fukuda et al. 2015, Gyarmati et al. 2012, Hussain et al. 2012, Joe-Wong et al. 2015, Lambrecht et al. 2007, Malone et al. 2014, Minne 2013, and Poularakis et al. 2014.
- Papers that have proposed analytical models of data caps to analyze the effect of data caps
    - on various characteristics of broadband service plans: Bauer and Wildman 2012, Dai and Jordan 2015, Dai et al. 2014, Economides and Hermalin 2015, Nevo et al. 2016, Poularakis et al. 2014, and Wang et al. 2016.
    - on subscription: Bauer and Wildman 2012, Dai and Jordan 2015, and Dai et al. 2014
    - on congestion: Bauer and Wildman 2012, Dai and Jordan 2015, Dai et al. 2014, Nevo et al. 2016, Odlyzko et al. 2012, and Wang et al. 2016.

- on welfare: Bauer and Wildman 2012, Dai and Jordan 2015, Dai et al. 2014, Economides and Hermalin 2015, Ford 2012, and Nevo et al. 2016

The papers surveyed are listed in Table 2. For each paper, the table lists the type of model or data and a summary of relevant results. The table also shows the source of support for purposes of transparency, if acknowledged in the paper or provided upon request by the author; we note that the results sometimes support the interests of a financial sponsor. The results are discussed in Sections 3-7.

Table 2. Summary of surveyed papers.

Paper	Support	Model or Data	Relevant Results
Bauer and Wildman 2012	National Cable & Telecommunications Association	Theoretical examples.	Data caps lower service prices, increase broadband deployment and aggregate network capacity, increase subscription, and increase consumer surplus.
Blackburn et al. 2013	Telefonica Research Barcelona	Usage in 2009-2012 of 1 million customers of a mobile broadband provider.	20% of mobile users had usage exceeding associated cost.
Chetty et al. 2012	Microsoft Research; NSF	Survey of 12 households in South Africa.	Uncertainty over usage poses substantial challenges.
Dai and Jordan 2015	NSF	Model of consumer subscription, usage, and utility. Model of monopoly broadband provider pricing. Model of capacity and congestion.	Profit-maximizing data caps are more stringent than heavy-users caps. Heavy-users caps do not significantly change service prices. Profit-maximizing caps do not significantly change prices for low speed plans, and reduce prices for high speed plans. Heavy-users caps reduce network capacity. Profit-maximizing caps reduce speed for low speed plans and increase speed for high speed plans. Heavy-users caps do not significantly increase subscription. Profit-maximizing caps reduce subscription. Both heavy-users caps and profit-maximizing caps reduce usage of low-income and heavy-usage subscribers to high speed plans. Heavy-users caps increase fairness and reduce consumer surplus. Profit-maximizing caps reduce consumer surplus, especially that of low-income subscribers.
Dai et al. 2014	NSF	Model of consumer subscription, usage, and utility. Model of duopoly broadband provider pricing. Model of capacity and congestion.	Heavy-users caps will impact customers of cable broadband service. Profit-maximizing data caps are more stringent than heavy-users caps. Data caps do not have a first order effect on service prices. Heavy-users caps increase speed of high speed plans. Profit-maximizing caps do not have a first order effect on speed. Heavy-users caps do not significantly increase subscription. Profit-maximizing caps do not have a first order effect on subscription. Profit-maximizing caps do not have a first order effect on consumer surplus.
Economides and Hermalin 2015	Newhouse Foundation	Model of consumer subscription, usage, and utility. Model of monopoly broadband provider pricing. Model of capacity, speed, and congestion.	Profit-maximizing data caps are lower and overage charges higher than would be welfare-maximizing. Profit-maximizing data caps increase network capacity, and reduce social welfare.
Felten 2011	?	Usage data in 2011from one broadband provider.	Heavy monthly users were active during peak usage periods, but most peak usage period traffic came from non-heavy users.
Ford 2012	Phoenix Center	Theoretical example.	Data caps increase social welfare.

Paper	Support	Model or Data	Relevant Results
Fukuda et al. 2015	Japan Ministry of Internal Affairs and Communications	Usage data collected in 2013-2015 from 1500 smartphone users in Tokyo.	Data caps caused heavy monthly users to decrease peak usage period traffic.
Gyarmati et al. 2012	European Union	Data collected in 2012 from the usage of a tier 1 backbone.	Heavy customers' contributions toward peak usage period usage was less than the contribution toward monthly usage.
Hussain et al. 2012	New American Foundation	No original data or model.	Data caps increase service prices, do not increase network capacity, and do not reduce congestion.
Howell and Layton 2016	none	No original data or model.	Data caps increase fairness.
Joe-Wong et al. 2015	Matanuska Telephone Association; NSF	Trials of pricing plans with 27 customers of a fixed broadband provider.	Data caps did not reduce peak period usage as much as off-peak period usage.
Kehl and Lucey 2015	New American Foundation		Data caps do not increase network capacity.
Lambrecht et al. 2007	Deutscher Akademischer Austauschd	2003 subscription and usage data from a German fixed broadband provider. Model of consumer subscription, usage, and utility.	Uncertainty over usage causes consumers to choose higher data caps than needed, and broadband providers to earn higher revenues.
Lyons 2013	Boston College; Mercatus Center at George Mason University	No original data or model.	Data caps reduce entry level plan prices, add fairness, increase network capacity, reduce congestion, increase speeds, and increase subscription.
Malone et al. 2014	Cable Television Laboratories, Inc.; NSF	Data collected in 2011-2013 from subscribers to a fixed broadband Internet access service.	Heavy monthly users were also heavy peak usage period users. Data caps reduced usage of heavy users in both peak and off-peak usage periods.
Minne 2013	none	No original data or model.	Data caps increase broadband provider revenue, and are used to protect incumbent pay-television service.
Nevo at al. 2016	NSF	Data collected in 2011-2012 from subscribers to a fixed broadband Internet access service. Model of consumer subscription, usage, and utility.	Data caps reduce service prices and increase broadband provider profit, increase speed, reduce usage, and reduce consumer surplus.
Odlyzko et al. 2012	Public Knowledge	No original data or model.	Consumers purchase higher data caps than needed. Data caps increase prices paid, and do not reduce congestion.
Poularakis et al. 2014	European Union, Technicolor Labs	Monthly usage in 2013-2014 of 260 subscribers to a European fixed broadband provider. Model of consumer subscription and utility. Model of monopoly broadband provider cost and pricing.	High correlation between monthly usage and peak usage period usage. Data caps reduce service prices for low speed plans and increase service prices for high speed plans.
Rogerson 2016	CTIA	No original data or model.	Data caps reduce service prices, increase broadband subscription, lower entry level prices, reduce congestion, increase speeds, increase subscription, and increase social welfare.
Sandvine 2009	Sandvine		Share of usage by top 1% has been decreasing.
Sandvine 2014	Sandvine		Heaviest 1% of users consume 12% of all usage.

Paper	Support	Model or Data	Relevant Results
Wang et al. 2015, Wang et al. 2016	China National Nature Science Foundation; Huawei; Singapore Agency for Science, Technology and Research; Singapore Ministry of Education	Model of consumer subscription, usage, and utility. Model of monopoly and duopoly broadband provider pricing. Model of capacity and congestion.	Profit-maximizing data cap increases with competition. Profit-maximizing data caps reduce service price, and reduce congestion.

The paper proceeds as follows. In Section 2, we summarize conflicting claims regarding the purposes of data caps and conflicting claims regarding competition. We also survey the relationship between monthly data usage and network congestion, and tentatively conclude that that there is likely a substantial overlap between users with heavy monthly usage and users with heavy usage during peak usage periods, but that a heavy user's monthly usage overstates her contribution toward congestion.

In Sections 3-7, we evaluate the conflicting claims regarding the effect of data caps on service prices, speeds, capacity, subscriptions, usage, congestion, and consumer welfare. In each section, we first present a survey of the relevant claims and literature about that effect, and we then present a critical analysis of these claims and literature. For each academic study, we examine the basis for the study's conclusions, including the assumptions of analytical models and the settings for empirical data. We consider the following economics and engineering characteristics of the model or data:

- fixed or mobile broadband;
- monopoly, duopoly, or competitive markets;
- the characteristics of the data cap;
- whether multiple service tiers are considered;
- the network capacity model;
- the network congestion model, and;
- the utility function.

Given the characteristics of each model or data, we analyze the limitations inherent in each paper's conclusions. We find that three characteristics of each model or data are critical in understanding the scope of application of the corresponding results, and hence in understanding the validity of conflicting claims.

First, the amount of service differentiation that exists *without data caps* strongly influences the incremental effect of data caps on prices, speeds, subscription, and consumer surplus. Mobile broadband service is usually delivered at download and upload speeds that are not differentiated based on the service plan, and hence data caps are a primary method of service differentiation. In contrast, fixed broadband service is almost always delivered at download and upload speeds that are differentiated based on the service plan, and hence data caps are a secondary method of service differentiation. We find that models of fixed broadband service that ignore service differentiation based on download and upload speed often make spurious predictions about the incremental effect of data caps on prices, speeds, subscription, and consumer surplus. We similarly find that models of mobile broadband service that ignore the potential benefits of service differentiation based on data caps may make incorrect predictions about the effect of data caps on prices, subscription, and consumer surplus if (and only if) service differentiation is used by mobile broadband providers to increase competition between themselves.

Second, the characteristics of the data cap strongly influences the incremental effect of data caps on subscription and consumer surplus. Caps set to recover the cost associated with heavy usage often have substantially different effects than caps set to maximize profit. We find that proponents' claims of increased subscriptions and increased consumer surplus are sometimes based on the assumption that data caps recover the cost associated with heavy usage, and the effects are moderated or reversed when data caps are set to maximize profit.

Third, the amount of competition and the effect of data caps upon competition strongly influences the incremental effect of data caps on prices, speeds, subscription, and consumer surplus. When there is a monopoly fixed broadband provider, data caps reduce consumer surplus. When there are two fixed broadband providers that offer different service tiers from each other, there is an indeterminate change in consumer surplus. When there are four mobile broadband providers, data caps likely increase consumer surplus. We find thus find that proponents' claims about increased consumer surplus are likely to be true for mobile broadband service, but false for fixed broadband service.

At the end of each of Sections 3-7, we present our own conclusions from this analysis about the likely effects of data caps. The ordering of these effects is structured so that we may use our analysis of the effects of data caps on service plans in our analysis of the effects on speed and capacity; and then use that analysis in our analysis of the effects on subscription, usage, and congestion; and finally of the effects on consumer surplus. In Section 8, we summarize our conclusions about the effects of various types of data caps in both fixed and mobile broadband.

In Section 9, we discuss how data caps may be evaluated under the FCC's 2015 Open Internet Order. We find that data caps intended to recover the cost of heavy usage are likely to qualify as reasonable network management if and only if there is a sufficient correlation between monthly usage and a user's contribution to congestion. For data caps that don't qualify as reasonable network management, we analyze the pertinent factors the FCC would use in assessing whether a data cap satisfies the Order's general conduct rule: competitive effects; effect on innovation, investment, or broadband deployment; and end-user control. We find that a mobile broadband heavy-users cap is likely to satisfy the general conduct rule due to positive effects on consumer choice and on innovation, investment, and broadband deployment, but that a fixed broadband heavy-users cap is likely to violate the general conduct rule due to negative effects on consumer choice and on innovation, investment, and broadband deployment. We also find that a mobile broadband profit-maximizing cap might satisfy the general conduct rule, but only if the benefits from increasing broadband provider investment and deployment outweigh the harms from disadvantaging an edge provider's ability to offer high-volume content and from corresponding reduced edge provider investment and innovation. A fixed broadband profit-maximizing cap is likely to violate the general conduct rule, due to negative effects on consumer choice, on competition, and on innovation, investment, and broadband deployment. Finally, data caps whose purpose is to protect incumbent pay-television services are similarly likely to violate the general conduct rule.

2. Background

2.1. Conflicting Claims Regarding the Purpose of Data Caps

This subsection presents conflicting claims regarding broadband providers' purposes in using data caps. Analysis of these claims is postponed until Sections 3-7.

Data caps are a form of usage-based pricing. In in its 2010 Open Internet Order, the Federal Communications Commission (FCC) recognized the benefits of some forms of usage-based pricing, explaining that "prohibiting tiered or usage-based pricing and requiring all subscribers to pay the same amount for broadband service, regardless of the performance or usage of the service, would force lighter end users of the network to subsidize heavier end users" (2010 Open Internet Order, paragraph 72). The focus of this paper is the subset of usage-based pricing implemented by data caps. In its 2015 Open Internet Order, the FCC comments about both the potential benefits and harms of data caps, explaining that "[d]ata caps […] can have a role in providing consumers options and differentiating services in the marketplace, but they also can negatively influence customer behavior and the development of new applications" (2015 Open Internet Order, paragraph 82).

Broadband providers claim that their purpose in using data caps is to manage congestion, to increase fairness, and to recover the cost associated with heavy users in order to fund incremental network capacity. As part of the GAO study, the four largest mobile broadband providers claimed their purpose in using data caps is to "address the usage of heaviest users, manage their networks, or address congestion" (GAO Report, 2014, page 20); similarly, almost all fixed broadband providers using data caps claimed their purpose is to address the usage of the heaviest data users.

Researchers who are proponents of data caps often agree that congestion, fairness, and/or cost recovery are the principal purpose(s). Howell and Layton 2016 emphasize cost recovery, suggesting that data caps "are an efficient means by which [broadband providers] may recover revenues from each customer rising in proportion with the costs that usage imposes on the [broadband provider] (including the costs of congestion that lower service quality for all users)." (Howell and Layton, 2016, pages 21-22) Other researchers emphasize price discrimination. In a white paper funded by CTIA[2], Rogerson 2016 interprets data caps as a form of price discrimination which allows a broadband provider to offer a set of service tiers defined (at least in part) by data caps. He argues that data caps "help manage congestion and ration scarce capacity and provide incentives for content providers and subscribers to use the

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[2] CTIA is a trade association whose members include large mobile broadband Internet access service providers. See http://www.ctia.org/about.

network efficiently” (Rogerson, 2016, page 16). In addition, Rogerson 2016 claims that efficiency gains will be largely passed through to subscribers.

However, broadband providers and researchers sometimes acknowledge that profit maximization – not congestion, fairness, or cost recovery – may be the principal motivation for using data caps. In a white paper funded by NCTA[3], Bauer and Wildman 2012 also interpret data caps as a form of second-degree price discrimination, explaining that a broadband provider may use data caps to offer alternative versions of broadband Internet access service differentiated in part by the data cap (Bauer and Wildman, 2012, pages 4-5). However, in their model, the broadband providers uses this form of price discrimination to maximize profit by setting parameters of service plans, including data caps, based on a user’s willingness-to-pay. Since they “expect that broadband users who frequently stream movies and TV programs … would be willing to pay more for a larger monthly data allowance than would individuals who spend most of their time online visiting shopping sites and friends’ Facebook pages”, they argue that a broadband provider may find that profit can be increased by incorporating data caps into service plans.

In contrast, public interest groups and researchers who are opponents of data caps express skepticism that data caps effectively manage congestion, and doubt that broadband providers are using data caps to recover the cost associated with heavy users. In a white paper sponsored by Public Knowledge[4], Odlyzko et al. 2012 acknowledge that usage-based pricing can be used beneficially, but express concern that “the reasonableness of [usage-based pricing] as a network management practice depends on the degree to which it actually addresses network congestion and the way it is implemented” (Odlyzko et al., 2012, pages 13-35). They then express skepticism that typical usage-based fixed broadband Internet access service pricing plans bear any relationship to the cost, and state that “[usage-based pricing] exists primarily as a mechanism to increase the return on invested capital for broadband service providers.” Similarly, in a white paper sponsored by the Open Technology Institute[5], Hussain et al. 2012 argue that *fixed* broadband providers are not using data caps to recover the costs associated with heavy users, citing decreasing network operating costs, noting that “[f]rom 2007 to 2010 the trend was clear: it cost Comcast less to operate its broadband network even as it added more and more users” (Hussain et al., 2012, page 5). They also suggest that *mobile* broadband providers may be using data caps to increase profit, noting that “the average revenue per user (ARPU) from [AT&T and Verizon] monthly subscription wireless data plans has steadily increased” during 2009-2012 (Hussain et al., 2012, page 11). They posit that “new tiered pricing plans rolled-out by Verizon Wireless and AT&T Wireless appear to be less about managing network use broadly or addressing congestion, and instead are designed to further increase profit margins on existing consumer data usage as overall subscriber growth in the mobile market slows down” (Hussain et al., 2012, page 9).

Opponents also claim that fixed broadband providers are using data caps to protect incumbent pay-television services. As part of the GAO study, some industry stakeholders “suggested that fixed providers—many of whom also provide television video content—could use [data caps] as a means to raise the price for watching online streaming video services—a competitor to their video services—as households continue to substitute television with streaming video” (GAO Report, 2014, page 26). Hussain et al. 2012 suggest that fixed broadband providers may be using data caps to protect legacy pay-television services, and express concern that “[d]ata caps have a chilling effect in the online marketplace, both on consumer behavior but also on potential service competitors” (Hussain et al., 2012, page 8). Odlyzko et al. 2012 express concern that fixed broadband providers may use data caps to impose an additional cost on their pay-television competitors (Odlyzko et al., 2012, page 48). Kehl and Lucey 2015 express concern that “[d]ata caps can discourage people from viewing online video content — and eliminating their TV subscriptions — which in turn reduces competition and innovation in the market for online video streaming services” (Kehl and Lucey, 2015, page 9). Minne 2013 argues that the purpose of data caps is “to create a new revenue source and retain high value cable TV subscribers” (Minne, 2013, pages 246-250). He notes that data caps on fixed broadband Internet access service are often set below the level required to replace traditional pay-television service by over-the-top video. He also cites revenue statistics from large cable providers to suggest that the likely purpose of fixed broadband data caps is to protect incumbent pay-television services. Economides and Hermalin 2015 similarly conjecture that data caps, in addition to allowing broadband providers to price discriminate and to

[3] NCTA is a trade association whose members include large fixed broadband Internet access service providers using cable modem technology. See https://www.ncta.com/who-we-are/about-ncta.
[4] Public Knowledge is a public interest group. See https://www.publicknowledge.org/about-us/.
[5] The Open Technology Institute is the technology program of the New American Foundation, a think tank. See https://www.newamerica.org/oti/about-us/.

alleviate congestion, may “cause content providers to lower their prices, raising consumer surplus and, thus, increasing what the [broadband providers] can capture” (Economides and Hermalin, 2015, pages 297-298).

2.2. Data Usage

Since the most common argument in favor of data caps is that they reduce network congestion, it is worth considering how monthly data usage relates to network congestion.

Data usage can be measured over various time scales. There are two time scales commonly discussed in telecommunications policy. Speed (as the term is commonly used in telecommunications policy) is the average number of bits per second transmitted and/or received by a device *during a period of a few seconds*. Monthly data usage is the total number of bytes transmitted and/or received by a subscriber *during a month*.

These two metrics have different implications, but neither relate directly to network congestion. A portion of a network becomes congested when the traffic arriving at a router exceeds that router’s capacity *for tens of milliseconds*. Such congestion can cause queuing delay and/or packet loss.

Whether a user notices network congestion depends on the application. If congestion is sustained for hundreds of milliseconds, it may impact the perceived quality of highly interactive applications such as voice or video calls. If congestion is sustained for several seconds, it may impact the perceived quality of moderately interactive applications such as web-browsing or video streaming. Congestion also reduces speed, because communication protocols reduce speed when congestion is detected.

However, monthly data usage only indirectly impacts congestion. If there is strong correlation between high monthly usage and high usage during the periods of tens of milliseconds in which routers are congested, then heavy monthly usage may indicate a user’s contribution toward network congestion.[6]

The distribution of monthly data usage has a long upper tail, with a small percentage of users responsible for a high percentage of monthly usage. On fixed broadband networks in North America, Sandvine estimated in 2014 that the 1% of users with the highest monthly downstream usage accounted for 12% of all monthly downstream usage, and the 50% of users with the lowest monthly downstream usage accounted for 7% of all monthly downstream usage (Sandvine, 2014, page 6).[7] Similarly, on mobile broadband networks in North America, Sandvine estimated in 2014 that the 1% of users with the highest monthly downstream usage accounted for 12% of all monthly downstream usage, and the 50% of users with the lowest monthly downstream usage accounted for 2% of all monthly downstream usage (Sandvine, 2014, page 9).[8] However, Sandvine also estimates that the share of the top 1% of users has been decreasing, from 25% in 2009 (Sandvine, 2009, page 2) to 12% in 2014.

The correlation between heavy monthly usage and users’ contributions to congestion remains somewhat unclear. Blackburn et al. 2013 estimated that in 2009-2012 20% of mobile Internet subscribers of a particular provider had usage whose associated cost exceeded the revenue from those subscribers (Blackburn et al., 2013, pages 3-4 and 6-9.).[9] They also suggested that reducing or eliminating such heavy usage would have resulted in a substantial increase in the broadband provider’s profit. Although this study found that there was some correlation between monthly usage and cost, it did not estimate the correlation. Since usage-related cost is a function of the capacity required to accommodate demand during peak usage periods, the question is whether there is a strong linear correlation between monthly usage and peak period usage. Malone et al. 2014 found that in 2011-2013 heavy monthly users of a particular fixed broadband service were consistently heavy users during peak usage periods (Malone et al. 2014, pages 1040-1044).[10] Similarly, Felten 2011 showed that in 2011 most heavy monthly users of a particular broadband provider were active during peak usage periods.[11]

While these results found a substantial overlap between users with heavy monthly usage and users with heavy usage during peak usage periods, they do not establish the correlation between heavy monthly usage and users’ contributions to congestion. Consider two ends of the range of likely possibilities. First, a heavy monthly user may be usually active during peak usage periods, and at a rate proportional to monthly usage; in this case, the heavy monthly user contributes to peak usage (and to required network capacity) proportional to monthly usage. Indeed,

[6] See e.g. FCC OIAC Report 2013, pages 16-17.
[7] They also estimated that the top 2% contributed 20% of monthly usage and the top 5% contributed 37% of monthly usage.
[8] They also estimated that the top 2% contributed 20% of monthly usage and the top 5% contributed 36% of monthly usage.
[9] The empirical study was based on based on the usage in 2009-2012 of 1 million customers of a mobile broadband provider.
[10] The empirical study was based on data collected in 2011-2013 from subscribers to a fixed broadband Internet access service.
[11] The empirical study was based on usage data in 2011 from one broadband provider.

Poularakis et al. 2014 showed that in 2013-2014 there was a high correlation among users of a particular fixed broadband service between monthly usage and user contributions to peak period network load (Poularakis et al., 2014, pages 297-298).[12] At the other end of the range of likely possibilities, a heavy monthly user may usually be active during peak usage periods, but at a rate commensurate with other active users; in this case, the heavy monthly user doesn't contribute disproportionally to peak usage (or to the required network capacity). Indeed, Felten 2011 found that most peak usage period traffic came from non-heavy users. Gyarmati et al. 2012 similarly found that in 2012, among business customers of an Internet backbone, a customer's monthly usage often differed substantially from its contribution toward peak utilization (Gyarmati, et al., 2012, pages 515-516.).[13] The paper also found that the proportion of a heavy customer's contribution toward peak usage period usage was less than the proportion of its contribution toward monthly usage.

More study is clearly warranted to establish the amount of correlation between heavy monthly usage and users' contributions to congestion. In particular, it remains unknown the degree to which data caps based solely on peak-period usage would be more effective than those based on monthly usage. Based on this limited literature, we tentatively conclude that there is likely a substantial overlap between users with heavy monthly usage and users with heavy usage during peak usage periods. However, we also tentatively conclude that a heavy user's monthly usage likely overstates her contribution toward congestion.

2.3. Competition

Some of the conflicting claims rest on assumptions about whether broadband providers have market power. With respect to fixed broadband providers, the providers and some academics claim that there is sufficient competition, and that such competition will retard any socially undesirable effects of data caps.[14] With respect to mobile broadband providers, Rogerson 2016 claims that the presence of four national mobile broadband providers in the United States with significant market shares has resulted in high levels of rivalry and low switching costs (Rogerson, 2016, pages 10-14). He argues that this competition ensures that the use of data caps will not allow mobile broadband providers to earn excessive profits (Rogerson, 2016, page 15).

In contrast, Odlyzko et al. 2012 cite statistics about market shares in both fixed and mobile broadband Internet access service and argue that "[c]oncentration in the market for fixed and [mobile] broadband service decreases the likelihood that market forces alone will suffice to keep either data caps high or prices low" (Odlyzko et al., 2012, page 35).

Hussain et al. 2012 see reduced competition among mobile broadband providers in the United States, noting that both AT&T and Verizon "have significantly larger spectrum holdings and more prime spectrum than the remaining competitors making it more difficult for other providers to offer similar speeds and coverage" (Hussain et al., 2012, page 12). They perceive the increasing use of data caps as a consequence of this reduced competition.

It is not the purpose of this paper to evaluate the conflicting claims about whether fixed and/or mobile broadband providers have market power. The FCC has rejected claims that the market for either fixed or mobile broadband Internet access service is sufficiently competitive to forbear from regulation. In the 2015 Open Internet Order, the Commission explained that "we cannot simply conclude, as a general matter, that there is extensive competition sufficient to constrain providers' conduct here" and that "even in a competitive market certain conditions could create incentives and opportunities for service providers to engage in discriminatory and unfair practices" (2015 Open Internet Order, paragraph 444). The remainder of this paper assumes that fixed broadband providers have substantial market power, and models them as monopolies or duopolies. We also assume that mobile broadband providers have less -- but still significant -- market power. Although Lyons 2013 argues that '[t]he real threat to consumer welfare is not usage-based pricing, but market power" (Lyons 2013, page 43), in the following we assume that it is easier to regulate data caps than to eliminate market power.

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[12] The empirical study was based on the monthly usage in 2013-2014 of 260 subscribers to a European fixed broadband provider. They measure the contribution to peak period network load by examining the traffic transmitted during 5 minute periods that exceed the 95th percentile of such 5 minute periods during the month.

[13] The empirical study was based on data collected in 2012 from the usage of a tier 1 backbone.

[14] See e.g. Lyons, 2013, pages 38-39.

3. The Effect of Data Caps on Service Pricing

Broadband providers and proponents of data caps often claim that the use of data caps results in lower service prices, at least for entry level plans.[15] Opponents of data caps often claim that the use of data caps monetizes scarcity and does not result in lower service prices.

3.1. Survey

Lyons 2013 supports the argument of broadband providers that a primary purpose of data caps is to institute fairness among users, explaining that also "[u]nder a flat-rate pricing system, lighter users end up paying a disproportionate share of overall network costs" and that data caps can "help broadband companies shift more network costs onto heavier users" (Lyons, 2013, pages 13-15). He believes that "[u]sage-based pricing may also make entry-level broadband access more affordable", and cites statistics showing that data caps may indeed reduce the price of entry level plans (Lyons, 2013, pages 27-29).

Rogerson 2016 similarly address mobile broadband Internet access service. He argues that usage-based pricing would allow a mobile broadband provider to serve a greater fraction of the market, implying that the prices of entry level plans would fall (Rogerson, 2016, page 23). In addition, he argues that "while allowing firms to use data caps or more generally to engage in any form of price discrimination will change the over-all structure of prices that different consumers face and will likely result in different consumption patterns among consumers, there is no reason to believe that it will result in over-all excessive profits" (Rogerson, 2016, page 15).

Hussain et al. 2012, however, noted that the incorporation of data caps in 2010-2011 to Verizon's and AT&T's mobile broadband service plans resulted in increased prices, including a more expensive basic plan (Hussain et al., 2012, page 11).

Odlyzko et al. 2012 discuss the potential impact of psychology upon consumer purchasing decisions. They note that consumers "are willing to pay extra for the peace of mind that flat rates offer them" and thus "[p]ricing preferences often lead users to pay more for flat rates than they would for [usage-based] pricing" (Odlyzko et al., 2012, pages 41-46).

Lambrecht et al. 2007 analyze 2003 broadband usage data, and find that consumers were substantially biased to choose a higher data cap than would minimize their costs (Lambrecht et al., 2007, pages 700-701). They posit that consumer uncertainty over usage allows broadband providers to earn higher revenues using data caps (Lambrecht et al., 2007, pages 707-709).

For more insight, we turn to analytical models. Bauer and Wildman 2012 illustrate the potential for data caps to result in lower service prices with a simple example that compares a pair of plans with data caps to a single plan with no data cap and no usage-based pricing (Bauer and Wildman, 2012, pages 6-9). In the example, there are two types of users who differ in their utility as a function of monthly data consumption. They show that a profit-maximizing broadband provider would offer both plans with data caps at lower prices than it would offer a single plan with no data cap, because second-degree price discrimination allows it to offer a lower priced product to consumers who would not otherwise subscribe.

Poularakis et al. 2014 propose a model that incorporates multiple speed tiers, in which a broadband provider sets service tier prices, rates, and data caps (Poularakis et al., 2014, pages 304-305). The model ignores overage policies. Under the model, numerical results show that profit-maximizing data caps may result in *reduced* service prices for low speed plans and *increased* service prices for high speed plans. The presence or absence of service tiers based on speed may thus be important in predicting the effect of data caps on service prices.

Economides and Hermalin 2015 propose a model that considers overage charges, in which a monopoly broadband provider sets access fees, data caps, and overage charges (Economides and Hermalin, 2015, pages 301-302). Consumers maximize surplus based on quasi-linear utility as a function of the amount of content acquired and congestion. The model shows that if network capacity is held fixed, profit-maximizing data caps are lower and overage charges higher than would be welfare-maximizing (Economides and Hermalin, 2015, pages 307-309, Propositions 6-7). The purpose and severity of the data cap may thus be important in predicting the effect of data caps on service prices.

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[15] See e.g. FCC OIAC Report 2013, pages 14-15 ("Depending on how it is structured, [data caps] can also enable additional lower-cost broadband plans to be offered to consumers, spurring adoption or better meeting the underserved demand from the low-end of the market.").

Dai and Jordan 2015 compare the effects of data caps intended to reduce congestion to the effects of data caps intended to maximize profit. User willingness-to-pay is represented as a function of the time devoted per month to Internet applications, performance, a user's relative utility for high bandwidth applications, and an opportunity cost of the time devoted which depends on the income of the user. A monopolist broadband provider sets service prices, download and upload speeds, data caps, and overage charges. It is assumed that network capacity is set so that the network load remains constant. Two types of data caps are considered: a *"heavy-users cap"* in which data caps and overage charges are set to recover the cost associated with heavy users, and a *"profit-maximizing cap"* in which data caps and overage charges are set to maximize profit. Dai and Jordan 2015's model shows that if a monopoly broadband provider uses *heavy-users data caps*, it does not significantly change the service prices of its various plans, since the prices have already been optimized and the data cap does not change that optimization (Dai and Jordan, 2015, pages 7-8).

Dai and Jordan 2015 also prove, under the model, that a broadband provider can increase profit by using caps that are lower and overage charges that are higher than when caps are used only to ensure that heavy users pay for their usage (Dai and Jordan, 2015, pages 11-13, Theorem 5.3). This property holds because reducing the data cap and increasing the overage charge results in increased overage charges and reduced capacity costs that more than compensate for a reduction in high speed plan subscribers (due to the data cap). Under likely conditions, they also prove, under the model, that *profit-maximizing caps* will result in unchanged prices for low speed plans, and in reduced prices for high speed plans, than when either no caps are used or heavy-users caps are used (Dai and Jordan, 2015, pages 11-13, Theorem 5.4). The price for low speed plans is insensitive to the data cap, because data caps on low speed plans don't generate significant revenue, and thus the pricing decision when using profit-maximizing caps is similar to that when using no caps. In contrast, a broadband provider can increase profit when using profit-maximizing caps by reducing the price for high speed plans, because it can entice some subscribers to low speed plans to upgrade to high speed plans and the resulting increase in revenue outweighs the increased capacity cost to accommodate the upgrades. Profit-maximizing data caps thus have qualitatively different effects on service prices than do heavy-users data caps.

Nevo et al. 2016 model demand for fixed broadband service based on empirical data. User willingness-to-pay is represented as a function of daily usage and download speed. Service prices, data caps, and overage charges are those used by one fixed broadband provider to serve approximately 55,000 subscribers. In the model, the mean overage price exceeds the median price per unit volume, and thus the caps are unlikely to be heavy-users caps. They use the model to predict user willingness-to-pay for speed and usage, under profit-maximizing plans with and without data caps. Numerical results show that the use of data caps results in lower average prices but higher profit (Nevo, et al., 2016, pages 23-25). However, the results don't break out changes in prices for low speed versus high speed plans.

Dai et al. 2014 model a duopoly consisting of two providers of fixed broadband Internet access service: one using cable modem technology and one using DSL technology. Because of differences in the broadband providers' marginal costs, the cable provider offers a higher speed than the DSL provider. The user and broadband provider models are otherwise similar to those used in Dai and Jordan 2015. If both broadband providers utilize *heavy-users caps*, the model predicts that the cable provider will set data caps low enough to impact its heavy users (Dai et al., 2014, page 4). In contrast, the DSL provider will find that it has very few heavy users, and that heavy-user data caps don't significantly impact its service price. However, if both broadband providers utilize *profit-maximizing caps*, under reasonable conditions it is proven that the cable provider will set lower data caps and higher overage charges than those used in heavy-users caps, because doing so results in increased overage charges and reduced capacity costs that more than compensate for the reduction in subscribers (Dai et al., 2014, page 5, Theorem 5). Any change in service price is a second order effect; in numerical results both broadband providers reduce their service prices to compete, but this may be dependent on parameter choices. The use of data caps by duopolies may thus result in substantially different effects on service prices than when used by a monopoly provider.

Wang et al. 2016 propose models of monopoly and duopoly ISPs with data caps and overage charges. They model user utility as linearly proportional to monthly usage, and consider profit-maximizing broadband providers who set an access fee, a data cap, and an overage charge. Numerical results show that the profit-maximizing data cap is likely to increase as market competition increases, because competition drives the profit-maximizing cap towards the heavy-users cap (Wang et al., 2016, pages 15-16). They also consider a related model in which broadband providers determine network capacity, and in which user demand and network capacity determine network congestion, which in turn affects usage. Using that model, they show that the use of profit-maximizing caps by a monopoly broadband provider will result in a lower service price (Wang et al, 2015).

3.2. Analysis

On its face, the academic literature appears to present conflicting conclusions about whether the use of data caps results in lower service prices, and if so for which plans. However, upon closer inspection, the characteristics of each model affects the scope of the claims put forward, and combining the results paints a more consistent picture.

First, consider whether the use of profit-maximizing data caps would result in lower services prices for *all services*. Such a result was found in the example provided by Bauer and Wildman 2012. However, by comparing a *pair* of plans with data caps to a *single* plan with no data cap and no usage-based pricing, Bauer and Wildman 2012 conflate two effects – the effect of data caps and the effect of price discrimination. Thus, the example does not illustrate whether the price reductions are the result of the data cap or of second degree price discrimination.

The academic literature that does separately consider these two effects paints a more complex picture. Whether prices rise or fall depends on the type of data cap employed, whether there are other means for price discrimination, and on the amount of competition.

Consider data caps intended to recover costs associated with heavy usage in fixed broadband Internet access service. Under such caps, the overage charge should be equal to the incremental cost of network capacity required to serve heavy users without a degradation in network performance (Dai and Jordan, 2015, page 11). In this case, none of the analytical models for either monopolies or duopolies find that service prices change substantially. This conflicts with the claims of proponents who believe that heavy-users caps will institute fairness which will in turn result in more affordable entry level plans. In contrast, as discussed in more detail in later sections, while the models indeed show that a heavy-users cap reduces usage by heavy users, they also show that the associated cost savings are not reinvested into lowering the price of entry level plans.

An alternative form of a heavy-users cap is based on consumer risk aversion to exceeding caps. Such a heavy-users cap sets overage charges high enough to dissuade consumers from exceeding the cap, and sets the cap on higher priced service plans to dissuade heavy usage that is associated with capacity costs that the broadband provider believes it cannot recover through service prices. In this case, there is a reason to expect a greater reduction in usage and hence in capacity costs. However, there is also no evidence that a broadband provider would use the reduced capacity cost to reduce the price of entry level plans.

Next, consider data caps intended to maximize profit of fixed broadband providers. The analytical models agree that profit-maximizing caps will be lower and overage charges higher than for heavy-users caps. Those used by duopolies will be closer to the heavy-users caps than those used by monopolies. This result supports the claim by opponents of data caps that profit-maximizing caps can be used to monetize scarcity. The differences between heavy-users caps and profit-maximizing caps in the level of the cap and the overage charges also undermines claims by proponents of data caps that attempt to equate profit-maximizing caps with congestion management.

The effect of profit-maximizing caps on service prices depends on whether there are other means for price discrimination. Fixed broadband providers offer a set of service plans that are principally differentiated by download and upload speeds. Thus, papers that ignore download and upload speed as a basis for price discrimination – including Bauer and Wildman 2012, and Lyons 2013 – cannot accurately predict the result of using data caps as an additional form of price discrimination on top of that already provided by plans differentiated by download and upload speeds.

The amount of competition is also pertinent. The analytical models show qualitatively different results for monopolies and duopolies. Monopoly models of fixed broadband providers show that profit-maximizing caps are likely to result in reduced prices for high speed plans, but are unlikely to result in significant changes in the price for low speed plans. A monopolist has the incentive to use data caps to both affect the behavior of and attract additional revenue from heavy users. As a side benefit, having protected itself against heavy users, it can earn higher profits by reducing the price of high speed plans and using the data cap to further price discriminate amongst subscribers to high speed plans. However, contrary to the expectations voiced by proponents of data caps, the monopolist has no incentive to plough these gains into reducing the price of entry level plans. Duopoly models of fixed broadband providers show that the effect of profit-maximizing caps on service prices is inconclusive and may be sensitive to the functional form of user utility.[16]

[16] The model presented by Poularakis et al. 2014 predicts *increased* prices for high speed plans. However, this is likely an artifact of the lack of overage charges in the model.

The evidence thus suggests that the claims of both proponents and opponents regarding the effect of data caps on fixed broadband service pricing are too simplistic. Profit-maximizing caps may result in a reduction in the service price of low speed plans only if there is sufficient competition to incentivize the competitors to further differentiate their products. Profit-maximizing caps may result in a reduction in the service price of high speed plans only if the broadband provider can use the overage charge to further price discriminate. However, if consumers are risk-adverse to exceeding caps, then it is likely that broadband providers offering high speed plans may instead respond by further differentiating their plans by data caps in order to reap gains from additional price discrimination.

The analysis of data caps in mobile broadband Internet access service is different for two reasons. First, mobile broadband Internet access service is usually *not* differentiated on the basis of download and upload speed.[17] Second, there is greater competition among mobile broadband providers. The analytical models agree that profit-maximizing mobile broadband caps will be lower and overage charges higher than for mobile broadband heavy-users caps. However, they also predict that as competition increases, profit-maximizing caps will increase to approach those of heavy-users caps.

Since mobile broadband Internet access service is usually not differentiated on the basis of speed, the arguments of Bauer and Wildman 2012, Lyons 2013, and Rogerson 2016 come back into play, as the data cap becomes the principal method for price discrimination.[18] The academic literature strongly indicates that the use of *heavy-users caps* as the principal form of second-degree price discrimination will result in differentiated service prices, including new lower priced entry-level plans. Unfortunately, there is scant academic literature that includes analytical models to predict the effect of *profit-maximizing caps* upon service prices in mobile broadband Internet access service. It is reasonable to conjecture that profit-maximizing caps may similarly result in differentiated service prices. The comparison between heavy-users caps and profit-maximizing caps likely depends on whether data caps are used by various providers to differentiate among each other, or whether they are used by various providers in similar manners. If used to differentiate between providers, then it is likely that competition will keep the service prices of plans with profit-maximizing caps close to those of plans with heavy-users caps. In contrast, if used similarly by various providers, to the extent that market power remains it is likely that the service prices of plans with profit-maximizing caps will be higher than the service prices of similar plans with heavy-users caps.

Our analysis of the effect of data caps is summarized in Tables 3-5.

4. The Effect of Data Caps on Speeds and Capacity

Proponents and opponents agree that data caps are likely to increase broadband provider revenue and/or decrease costs. However, they disagree over whether any additional revenue would be reinvested in network capacity. Broadband providers and proponents often claim that the use of data caps results in greater network capacity than would exist without the use of data caps.[19] The reason usually given is that data caps increase the incentive for broadband providers to add capacity, since the incremental capacity will benefit a broader set of users. They also often claim that that the increased capacity and reduced usage by heavy users results in increased download and upload speeds. Opponents of data caps often claim that the use of data caps either does not impact network capacity or incentivizes broadband providers to reduce network capacity to further monetize scarcity.

4.1. Survey

Lyons 2013 discusses the high fixed costs of providing broadband Internet access service, stating that "the challenge is therefore to design a pricing structure that spreads fixed costs intelligently across the company's customer base" (Lyons, 2013, pages 21-26). He then argues that data caps may be an effective method of recovering fixed network costs. He argues that even if price discrimination based on speed tiers is used, additional price discrimination using data caps can result in added economic efficiency, because "[s]peed tiers segment the customer base by varying quality of service, while data tiers vary quantity of service." He also responds to critics who believe that data caps will allow a broadband provider to raise rates without investing in network expansion by explaining

[17] While some devices use more advanced technologies that result in higher download and upload speeds, the service price only secondarily reflects this via different device leasing prices.

[18] However, recently at least one mobile broadband provider has introduced plans with speed tiers.

[19] See e.g. GAO Report, 2014, page 20. (Two large fixed broadband providers claimed that "they are continually upgrading and expanding their networks to meet demand and [data caps] can be used to ensure that heavier users contribute more to those costs than lighter users.")

that "[a] provider could create artificial scarcity only if it has market power" and that "a monopolist offering flat rates may exploit this power by increasing the rate for unlimited service and pocketing, rather than reinvesting, the added revenue" (Lyons, 2013, page 32).

In contrast, Hussain et al. 2012 perceive that revenues gained through the use of data caps (including reduced usage) have *not* been reinvested by broadband providers, who have instead been "content to maintain the status quo and reap these efficiencies as a bonus rather than an opportunity to increase investment" (Hussain et al., 2012, 6). In a recent white paper sponsored by the Open Technology Institute, Kehl and Lucey 2015 claim that "[t]he money being generated by data caps does not appear to be reinvested in network upgrades" (Kehl and Lucey, 2015, page 8).

Indeed, the FCC OIAC suggested that the use of data caps may reduce the need for incremental capacity, explaining "[o]ver the long run a data cap […] can help manage network growth if users and/or edge service providers respond to the cap or threshold with less or more efficient data use; a carrier would then incur less costly operations and may be able to make less expensive infrastructure upgrades over longer periods" (FCC OIAC Report, 2013, pages 15-16).

For more insight, we again turn to analytical models. Bauer and Wildman 2012 consider a network capacity cost model in which a portion of last-mile costs are directly attributable to specific users and the remaining network costs are shared (Bauer and Wildman, 2012, pages 12-14). They state that broadband providers must recover shared costs by charging prices that are higher than directly attributable costs. They argue that usage-based pricing will increase profit, which will in turn increase broadband deployment, and thereby increase total network capacity. They conclude that "limitations on usage-based pricing [that] prevent ISPs from collecting contributions to common infrastructure costs from individuals who would take a low price-low data tier option" can be expected to result in ISPs "invest[ing] in fewer and less extensive networks".

Economides and Hermalin 2015, using the model discussed above, show that profit-maximizing data caps will result in higher network capacity than would plans with no data caps, because higher capacity enables higher usage which in turn enables a broadband provider to extract greater surplus (Economides and Hermalin, 2015, pages 312-313, Proposition 10).

Nevo et al. 2016 examine the effect of data caps on the speed experienced by users. Using the model discussed above, they find that the use of data caps increases the average speed (Nevo et al., 2016, pages 23-25). However, the effect on various speed plans is not analyzed.

In contrast, Dai and Jordan 2015 find that the effect of data caps on speed and capacity depends critically on whether a data cap is a heavy-users cap or a profit-maximizing cap. Dai and Jordan 2015 categorize network costs into a fixed cost that does not depend on either the number of subscribers or the traffic, a variable access cost that depends on the number of subscribers but not the traffic, and a variable capacity cost that depends on the capacity of the network. They then show that *heavy-user caps* result in *reduced* network capacity proportional to the reduction in heavy usage. The monopoly broadband provider does not reinvest the cost savings, nor modify the speeds of various plans, since it has no incentive to do so.

Dai and Jordan 2015 also show that *profit-maximizing caps* result in qualitatively different effects on speeds and capacity. When a monopoly broadband provider uses profit-maximizing caps, Dai and Jordan 2015 prove (under conditions that are likely to hold) that such caps will result in *reduced* speeds for low speed plans and *increased* speeds for high speed plans, than when either no caps are used or heavy-users caps are used (Dai and Jordan, 2015, pages 11-13, Theorem 5.4). The broadband provider has an incentive to reduce the speed of low speed plans, because the incremental revenue from subscribers to low speed plans who upgrade to high speed plans outweighs the loss in revenue from subscribers to low speed plans that no longer subscribe. However, the broadband provider also has an incentive to increase the speed of high speed plans, because the incremental revenue from subscribers to low speed plans who upgrade to high speed plans outweighs the additional capacity cost required to accommodate these upgrades. The net change in network capacity is inconclusive.

Dai et al. 2014 illustrate the effect of competition. Using the duopoly model discussed above, they find that if both broadband providers utilize *heavy-users caps*, the cable provider will increase its relatively high speed in order to further differentiate its service from the DSL provider's service, since it can now do so without losing money on heavy users (Dai et al., 2014, page 4). In contrast, the DSL provider will not significantly modify its speed, since it sees no significant change in revenue or usage. If both broadband providers utilize *profit-maximizing caps*, any change in speeds is a second order effect; in numerical results both broadband providers reduce their speeds, but this may be dependent on parameter choices.

4.2. Analysis

Proponents' and opponents' claims about the effect of data caps upon network capacity and network speeds are clearly in conflict. The models that led to these conflicting claims merit further examination.

The claims in Bauer and Wildman 2012 and in Lyons 2013 rest on two assumptions: that data caps will increase subscription, primarily due to lower cost entry level plans, and that either some incremental revenue will be reinvested in network capacity or that higher profit will increase aggregate network capacity by increasing broadband deployment.

First consider data caps intended to recover costs associated with heavy usage in fixed broadband Internet access service. In the previous section, we concluded that heavy-users caps are unlikely to significantly affect service prices, and thus there is unlikely to be additional revenue from additional subscriptions. Indeed, if heavy-users caps generate overage fees, then the monopoly analytical model in Dai and Jordan 2015 shows that the caps result in *reduced* network capacity, since heavy usage is reduced and thus less capacity is required to maintain the same network performance. Similarly, if consumers are risk adverse to paying overage fees, then usage and capacity will drop. In contrast, the duopoly analytical model in Dai et al. 2014 shows that while the DSL provider likely has no gains to reinvest, the cable provider will reinvest a portion of heavy-users overage fees; however, it is inconclusive whether this investment will exceed the reduction in capacity needed due to reduced usage, and thus inconclusive whether there is a net increase in capacity.

Network capacity, however, is not directly perceived by consumers. Instead, consumers perceive network performance, including download and upload speeds. If network capacity is set to achieve the desired network load, then consumers will principally judge network performance by download and upload speeds. Proponents of data caps often claim not only that the use of data caps results in increased network capacity, but also that increased capacity and reduced usage by heavy users results in increased download and upload speeds. However, they do not actually demonstrate this claim using any analytical models. The analytical models in the literature show that the effect of heavy-users data caps upon speeds depends on the amount of competition. The monopoly model used by Dai and Jordan 2015 shows that heavy-users caps would not significantly affect speeds. However, the duopoly model by Dai et al. 2014 shows that when there is competition, heavy-users caps are likely to result in an increase in the speed of high speed plans, whether or not capacity increases.

Next consider data caps on fixed broadband Internet access service that are intended to maximize profit. In the previous section, we concluded that profit-maximizing caps used by monopoly broadband providers are likely to result in reduced prices for high speed plans, but are unlikely to result in significant changes in the price for low speed plans. Thus, the claim that subscription increases due to profit-maximizing caps is again likely incorrect.

However, the analytical models do predict increased broadband provider revenue from the use of profit-maximizing caps. The question thus remains whether this increased revenue is reinvested into network capacity. The monopoly model by Economides and Hermalin 2015 predicts that some of the increased revenue will be reinvested into network capacity, resulting in increased speed. The monopoly model by Dai and Jordan 2015 finds that the effect of profit-maximizing caps on capacity is inconclusive and may be sensitive to the functional form of user utility. There are two differences between the Economides and Hermalin 2015 and Dai and Jordan 2015 models that could result in such a discrepancy. First, the two models use different forms of utility. Second, the Dai and Jordan 2015 model explicitly considers multiple service plans differentiated by speed while the Economides and Hermalin 2015 model does not.

But, again, it is speed – not capacity – that is directly observed by consumers. The monopoly model by Dai and Jordan 2015 predicts reduced speeds in lower speed plans and increased speeds in higher speed plans, whether or not capacity changes. The duopoly model by Dai et al. 2014 shows that any changes in speed are second order effects, and may be sensitive to the nature of the competition.

The discrepancy between these nuanced conclusions about the effect of data caps on capacity and speeds and the predictions of Bauer and Wildman 2012 and of Lyons 2013 that data caps increase overall network capacity is worthy of consideration. Bauer and Wildman 2012 argue that the use of profit-maximizing data caps likely increases overall network capacity by increasing broadband deployment. However, they do not state whether capacity per user would increase. In contrast, the Economides and Hermalin 2015 and Dai and Jordan 2015 models consider capacity per user, but do not consider changes in broadband deployment.

In summary, the evidence suggests that the effects of data caps on speeds and capacity depends strongly on the type of data cap. Heavy-users caps are unlikely to substantially increase network capacity. They may, however, result in an increase in the speed of high speed plans, if it results in the higher speed broadband provider attempting to further differentiate itself from a lower speed competitor. Profit-maximizing caps are also unlikely to substantially increase network capacity. They are likely to result in changes in the speeds of various plans. However, any changes in speeds is likely to be closely related to the nature of the competitor's service plans, and it is unlikely that most plans see increases in speed.

Finally, consider data caps on mobile broadband Internet access service that intended to maximize profit. The use of *heavy-users caps* in mobile broadband service will increase the profitability of the broadband provider, and competition will motivate the providers to reinvest some of this profit into incremental capacity. The reduced congestion, as discussed in more detail below, will result in increased throughput, which will be observed by users as higher speeds.[20] The effect of *profit-maximizing caps* on speed is less clear. Both proponents and opponents expect that data caps reduce usage and thus cost. Thus, the question remains whether the reduced cost will be passed on to users in the form of increased network performance. In the face of intense competition based on average download speed, it is reasonable to expect that a portion of the reduced cost will be passed on. However, it is unknown how this compares to the network performance under heavy-user caps.

5. The Effect of Data Caps on Subscriptions

Proponents of data caps often claim that data caps increase broadband Internet subscription, while opponents generally disagree.

5.1. Survey

Lyons 2013 believes that data caps will reduce the price of entry-level broadband plans, and that they will alleviate congestion and thus presumably increase speeds. For both reasons, he argues that data caps will result in increased subscription, explaining that the use of data caps allows broadband providers to "offer[] service to more people who value the service above marginal cost, while at the same time it narrows the 'digital divide' between those who can afford broadband access and those who cannot" (Lyons, 2013, pages 27-29).

Rogerson 2016 applies similar arguments to mobile broadband providers. He believes that that the use of profit-maximizing data caps will result in mobile broadband providers offering lower-priced entry-level plans (Rogerson. 2016, pages 22-25). He also argues that data caps help manage congestion, and thus presumably increase speeds (Rogerson, 2016, pages 16-22). For both these reasons, he argues that data caps will result in expanded access to broadband, especially for lower income consumers.

Opponents of data caps have expressed skepticism of both the claim that data caps result in decreased service prices and the claim that data caps result in increased speeds.

For more insight, we again turn to analytical models. Bauer and Wildman 2012's first example shows that a profit-maximizing broadband provider may offer a pair of plans with data caps at lower prices than it would offer a single plan with no data cap and no usage-based pricing. Although this example does not consider capacity or network performance, they generalize from their example to conclude that the use of data caps increases the number of consumers who subscribe to broadband Internet access service, explaining that "more lower demand consumers will take broadband service if providers are allowed to employ tiered pricing plans than if they are required to provide all customers with unlimited data service for a single fixed fee (or flat rate)" (Bauer and Wildman, 2012, pages 6-9). Their second example considers a network capacity cost model, and shows that the use of profit-maximizing data caps may increase network capacity. Since the examples show decreased prices and increased performance, they are consistent in showing that there may be increased subscription.

In contrast, Dai and Jordan 2015, using the model discussed above, show that the use of *heavy-users caps* by a monopoly provider results in changes in existing subscribers' choices among low-speed and high-speed plans, but is unlikely to increase overall subscription (Dai and Jordan, 2015, pages 11-12). They find that subscribers to high speed plans who have high valuations on video streaming but low incomes will find it desirable to downgrade to a lower speed plan due to overage charges for heavy usage. However, they do not find any other significant changes in subscription. In particular, they find that heavy-users caps are unlikely to result in reductions in the price of entry-level plans, since the prices have already been optimized and the data cap does not change that optimization. They

[20] The transmission speed, which is determined by the physical layer protocol, will not change due to reduced congestion. However, the average number of bits per second transmitted and/or received by a device during a period of a few seconds, commonly called "throughput", will increase.

also find that such caps are unlikely to result in increase in the performance of entry-level plans, since it is presumed that broadband providers set capacity to manage network load. Dai et al. 2014 similarly show that that the use of heavy-users caps by a duopoly consisting of one DSL provider and one cable provider is unlikely to increase overall subscription (Dai et al., 2014, page 4).

Dai and Jordan 2015 show that the use of *profit-maximizing caps* by a monopoly provider results in changes in existing subscribers' choices among low-speed and high-speed plans, but is likely to *reduce* overall subscription (Dai and Jordan, 2015, pages 14-15). They find that some subscribers to low-speed plans will find it desirable to drop their Internet subscription, due to the decreased speed of the low-speed plan. Other low-speed plan subscribers will upgrade to a higher-speed plan, due to the increased speed and the reduced price of those plans. In addition, some heavy users on high-speed plans will downgrade to a low-speed plan, due to the impact of the data cap.

In contrast, Dai et al. 2014 show that that the use of profit-maximizing caps by a *duopoly* consisting of one DSL provider and one cable provider do not result in any first order effects upon overall subscription (Dai et al., 2014, pages 5-6.). However, second order effects may result *an increase* in overall subscription. Under the parameters used in Dai et al. 2014, the use of data caps by the cable provider disadvantages the DSL provider, who responds by lowering both the prices and the quality of entry-level plans. However, the price decrease dominates the reduction in quality, and thus entry-level subscription increases.

5.2. Analysis

Proponents' and opponents' claims about the effect of data caps on subscriptions are clearly in conflict. The models that led to these conflicting claims merit further examination. A user's decision whether to subscribe to broadband Internet access service, and if so to which plan, depends jointly on the prices and performance of these plans. It should thus be possible to combine the analysis in Section 3 regarding prices and the analysis in Section 4 regarding performance to estimate the resulting subscriptions.

Proponents uniformly agree that data caps will reduce the price of entry-level plans and increase speeds, and that subscription will thus increase. However, the models by these proponents that show price reductions typically assume profit-maximizing caps. In contrast, the models that show performance increases typically assume some form of heavy-users caps by assuming the purpose of data caps is to reduce congestion. To clarify the validity of each claim, and whether the combination results in increased subscription, these two types of caps should be considered separately.

First consider data caps intended to recover costs associated with heavy usage in fixed broadband Internet access service. In previous sections, we concluded that heavy-users caps are unlikely to substantially affect service prices, and are unlikely to significantly affect the performance of entry-level plans. Without changes in either the price or performance of entry-level plans, the heavy-users analytical models for both monopoly and duopoly providers find that such data caps are unlikely to increase overall subscription. These results likely differ from the predictions of proponents for two reasons. First, as discussed in Section 3, some of the proponents' models do not separate the effect of price discrimination based on speed from the incremental effect of price discrimination based on data caps. Second, the proponents do not explicitly model heavy-users caps, and thus can't accurately predict the effect on network performance.

Next consider data caps on fixed broadband Internet access service that are intended to maximize profit. Bauer and Wildman 2012's model leads them to conclude that profit-maximizing caps will increase broadband Internet access service subscription. They also briefly argue that increased network capacity and reduced usage will lead to lower congestion. The application of these conclusions is limited by the nature of the model, namely a comparison between a pair of plans with data caps to a single plan with no data cap and no usage-based pricing. As discussed in Section 3, this conflates two effects – the effect of data caps and the effect of price discrimination.

The academic literature on fixed broadband Internet access service shows that price discrimination based on download and upload speed results in the offering of lower priced plans, and hence an increase the number of consumers who subscribe to fixed broadband Internet access service.[21] It is less clear, however, whether the *addition of data caps* to a menu of service tiers already differentiated by download and upload speeds would result in a *further reduction* of the prices of entry level plans and thus a further increase in the number of subscribers. Indeed,

[21] See for instance W. Dai and S. Jordan, "ISP Service Tier Design," IEEE/ACM Transactions on Networking, vol. 24, no. 3, June 2016, http://ieeexplore.ieee.org/document/7080910/.

Dai and Jordan 2015 found that a monopolist is likely to *reduce* the speed of lower speed plans while not significantly changing the price of such plans, potentially resulting in *decreased* subscription. In contrast, Dai et al. 2014 found that when cable and DSL providers compete, the use of profit-maximizing data caps results in no first order effect. Second order effects might result in the DSL provider offering a lower price and lower quality product. This occurs because the cable provider benefits from profit-maximizing data caps while the DSL provider does not. In summary, it is probable that profit-maximizing caps result in increased subscription *only when* multiple broadband providers use them to further differentiate their service plans from each other.

Finally, consider the use of data caps by mobile broadband providers. In Section 3, we found that the use of *heavy-users caps* is likely to result in differentiation of service plans, including new lower priced entry-level plans. We also found that heavy-users caps reduce network costs, which in turn result in higher user throughput. The combination of lower entry-level prices and increased network performance will increase overall subscription. The effect of *profit-maximizing caps* on overall subscription is less clear, and there is no specific analysis. In Section 3 we conjecture that profit-maximizing caps would also result in increased differentiation of service plans and prices, and in Section 4 we found that they would also reduce congestion and increase network performance. The combination of increased performance and potentially reduced entry-level prices is then likely to result in increased subscription. The comparison between overall subscription under heavy-users caps versus under profit-maximizing caps likely depends on whether data caps are used by various providers to differentiate from each other. If data caps are used by mobile broadband providers to differentiate between each other, then it is likely that competition will result in an overall subscription close to that of plans with heavy-users caps. In contrast, if data caps are used by mobile broadband providers in a manner similar to each other, it is likely that the overall subscription under profit-maximizing caps will lag that under heavy-users caps. In addition, it is worth noting that we concluded in Section 3 that mobile broadband profit-maximizing caps will be lower and overage charges higher than for mobile broadband heavy-users caps. We must thus consider whether increased subscription may come at the cost of reduced user surplus; we discuss this below.

6. The Effect of Data Caps on Usage and Congestion

Proponents assert that data caps affect a small proportion of users, while opponents worry that over time they will affect a large proportion. Proponents often assert that data caps are high enough so that they don't affect typical consumer use, while opponents calculate that data caps are low enough to discourage subscribers of cable television services from discontinuing that service in favor of over-the-top video. Although both proponents and opponents of data caps generally agree that their use reduces broadband Internet usage, they often disagree about whether data caps reduce congestion. Proponents assert that regulating monthly usage reduces congestion, while opponents often claim that the two are unrelated.

6.1. Survey

Lyons 2013 argues that data caps can be used to reduce congestion, explaining that "[u]sage-based pricing can also be a tool to compel more efficient network operation. If the price a customer pays for use reflects the cost that use imposes on the network, the customer is less likely to overuse the network" (Lyons, 2013, page 29).

Rogerson 2016 makes similar arguments for mobile broadband service (Rogerson, 2016, pages 16-22). He observes that "mobile subscribers generally limit their use of mobile devices to some extent and also attempt to offload their usage to" fixed broadband Internet service (commonly using Wi-Fi) as a result of data caps and/or throttling of heavy-users. He claims that "it is completely clear that demand for mobile data transmission would vastly exceed the available supply if all current subscribers to mobile broadband were enrolled in completely unlimited plans under which they paid a fixed fee for monthly service with no data cap or limits of any sort." He concludes that without data caps, mobile providers "could [be] overwhelm[ed] with vastly more traffic than they could handle". Without data caps, he sees mobile broadband providers as facing a choice between low prices that would result in "massive amounts of congestion that would make the network essentially unusable for significant fractions of the day in significant fractions of the country" and high prices that would result in "a significant share of U. S. consumers that currently subscribe to mobile broadband service [] priced out of the market".

In contrast, others see a disconnect between heavy monthly usage and network congestion. Odlyzko et al. 2012 believe that usage-based pricing reduces aggregate usage compared to flat-rate plans (Odlyzko et al., 2012, page 46). However, they argue that usage-based pricing is an ineffective means to address network congestion, explaining that "unless [usage-based pricing] contains a time-of-day billing feature and some immediate feedback on congestion it is hard to imagine how it can be used as a congestion management tool" (Odlyzko et al., 2012, pages 28-30). Hussain et al. 2012 agree that data caps reduce usage, but similarly argue that data caps cannot be used to effectively manage network congestion, noting that "[t]he main challenge for network engineers is how to deal with demand during peak hours" and "unnecessarily limits use even when the network is not congested" (Hussain et al., 2012, page 6). In response, Rogerson 2016 argues that instantaneous usage-based pricing is impractical (Rogerson, 2016, pages 19-20).

Others point out uncertainties regarding usage. Chetty et al. 2012 study twelve households in South Africa, and find that uncertainties related to the use of data caps pose substantial challenges, including tracking usage, estimating potential usage, and sharing usage among families (Chetty, et al., 2012, pages 3023-3028). The GAO similarly reported that study participants exhibited confusion over data consumption, and expressed concerns about tracking device usage and about the potential effect of data caps on their Internet use (GAO Report, 2014, pages 16-19).

Both analytical and empirical studies confirm that data caps reduce usage. Nevo et al. 2016 found that the use of data caps by one fixed broadband provider likely reduced average usage (Nevo et al., 2016, pages 23-25). Dai and Jordan 2015's model predicts that both heavy-users caps and profit-maximizing data caps reduce usage. They also predict that the usage reduction is primarily that of low-income and heavy-usage subscribers to high speed plans (Dai and Jordan, 2015, pages 11-12). Malone et al. 2014 found that data caps reduced usage of heavy users and that the percentage reduction was largest for the heaviest users (Malone et al., 2014, page 1036).

Other papers provide useful insight into the relationship between monthly usage and congestion. Fukuda et al. 2015 showed that many users paying overage charges substantially decreased their usage during the peak usage period, establishing that there was some correlation between heavy monthly usage and congestion (Fukuda et al., 2015, pages 262-263).[22] Wang et al. 2016 predicted a correlation, using the monopoly model discussed above, by showing that congestion increases with the size of the data cap, decreases with the service price, and decreases with more competition.

Others attempted to determine the amount of the correlation. Malone et al. 2014 found that overall usage dropped by the same proportion in peak and off-peak usage periods (Malone et al., 2014, pages 1040-1044). In their study, the broadband provider offered plans with data caps in which the overage charge substantially exceeded the average price per volume of the service price, and thus the data caps were harsher than heavy-users caps. Joe-Wong et al. 2015 found that although data caps reduced monthly usage, they did not reduce peak period usage as much as off-peak period usage, establishing an upper bound on the amount of correlation (Joe-Wong, et al., 2015, pages 103-104).[23]

6.2. Analysis

Although most parties agree that data caps reduce usage, proponents' and opponents' claims about the effect of data caps on congestion are clearly in conflict. The models that led to these conflicting claims merit further examination.

Since congestion is often discussed in relation to heavy usage for which a broadband provider receives less revenue than the associated cost, it is worth starting by examining the effect of heavy-users caps by fixed broadband providers. Both proponents and opponents agree that heavy-users caps will reduce aggregate usage, and the analytical models agree. More specifically, the usage of existing broadband subscribers will decrease, in particular that of low-income heavy users who are sensitive to the heavy-users cap and overage charge. In addition, in Section 5 we concluded that heavy-users caps are unlikely to increase subscriptions to fixed broadband Internet access service, and thus are unlikely to add usage from new subscribers. Indeed, Dai and Jordan 2015 found that a monopolist is likely to reduce the speed of lower speed plans while not significantly changing the price of such plans, potentially resulting in decreased subscription.

Nevertheless, the question remains whether the reduced usage under heavy-users caps results in reduced congestion. Although none of the proponents explicitly model usage, many discuss in detail how data caps can reduce congestion. Lyons 2013 asserts that usage-based pricing that "reflects the cost that use imposes on the

[22] The empirical study was based on usage data collected in 2013-2015 from 1500 smartphone users in Tokyo.
[23] The empirical study was based on data collected in 2012-2013 from the usage of 27 mobile broadband subscribers.

network" (i.e., heavy-users caps) can more fairly apportion costs, and that this will result in less overuse and reduced congestion (Lyons, 2013, page 29). In the short-term, reduced usage from newly added heavy-users caps will indeed reduce congestion, as capacity remains fixed. However, in the long term, broadband providers will augment network capacity based on the desired performance of the dominant applications, returning congestion to the desired level. Thus, in the long term, the reduced usage under heavy-users caps will result in slower augmentation of network capacity but not reduced congestion.

That said, the question remains whether heavy-users caps can more fairly apportion costs. Heavy-users caps impose costs upon heavy users in relation to their monthly usage, while usage-sensitive capacity costs are a function of the capacity required to accommodate demand in peak usage periods. However, in Section 2.2 we concluded that it is likely that there is a moderate correlation between monthly usage and peak-period usage. Thus, it is likely that heavy-users caps increase fairness.

Next consider the effect upon usage and congestion of *profit-maximizing caps* by fixed broadband providers. Since profit maximization results in lower caps and higher overage charges than when heavy-users caps are used, it follows that profit-maximizing caps will result in even lower usage than will heavy-users caps. In the short term, Wang et al. 2016 show that the more stringent profit-maximizing caps reduce congestion. The studies by Fukuda et al. 2015 and Malone et al. 2014 similarly showed that overage charges reduced usage during the peak usage period. In the long term, however, there is no reason to believe that profit-maximizing caps affect congestion, as broadband providers will similarly set capacity based on the desired performance of the dominant applications.

That said, whether a data cap is a heavy-users cap or a profit-maximizing cap does affect the question of fairness. The study by Malone et al. 2014 indicated that profit-maximizing caps were likely to reduce the usage most for the heaviest users, thus resulting in increased fairness. The studies by Malone et al. 2014 and Joe-Wong et al. 2015 seem to show conflicting results about the shift in peak versus off-peak usage. However, taken together they likely indicate two trends. First, heavy users have greater demands than non-heavy users in peak usage periods, but not by as great a ratio as in off-peak usage periods. Second, profit-maximizing caps reduce the usage of heavy users in both peak and off-peak usage periods. The reduction in peak usage period demand is thus not as great as the reduction in monthly usage. Correspondingly, although profit-maximizing caps increase fairness compared to unlimited plans, they penalize heavy-users more than is fair.

The differences in the various claims center on how costs are apportioned, and on how this affects investment. Most parties agree that second-degree price discrimination may be an economically efficient method for apportioning costs, but disagree about whether profit-maximizing data caps are a socially beneficial method of doing so.

As presented by Bauer and Wildman 2012, costs are often separated into costs attributable to individual subscribers and non-attributable costs shared among subscribers. More precisely, as presented by Dai and Jordan 2015, attributable costs can be further separated into variable access costs and variable capacity costs. Then, variable access costs can be assessed in the monthly service price, and variable capacity costs can be assessed using heavy-users caps and overage charges. Profit-maximizing caps, therefore, do not result in increased fairness in attributing either variable access costs or variable capacity costs. To the extent to which monthly usage is correlated with peak period usage, heavy-user caps already impose on heavy users their fair share of variable capacity costs. Heavy-users caps, by their definition, include the best available capacity price signal among those based on monthly usage. Profit-maximizing caps decrease – not increase – the effectiveness of the capacity price signal. The only remaining question about apportioning costs is whether usage-based pricing is an efficient manner of allocating non-attributable costs. But for fixed broadband service, there is no evidence as to why allocating non-attributable costs on the basis of data caps is more efficient than allocating them on the basis of the speed of the service plan.

Finally, consider the effect of data caps in *mobile broadband service* upon usage, congestion, and fairness. Proponents and opponents agree that heavy-users caps reduce the usage of current subscribers, and the analytical models agree. In Section 5, we found that heavy-users caps would also increase overall subscription, resulting in added usage. However, as the incremental subscription is likely that of light users, the decreased heavy usage will dominate the increased usage from incremental subscription, and thus overall usage will drop. The increased profit will be reinvested into network capacity, and congestion will be reduced. Fairness will increase, as heavy-users no longer subsidize non-heavy users. The effect of profit-maximizing caps upon usage, congestion, and fairness is similar. Usage will drop, likely by an even greater amount than under heavy-users caps, due to decreased heavy usage from more stringent data caps and overage charges. Although not all increased profits will be invested into network capacity, congestion will still decrease. Fairness will increase compared to unlimited plans, but will decrease compared to the use of heavy-users caps.

7. The Effect of Data Caps on Consumer Surplus

After making various claims about the effect of data caps on service prices, speeds, capacity, subscriptions, usage, and congestion, proponents and opponents ultimately disagree about whether they are in the public interest. Proponents often believe that data caps increase consumer surplus, or if not then at least increase social welfare. Opponents invariably believe data caps decrease consumer surplus.

7.1. Survey

Bauer and Wildman 2012 state that the theoretical economics literature "tells us that [social] welfare is often increased by" second-degree price discrimination (Bauer and Wildman, 2012, page 6). As discussed in Section 3, Bauer and Wildman 2012 provide a simple example to compare the use of a pair of plans with data caps to a single plan with no data cap and no usage-based pricing (Bauer and Wildman, 2012, pages 6-9). In the example, the use of data caps may increase the broadband provider's profit. Although the example does not establish whether either consumer surplus or social welfare is increased with the use of data caps, they believe that reduced prices of lower quality entry-level plans and the resulting increased subscription will usually increase consumer surplus.

As described in Section 2, Rogerson 2016's principal argument is that the mobile industry is competitive, and that the efficiency gains created by usage based pricing will be largely passed through to subscribers. However, drawing from the economics literature on price discrimination by an unregulated monopolist, he also states that an unregulated monopoly mobile provider "would likely earn higher profits by engaging in usage-based pricing", and that usage-based pricing increases social welfare, defined as the sum of consumer surplus and industry profits (Rogerson, 2016, page 23). He also claims that "it may be that total consumer surplus will increase as well", due to increased subscription resulting from higher markups on high-usage plans and lower markups on low-usage plans.

In a white paper sponsored by the Phoenix Center, Ford 2012 provides a simple example to compare social welfare (defined as the sum of consumer surplus and provider profit) under a pair of tiers, the lower of which is insufficient to support video, to that under a single service tier. In the example, there are three users who differ in their utilities for the pair of tiers as well as for a standalone video service. The example purports to show that social welfare is maximized by a profit-maximizing broadband provider that offers the pair of tiers (Ford, 2012, pages 3-5). The cause of increased social welfare in the example is an increase in broadband provider profit that exceeds the reduction in consumer surplus.

Dai and Jordan 2015's model predicts that heavy-user data caps result in decreased surplus of heavy users. The reduced surplus is transferred to the broadband provider through increased profit, due to the reduction in cost associated with the reduction in usage. Although consumer surplus is reduced, it does more fairly distribute costs among users, to the extent that heavy monthly usage is correlated with user contributions to congestion.

Dai and Jordan 2015 also show that, compared to no data caps, profit-maximizing data caps increase the surplus of high speed tier subscribers who have moderate valuations on video streaming and moderate-to-high incomes, since these users benefit from the reduced tier price and increased tier rate (Dai and Jordan, 2015, pages 15-16). However, the surplus of high speed tier subscribers who have moderate-to-high valuations on video streaming and low-to-moderate incomes decreases, since the effect of the cap and overage charges outweigh the reduction in tier price and the increase in tier rate. The surplus of low speed tier subscribers also decreases, due to reduced tier speeds. Using numerical parameters gathered from Internet statistics, they observe that, compared to no data caps, profit-maximizing data caps decrease total user surplus and increase broadband provider profit by similar amounts. The reduction in total user surplus is increasing with the proportion of heavy users and with income inequality.

Economides and Hermalin 2015, using the model discussed above, derive several interesting results about social welfare. First, they show that absent congestion and if network capacity is held fixed, any overage charge reduces social welfare (Economides and Hermalin, 2015, pages 303-305, Corollary 1). Next, they show that, if there is a polynomial congestion externality and if network capacity is held fixed, then profit-maximizing caps likely reduce social welfare compared to no data caps (Economides and Hermalin, 2015, page 311, Proposition 9).[24]

The GAO found, based on a study of the economics literature, that the effect of data caps on consumer surplus depends on the amount of competition. Specifically, they found that "[i]n a competitive market place, [usage-based

[24] They also propose a different model in which they explore the effect of heterogeneous consumers and content; they find similar results in Propositions 15-16.

pricing] may enhance consumer welfare because firms may compete to offer different versions of a product at competitively low prices", whereas "[i]n markets that are not very competitive, this kind of price discrimination may not be beneficial because limited competition gives the seller greater ability to make take-it-or-leave-it offers to consumers—who may face few choices to move to other providers—that may enhance providers' profits at the expense of consumer welfare" (GAO Report, 2014, pages 22-23).

Nevo et al. 2016 find that the use of data caps may reduce consumer surplus, but the direction of the effect may be sensitive to model parameters (Nevo et al., 2016, pages 23-25). They find that competition from another fixed broadband provider offering slower speed plans produces similar effects.

Dai et al. 2014 show that under a duopoly, profit-maximizing data caps increase the surplus of subscribers to low speed tiers, since these users benefit from the reduced tier price more than they are hurt by the decreased speed, and decrease the surplus of heavy users (Dai et al., 2014, pages 5-6). Total user surplus may either decrease or increase, depending on the distribution of user utility. The DSL provider's profit decreases, since it loses market share and decreases service prices. The cable provider's profit increases, since it gains market share and is now earning a profit on heavy users. The shift from consumer surplus to total provider profit may be substantial if the marginal capacity cost is high or if there are a large number of heavy users.

7.2. Analysis

The claim by proponents of data caps that their use increases consumer surplus relies primarily on the belief that subscription increases in reaction to new lower priced (and perhaps lower speed) plans. As above, it is worthwhile to separately consider the use of heavy-users caps and of profit-maximizing caps.

Proponents do not explicitly model *heavy-users caps*. However, they generally claim that data caps intended to recover the cost associated with heavy users result in increased subscription due to more fair cost sharing. In contrast, we found in Section 5 that analytical models contradict these claims, and that heavy-users caps are unlikely to result in increased subscription to fixed broadband Internet access service. Any change in consumer surplus, therefore, must come from the effect on existing subscribers, and this effect depends on competition. When used by a monopoly provider, the analytical models show that heavy-users caps do not affect the consumer surplus of non-heavy users (since there is no significant change to either price or speed) and reduce the consumer surplus of heavy users (due to the cap). The reduced consumer surplus of heavy users is transferred to increased broadband provider profit. The broadband provider, in turn, is unlikely to reinvest the increased profit in a manner that increases consumer surplus. In contrast, when used by duopoly providers, the analytical models show that heavy-users caps affect both moderate and heavy users. Moderate users see an increase in the speed of high speed plans, with no change in price, and thus experience increased consumer surplus. Heavy users feel the impact of the data cap outweighs the increase in speed, and thus experience reduced consumer surplus. The change in total consumer surplus is indeterminate.

In both monopoly and duopoly, even if there is a reduction in total consumer surplus, heavy-users caps increase fairness. Broadband providers may have been losing money on the heaviest users, if the variable capacity cost is high, and thus the heaviest users may have been subsidized by other users. With heavy-users caps, this loss is eliminated.

Next consider the use of *profit-maximizing caps* by fixed broadband providers. Here the claim by proponents that increased subscription results in increased consumer surplus is central. However, the analytical models show that it is the second-degree price discrimination provided by offering multiple plans differentiated by speed that is the dominant cause for increased subscription. The effect again depends on competition. When used by a monopoly provider, the analytical models show that profit-maximizing caps reduce the consumer surplus of light users (due to decreased speeds and no price change), increase the consumer surplus of moderate users (due to increased speeds and reduced prices), and decrease the consumer surplus of heavy users (due to the impact of the data cap). Overall consumer surplus decreases, and it decreases more dramatically than under heavy-users caps, as additional consumer surplus is transferred to additional broadband provider profit. When used by duopoly providers, adding profit-maximizing data caps to already differentiated plans is likely to further increase subscription only to the extent that it is used by multiple broadband providers to further differentiate their products from each other, not to further differentiate a single broadband provider's existing products. Furthermore, any increase in subscription is likely to be dominated by changes in the consumer surplus of current subscribers. If there are few heavy users and strong competition, then the overall change in consumer surplus may be small and positive. However, if there are a substantial number of heavy users and/or weak competition, the overall change in consumer surplus may be large and negative, resulting in a substantial transfer to broadband provider profits.

Finally, consider the use of data caps by *mobile broadband providers*. Heavy-users caps are likely to increase overall consumer surplus, due to the benefits of differentiation in service plans, reduced congestion, and increased subscription. There is insufficient analysis to provide a definitive prediction on the effect of *profit-maximizing caps* on consumer surplus. In Section 5, we concluded that if the use of such caps results in increased differentiation between the plans offered by competing mobile broadband providers, then it is likely to result in increased subscription. We also conclude that profit-maximizing caps may result in reduced cost that may in part be passed on to consumers in the form of increased network performance. The combination of increased subscription and increased network performance would likely result in increased consumer surplus. However, it is reasonable to expect that the magnitudes of both the increased subscription and increased network performance will be less than those under heavy-users caps, and therefore that any increase in consumer surplus will similarly be less than that under heavy-users caps.

8. Summary

Our analysis of the effect of data caps on service prices, speeds, subscriptions, usage, and consumer surplus is summarized in Tables 3-5.

Heavy-users caps used by a monopolist fixed broadband provider are likely to result in reduced usage by heavy users, but no significant change in service prices, speeds, or overall subscriptions. They are likely to increase fairness by transferring consumer surplus of heavy users to broadband provider profit.

Profit-maximizing caps used by a monopolist fixed broadband provider are likely to result in reduced usage by heavy users, decreased speeds of low speed plans, increased speeds and reduced prices of high speed plans, and reduced overall subscription. They are likely to increase fairness compared to unlimited plans, but reduce fairness compared to heavy-users caps, and they are likely to reduce consumer surplus by more than is required to increase fairness.

Table 3. Monopoly fixed broadband provider.

Type of data cap	**Heavy-users cap**	**Profit-maximizing cap**
Caps, overage charges	Cap set to the capacity paid for in the service price, and overage charge set by the marginal cost for capacity.	Cap is lower than the heavy-users cap, and overage charge is higher than in the heavy-users cap.
Prices	No change in service prices.	No change in the prices of low speed plans; decreased prices of high speed plans (compensated by overage charges on heavy users)
Speeds	No change in download or upload speeds.	Decreased speed in low speed plans; increased speed in high speed plans.
Subscriptions	Movement between plans, but no change in overall subscription.	Decrease in overall subscription, due to the decreased speed in low speed plans.
Usage, congestion, and fairness	Reduced usage, primarily by low income heavy users. Reduction in short-term congestion. Increased fairness.	Reduced usage, more so than under heavy-users caps. Reduction in short-term congestion. Increased fairness compared to unlimited plans, but decreased fairness compared to heavy-users caps.
Consumer surplus	Reduced consumer surplus for heavy users, directly proportional to increased fairness.	Compared to unlimited plans: reduced consumer surplus of light and heavy users, increased consumer surplus of moderate users. Reduced overall consumer surplus compared to both unlimited plans and heavy-users caps.

Heavy-users caps used by duopoly fixed broadband providers are likely to result in reduced usage by heavy users, and an increase in the speed of high speed plans, but no significant change in service prices or overall subscriptions. They are likely to increase fairness by transferring consumer surplus of heavy users to broadband provider profit, and to increase the consumer surplus of moderate users who benefit from increased speed.

Profit-maximizing caps used by duopoly fixed broadband providers are likely to result in reduced usage by heavy users, and in moderate reductions in the prices of high speed plans. If the caps are used to further differentiate the products offered by the two providers, they may also result in moderate reductions in the speeds and prices of low-speed plans, and moderate increases in overall subscription. They are likely to increase fairness compared to unlimited plans, but reduce fairness compared to heavy-users caps, and they are less likely to increase consumer surplus than are heavy-users caps.

Table 4. Duopoly fixed broadband providers.

Type of data cap	Heavy-users cap	Profit-maximizing cap
Caps, overage charges	Cap set to the capacity paid for in the service price, and overage charge set by the marginal cost for capacity.	More stringent than heavy-users caps under duopoly, but less stringent than profit-maximizing caps under monopoly.
Prices	No 1st order effect on service prices.	No 1st order effect on service prices. If caps are used to differentiate from the other broadband provider, 2nd order effects may result in decreased price of low speed plans and increased price of high speed plans.
Speeds	No change in the speed of low speed plans; increased speed in high speed plans.	No 1st order effect on speeds. 2nd order effects may result in decreased speed of low speed plans.
Subscriptions	Movement between plans, but no change in overall subscription.	Movement between broadband providers, but no 1st order effect on overall subscription. If caps are used to differentiate from the other broadband provider, 2nd order effects may result in an increase in overall subscription.
Usage, congestion, and fairness	Reduced usage, primarily by low income heavy users. Reduction in short-term congestion. Increased fairness.	Reduced usage, more so than for heavy-users cap under duopoly, but less so than for profit-maximizing caps under monopoly. Reduction in short-term congestion. Increased fairness compared to unlimited plans, but decreased fairness compared to heavy-users caps.
Consumer surplus	Increased consumer surplus of moderate users, decreased consumer surplus of heavy users. Indeterminate change in overall consumer surplus.	Compared to unlimited plans: Increased consumer surplus of light users, decreased consumer surplus of heavy users. Indeterminate change in overall consumer surplus. Reduced overall consumer surplus compared to heavy-users caps.

Heavy-users caps used by mobile broadband providers are likely to result in reduced usage by heavy users, more differentiated service plans including new lower priced entry-level plans, increased user throughput, and increased overall subscription.

Profit-maximizing caps used by mobile broadband providers are likely to result in reduced usage by heavy users, more differentiated service plans including new lower priced entry-level plans, and increased user throughput. They are likely to result in increased overall subscription compared to unlimited plans, but decreased overall subscription compared to heavy-users caps. They are also likely to increase fairness compared to unlimited plans, but reduce fairness compared to heavy-users caps, and they are likely to increase consumer surplus by less than would heavy-users caps.

Table 5. Mobile broadband providers.

Type of data cap	Heavy-users cap	Profit-maximizing cap
Caps, overage charges	Caps set to differentiate a provider's plans. Overage charge set by the marginal cost for capacity.	More stringent than heavy-users caps, but less stringent as competition increases.
Prices	Differentiated prices for differentiated plans, including new lower priced entry-level plans.	Differentiated prices for differentiated plans, including new lower priced entry-level plans. If used to differentiate providers, prices will be similar to those under heavy-users caps; otherwise, prices will be higher.
Speeds	Increased user throughput.	Increased user throughput.

Type of data cap	Heavy-users cap	Profit-maximizing cap
Subscriptions	Increased overall subscription.	Increased overall subscription compared to unlimited plans, but lower compared to heavy-users caps.
Usage, congestion, and fairness	Reduced usage. Decreased congestion. Increased fairness.	Reduced usage, even more so than under heavy-users caps. Decreased congestion. Increased fairness compared to unlimited plans, but decreased fairness compared to heavy-users caps.
Consumer surplus	Increased overall consumer surplus.	Increased overall consumer surplus compared to unlimited plans, but decreased compared to heavy-users caps.

Comparison of this summary to the conflicting claims of regarding the purposes and effects of data caps yields a more nuanced view that depends strongly on the type of data cap and the amount of competition.

With respect to the use of data caps by fixed broadband providers, the claims of proponents that data caps manage congestion and increase fairness apply to heavy-users caps, but less so to profit-maximizing caps. The claims of opponents that data caps monetize scarcity and increase profit apply to profit-maximizing caps, but less so to heavy-users caps. Proponents' claims that data caps result in lower priced entry-level plans and increased subscription hold if profit-maximizing caps are used by duopolies to further differentiate their products, but not if profit-maximizing caps are used in the absence of such competition, and not for heavy-users caps.

Proponents' claims that recovered costs are reinvested into network capacity don't fare well under either type of caps on fixed broadband service. The claim by some opponents that data caps incentive broadband providers to reduce network capacity to further monetize scarcity also does not fare well.

Proponents' claims that data caps increase fairness is likely correct, especially for heavy-users caps. However, opponents' claims that data caps reduce consumer surplus is also likely to be true when profit-maximizing caps are used by monopolists.

With respect to the use of data caps by mobile broadband providers, proponents' claims fare better due to the increased competition. The user of heavy-users caps in mobile broadband service has the clearest benefit compared to unlimited plans, resulting as the proponents claim in increased subscription, higher throughput, increased fairness, and increased consumer surplus. However, profit-maximizing caps reduce much of those benefits.

9. Implications under the 2015 Open Internet Order

The 2015 Open Internet Order does not pass judgement on whether data caps would violate any its rules, but it does discuss how they would be judged. The Order notes that data caps "may benefit consumers by offering them more choices over a greater range of service options, and, for mobile broadband networks, such plans are the industry norm today, in part reflecting the different capacity issues on mobile networks" (2015 Open Internet Order, paragraph 153). The Order also notes that "[c]onversely, some commenters have expressed concern that such practices can potentially be used by broadband providers to disadvantage competing over-the-top providers." It then declares that any concerns about data caps will be addressed on a case-by-case basis under the general conduct rule in the Order.

In addition, data caps are covered by the Order's transparency rule. The transparency rule requires that broadband Internet access service providers "publicly disclose accurate information regarding the network management practices, performance, and commercial terms of its broadband Internet access services sufficient for consumers to make informed choices regarding use of such services and for content, application, service, and device providers to develop, market, and maintain Internet offerings" (2010 Open Internet Order, paragraph 54). The 2015 Open Internet Order clarifies that the required disclosures include "any data caps or allowances that are a part of the plan the consumer is purchasing, as well as the consequences of exceeding the cap or allowance" (2015 Open Internet Order, paragraph 164). In addition, the when a network practice is applied to traffic associated with a particular user or user group, the disclosures must include "the purpose of the practice, which users or data plans may be affected, the triggers that activate the use of the practice, the types of traffic that are subject to the practice, and the practice's likely effects on end users' experiences" (2015 Open Internet Order, paragraph 169). These requirements may be particularly important for mobile broadband plans that are branded as "unlimited". If such plans throttle users whose monthly usage exceeds a threshold (as most do), then the transparency rule requires that the likely effect of such throttling on end user's experiences. Many such disclosures state only that throttling of heavy users may result in decreased performance such as reduced speeds and increased latency, but do not disclose anything about the frequency or severity of such decreased performance. It is unlikely that such limited disclosures could be reasonably construed as providing information sufficient for consumers to make informed choices regarding use of mobile broadband Internet access service.

The general conduct rule provides protection against broadband provider practices that that harm Internet openness.[25] Specifically, the rule states that broadband Internet access service providers shall not "unreasonably interfere with or unreasonably disadvantage (i) end users' ability to select, access, and use broadband Internet access service or the lawful Internet content, applications, services, or devices of their choice, or (ii) edge providers' ability to make lawful content, applications, services, or devices available to end users" (2015 Open Internet Order, paragraph 136). The rule allows an exception for "reasonable network management", which is defined and discussed below.

The Order sets out a non-exhaustive list of factors to be used in assessing a network practice under the general conduct rule (2015 Open Internet Order, paragraphs 138-145). The most pertinent factors for evaluation of data caps are: competitive effects; effect on innovation, investment, or broadband deployment; and end-user control. Each of these factors is discussed below.

9.1. Reasonable Network Management

Network practices that qualify as reasonable network management do not violate the general conduct rule, regardless of the other factors for evaluation. Since proponents of data caps often propose that the primary purpose of data caps is to manage network congestion, it is worthwhile considering whether they may qualify as reasonable network management.

The Order defines the term "network management practice" as "a practice that has a primarily technical network management justification, but does not include other business practices" (2015 Open Internet Order, paragraph 215). It then states that "[a] network management practice is reasonable if it is primarily used for and tailored to achieving a legitimate network management purpose, taking into account the particular network architecture and technology of the broadband Internet access service."

The first question is thus whether data caps have a primarily technical network management justification. The answer critically depends on whether a data cap is a heavy-users cap or a profit-maximizing cap, as heavy-users caps and profit-maximizing caps have different purposes.

Thus, the FCC would first need to determine the nature of the cap. Recall that heavy-users caps have caps and overage charges set to recover the cost associated with heavy users. As discussed in Section 4, network costs can be categorized into a fixed cost that does not depend on either the number of subscribers or the traffic, a variable access cost that depends on the number of subscribers but not the traffic, and a variable capacity cost that depends on the capacity of the network. Although proponents and opponents disagree about whether the fixed cost should be allocated on the basis of monthly usage, both sides agree that the fixed costs and variable access costs are substantial, and that they should be reflected in the monthly service price (excluding any overage charges). A data cap could thus be considered as a heavy-users cap *only if* the overage charge (in $/GB) is *substantially less* than the average price per unit volume of the service tier (i.e. the monthly service price divided by the data cap, in $/GB). The data caps examined by Fukada et al., Malone et al. 2014, Nevo et al. 2016, and Joe-Wong et al. 2015 all have overage charges that *exceed* the average price per unit volume of the service tier, and thus are not heavy-users caps.

Profit-maximizing caps, by their definition, have a primarily business justification. The Order specifically notes that "a practice that permits different levels of network access for similarly situated users based solely on the particular plan to which the user has subscribed" does not qualify as reasonable network management (2015 Open Internet Order, paragraph 216). Profit-maximizing caps thus must be evaluated under the factors used in assessing a network practice under the general conduct rule. Data caps whose purpose is to protect incumbent pay-television services would similarly not qualify as reasonable network management.

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[25] The FCC is currently considering changes to the 2015 Open Internet Order's rules. See Federal Communications Commission, *Restoring Internet Freedom*, Notice of Proposed Rulemaking, WC Docket No. 17-108, May 18, 2017, accessed Aug. 17, 2017, http://apps.fcc.gov/edocs_public/attachmatch/FCC-17-60A1.docx. The NPRM proposes to eliminate the general conduct rule, seeks comment on whether to modify the no-throttling rule, and seeks comment on whether to keep, modify, or eliminate the transparency rule. Nevertheless, we believe the analysis in this paper is of both academic and policy interest. If the FCC issues an Order, it is likely to be litigated. In addition, the United States Congress may attempt to write Open Internet rules.

In contrast, proponents argue that when data caps and overage charges are set to recover the cost associated with heavy users, namely heavy-users caps, the primary purpose is to manage congestion. Furthermore, the 2010 Open Internet Order explicitly states that alleviating congestion is a technical network management justification (2010 Open Internet Order, paragraph 82). The question thus boils down to whether regulating monthly usage reduces congestion. Proponents assert it does, while opponents often claim that the two are unrelated. In Section 4, we found that in the short-term reduced usage from newly added heavy-users caps will reduce congestion, and that in the long-term broadband providers will augment network capacity based on the desired performance of the dominant applications, returning congestion to the desired level. The short-term benefit is likely sufficient to determine that heavy-users caps have a primarily technical management justification. Thus, heavy-users caps could likely be evaluated to determine whether they are reasonable network management.

For heavy-users caps, the next question is thus whether they are "primarily used for and tailored to achieving" a reduction in congestion. The question of whether heavy-users caps are "tailored to" alleviating congestion focusses on whether they are a reasonable method for doing so. Proponents argue that data caps are an efficient and effective means for alleviating congestion. Opponents argue that data caps are an ineffective means for alleviating congestion, pointing toward the weak correlation between monthly usage and peak-period usage and arguing for more tailored methods. The academic literature shows that there is a strong correlation between heavy monthly users and heavy peak usage period users. However, the relationship between monthly usage and peak period usage is not linear, and thus the correlation between monthly usage and a user's contribution to congestion is only moderate. There are reasonable arguments on both sides here. The Order states that "[i]n evaluating congestion management practices, […] we will also consider whether the practice is triggered only during times of congestion and whether it is based on a user's demand during the period of congestion" (2015 Open Internet Order, paragraph 220). Data caps fail both parts of this test. On the other hand, a broadband provider need not show that data caps are the *most tailored* method for alleviating congestion.[26] Thus, it is unclear whether heavy-users caps would be judged as sufficiently tailored.

If heavy-users caps are judged as sufficient tailored, the only remaining question is whether heavy-users caps are "primarily used for" alleviating congestion. In Section 7 we noted that heavy-users caps result in a transfer from the consumer surplus of heavy users to broadband provider profit. Thus, there is a benefit to the broadband provider other than reducing congestion. However, since the transfer of consumer surplus is directly related to the increase in fairness, a strong argument can be made that the primary use of heavy-users caps is to alleviate congestion.

In summary, good arguments can be made on both sides of whether heavy-users caps satisfy the definition of reasonable network management, and thus would not violate the general conduct standard. However, profit-maximizing caps would not qualify as reasonable network management, and thus must be evaluated under the other factors guiding application of the general conduct rule.

9.2. Competitive Effects

In laying out the landscape for the competitive effects factor, the Order discusses both the potential incentive and potential ability of a broadband provider to use network practices that have anti-competitive effects.

With respect to incentive, the Order notes that "broadband providers have incentives to interfere with and disadvantage the operation of third-party Internet-based services that compete with the providers' own services" (2015 Open Internet Order, paragraph 140). More specifically, the FCC stated in the 2010 Open Internet Order 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" and that "[b]y interfering with the transmission of third parties' Internet-based services or raising the cost of online delivery for particular edge providers, telephone and cable companies can make those services less attractive to subscribers in comparison to their own offerings" (2010 Open Internet Order, paragraph 22).

The FCC could analyze whether a broadband provider's purpose in using data caps coincides with such an anti-competitive incentive. Proponents often argue that the principal purpose of data caps is to manage congestion and increase fairness, and that these purposes are in no way anti-competitive. Opponents often argue that the principal purpose of data caps is to increase profit and/or to retain subscribers to the broadband providers' pay-television services. Heavy-users caps do not have anti-competitive incentives. Profit-maximizing caps do not have anti-

[26] The FCC rejected a proposal that "network management techniques … would only be reasonable if they were used temporarily, for exceptional circumstances, and have a proportionate impact to solve a targeted problem." See 2015 Open Internet Order, paragraph 222.

competitive incentives, but may have anti-competitive effects, as discussed further below. Caps intended to protect incumbent pay-television services clearly have anti-competitive incentives. As discussed above, the FCC could analyze the purpose of a data cap by examining the ratio of the overage charge to the average price per unit volume of the service tier.

More likely, however, the FCC would place the emphasis not on the incentive but on the exercising of an ability. The Order notes that "[p]ractices that have anti-competitive effects in the market for applications, services, content, or devices would likely unreasonably interfere with or unreasonably disadvantage edge providers' ability to reach consumers in ways that would have a dampening effect on innovation, interrupting the virtuous cycle" (2015 Open Internet Order, paragraph 140). The Order also specially notes that "[d]ata caps or allowances, which limit the amount and type of content users access online, can have a role in providing consumers options and differentiating services in the marketplace, but they also can negatively influence customer behavior and the development of new applications" (2015 Open Internet Order, paragraph 82). It is well established in the literature that data caps may influence customer behavior, but proponents and opponents differ in their view of whether such influence is positive or negative. Similarly, proponents and opponents differ in their view of whether data caps negatively influence the development of new applications. Fortunately, the general conduct rule states more specific tests, and separately considers the effect of a network practice on end users and on edge providers.

With respect to edge providers, the question is whether a specific data cap unreasonably interferes with or unreasonably disadvantages an edge provider's ability to make lawful content, applications, services, or devices available to end users. The Order states that "[p]ractices that have anti-competitive effects in the market for applications, services, content, or devices would likely unreasonably interfere with or unreasonably disadvantage edge providers' ability to reach consumers" (2015 Open Internet Order, paragraph 140). Data caps clearly interfere with or disadvantage an edge provider's ability to offer high-volume content. The question is whether this inference or disadvantage is *unreasonable*. Here, the comparison must be between a broadband provider's own non-broadband services and the high-volume edge provider services that compete with them. Since broadband providers must cover the capacity cost of their non-broadband services, charging the broadband user overage fees that correspond to the cost of heavy usage does not disadvantage competing over-the-top services. Hence, *heavy-users caps* do not unreasonably interfere with or disadvantage an edge provider's ability to offer high-volume content. In contrast, because *profit-maximizing caps* do more than recover cost associated with usage, they must be analyzed for potential anti-competitive effects. Hard caps would clearly have anti-competitive effects upon competing over-the-top video providers. Thus, there is a strong argument that profit-maximizing caps may indeed disadvantage an edge provider's ability to offer high-volume content. Similarly, data caps intended to protect a broadband provider's incumbent pay-television services would disadvantage an edge provider's ability to offer high-volume content.

With respect to end users, the question is whether a specific data cap unreasonably interferes with or unreasonably disadvantages an end user's ability to select, access, and use broadband Internet access service or the lawful Internet content, applications, services, or devices of their choice. The Order states that "anticompetitive practices are likely to harm consumers' and edge providers' ability to use broadband Internet access service to reach one another" (2015 Open Internet Order, paragraph 140). The analysis of the effect on an end user's ability thus is similar to the effect on an edge provider, since anticompetitive practices would affect an end user through a diminishing of applications available.

9.3. Effect on Innovation, Investment, or Broadband Deployment

This factor focusses on what the FCC calls the "virtuous [cycle] of innovation in which new uses of the network—including new content, applications, services, and devices—lead to increased end-user demand for broadband, which drives network improvements, which in turn lead to further innovative network uses" (2010 Open Internet Order, paragraph 77). In applying this factor, the Order states that "practices that stifle innovation, investment, or broadband deployment would likely unreasonably interfere with or unreasonably disadvantage end users' or edge providers' use of the Internet" (2015 Open Internet Order, paragraph 142).

Proponents argue that data caps recover cost in order to fund incremental network capacity. Opponents express doubt that data caps impact network capacity. In addition, opponents express concern that data caps impede innovation and investment by edge providers.

Consider investment by broadband providers. In Section 4 we concluded that the use of data caps by *mobile broadband providers* will result in increased network capacity, but that their use by *fixed broadband providers* is unlikely to result in increased network capacity.

Next consider broadband deployment. In Section 5 we concluded that the use of *heavy-users caps* by fixed broadband providers is unlikely to significantly affect overall subscription, that the use of *profit-maximizing caps* by fixed broadband providers is likely to reduce overall subscription, and that the use of either type of data cap by *mobile broadband providers* will result in increased overall subscription.

However, innovation and investment includes both that by broadband providers and that by edge providers, and thus the effect of data caps on broadband providers and on edge providers must both be considered. As discussed above, profit-maximizing caps interfere with or disadvantage an edge provider's ability to offer high-volume content, and hence reduce innovation and investment by such edge providers.

In summary, a fixed broadband provider's use of *heavy-users caps* is unlikely to significantly affect investment, innovation, or broadband deployment; but their use of *profit-maximizing caps* is likely to reduce overall investment, innovation, and broadband deployment. A mobile broadband provider's use of *heavy-users caps* is likely to increase overall investment, innovation, and broadband deployment. Finally, mobile broadband provider's use of *profit-maximizing caps* is likely to increase broadband provider investment and deployment, but reduce edge provider investment and innovation; the overall effect is indeterminate.

9.4. End-user control

The Order states that "[a] practice that allows end-user control and is consistent with promoting consumer choice is less likely to unreasonably interfere with or cause an unreasonable disadvantage affecting the end user's ability to use the Internet as he or she sees fit" (2015 Open Internet Order, paragraph 139). There are two elements to user choice pertinent to data caps: choice between service plans and choice in how to use a service plan.

With respect to user choice between service plans, proponents see data caps as a form of second-degree price discrimination. They are thus likely to argue that data caps allow for increased consumer choice among a more highly differentiated set of broadband service plans. This is true for mobile broadband plans, which are unlikely to be otherwise differentiated. However, for fixed broadband Internet access service that is already differentiated by download and upload speeds, it is unlikely that the addition of data caps provides any significant increase in differentiation. Fixed broadband providers do not currently offer, for instance, multiple plans with the same speed but different data caps. Furthermore, if data caps resulted in increased consumer choice, then one would expect to see increased overall subscription and increased consumer surplus. However, we concluded in Sections 5 and 7 that no such effects are likely when data caps are used in fixed broadband service.

With respect to user choice in how to use a service plan, we found in Section 6 that all forms of data caps reduce heavy usage. Thus, data caps clearly interfere with or disadvantage an end user's ability to use high-volume Internet content. The question is whether this interference or disadvantage is *unreasonable*. Heavy-users caps reflect the cost of that usage, and hence do not *unreasonably disadvantage* an end user's ability to use high-volume Internet content. In contrast, profit-maximizing caps have lower data caps and higher overage charges than necessary to recover the cost of heavy usage, and thus the question of reasonableness remains. Here, proponents argue profit-maximizing caps provide a form of second-degree price discrimination that will usually increase consumer surplus, and thus presumably not be unreasonable. However, in Section 7 we concluded that profit-maximizing caps *reduce* consumer surplus compared to heavy-users caps. Thus, there is a strong argument that profit-maximizing caps may indeed unreasonably disadvantage an end user's ability to use high-volume Internet content.

9.5. Conclusion

Data caps could be evaluated by the FCC on a case-by-case basis under the 2015 Open Internet Order's general conduct rule. A complainant may claim that data caps are not primarily intended to manage congestion and thus do not qualify as reasonable network management; harm competition in information services between broadband providers and edge providers; reduce innovation and investment by edge providers; and leave the consumer with few choices to access high-volume Internet content. In contrast, broadband providers are likely to claim that data caps an effective and efficient means of managing congestion, and thus fall under the reasonable network management exception to the rule. If such a practice does not qualify as reasonable network management, broadband providers are likely to claim that data caps increase fairness and are not anti-competitive; result in additional investment, innovation, and broadband deployment by broadband providers; do not impede edge provider investment and innovation; and are subject to consumer choice.

We found that the validity of these claims depends on whether a data cap is a heavy-users cap or a profit-maximizing cap. The FCC must therefore determine the nature of the cap, likely by comparing the overage charge per unit volume to the average price per unit volume of the service tier.

Heavy-users caps are likely to be determined to have a primarily technical management justification, namely alleviating congestion. There are reasonable arguments on both sides of whether a heavy-users cap is primarily used for and tailored to achieving a reduction in congestion. On the upside, there is a strong correlation between heavy monthly users and heavy peak usage period users, and heavy-users caps increase fairness. On the downside, the correlation between correlation between monthly usage and a user's contribution to congestion is only moderate and thus not directly based on a user's demand during the period of congestion. Furthermore, heavy-users caps are not triggered only during times of congestion. We expect that determination of whether a heavy-users cap qualifies as reasonable network management would turn on the strength of the correlation between monthly usage and a user's contribution to congestion.

If a heavy-users cap does not qualify as reasonable network management, then it must be considered under the factors used in assessing a network practice under the general conduct rule. Heavy-users caps do not have anti-competitive incentives, and do not unreasonably interfere with or disadvantage an edge provider's ability to offer high-volume content. Thus, there are neither positive nor negative competitive effects. The effect of a heavy-users cap on innovation, investment, and broadband deployment is different for fixed and for mobile broadband service. The use of a heavy-users cap by a *fixed broadband provider* is unlikely to result in increased network capacity and is unlikely to significantly affect overall subscription, and is thus unlikely to significantly affect investment, innovation, or broadband deployment. In contrast, the use of a heavy-users cap by a *mobile broadband provider* will result in increased network capacity and in increased overall subscription, and is thus likely to increase overall investment, innovation, and broadband deployment. Furthermore, heavy-users caps in fixed broadband service are unlikely to increase consumer choice when service is already differentiated by speed, whereas their use in mobile broadband service will increase consumer choice compared to undifferentiated unlimited plans.

In summary, a heavy-users cap is likely to qualify as reasonable network management if it can be shown that there is sufficient correlation between monthly usage and a user's contribution to congestion. If it does not qualify, a mobile broadband heavy-users cap is likely to satisfy the general conduct rule, due to positive effects on consumer choice and on innovation, investment, and broadband deployment. However, a fixed broadband heavy-users cap is likely to violate the general conduct rule, due to negative effects on consumer choice and on innovation, investment, and broadband deployment.

The analysis of *profit-maximizing caps* and of caps whose purpose is to protect incumbent pay-television services is very different. First, a cap of either sort would not qualify as reasonable network management, because it has a primarily business justification. The analysis thus entirely focusses on the factors used in assessing a network practice under the general conduct rule. Profit-maximizing caps do not have anti-competitive incentives, but they are likely to have anti-competitive effects by disadvantaging an edge provider's ability to offer high-volume content. Caps whose purpose is to protect incumbent pay-television services have both anti-competitive incentives and similar anti-competitive effects. The use of a profit-maximizing cap by a *fixed broadband provider* is unlikely to result in increased network capacity, is likely to reduce overall subscription, and is likely to interfere with or disadvantage an edge provider's ability to offer high-volume content, and is thus likely to reduce investment, innovation, or broadband deployment. In contrast, *mobile broadband provider's* use of profit-maximizing caps is likely to increase broadband provider investment and deployment, but reduce edge provider investment and innovation, and these two effects must be compared. Furthermore, profit-maximizing caps in fixed broadband service are unlikely to increase consumer choice when service is already differentiated by speed, whereas their use in mobile broadband service will increase consumer choice compared to undifferentiated unlimited plans.

In summary, neither profit-maximizing caps nor caps whose purpose is to protect incumbent pay-television services will qualify as reasonable network management. A mobile broadband profit-maximizing cap might satisfy the general conduct rule, but only if the benefits from increasing broadband provider investment and deployment outweigh the harms from disadvantaging an edge provider's ability to offer high-volume content and from corresponding reduced edge provider investment and innovation. A fixed broadband profit-maximizing cap is likely to violate the general conduct rule, due to negative effects on consumer choice, on competition, and on innovation, investment, and broadband deployment. Data caps whose purpose is to protect incumbent pay-television services are similarly likely to violate the general conduct rule.

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