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Research Paper

Controlling digital piracy via domain name system blocks: A natural experiment

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ABSTRACT

We study the impact of batch DNS filtering of copyright-infringing websites, a novel administrative-based process that does not require judicial involvement. In partnership with a large telecommunication provider, we measure the impact of this intervention on piracy activity and the legal alternatives integrated into households' media subscription bundles, an aspect largely unexplored in prior literature. We find a significant reduction in Internet traffic, which proxies piracy activity. However, we do not observe statistically significant changes in the consumption of the legal alternatives under consideration, only a slight increase in TV viewership. To further understand these outcomes, we examine the heterogeneity of these results based on households' pre-block usage intensity of digital piracy and demographic characteristics. Our work contributes to the literature on the effectiveness of piracy control strategies and informs policy makers and industry practitioners about the benefits and limitations of DNS-based website blocking.

1. Introduction

Digital piracy, the illegal sharing and accessing of copyrighted content online, continues to be a significant issue in today's digital age, where affordable streaming services abound. In 2022 alone, Chatterley (2014) measured 215 billion visits to piracy websites, marking an 18% increase compared to the previous year. TV piracy alone clocked in 99.6 billion visits, accounting for 46% of total visits. According to the U.S. Chamber of Commerce (2019), the U.S. economy suffers a minimum revenue loss of $29.2 billion annually due to digital video piracy. In the last decade, public initiatives targeting suppliers of infringing content have gained traction, particularly in Europe, where several countries have adopted website-blocking tactics.

We analyze a website-blocking intervention that offers distinct advantages over previously studied website-blocking approaches (e.g., Poort et al. (2014); Danaher et al. (2020)). Specifically, it relies on DNS-based batch website blocking implemented through a public-private partnership involving a governmental copyright protection agency, representatives from creative industries and consumer associations, and Internet service providers. This initiative aimed to identify, report, and block access to websites hosting copyright-infringing media content.

This website-blocking approach stands out for several reasons. Unlike litigation or court orders, which involve lengthy legal proceedings, this method enables immediate intervention. It is also a more cost-effective solution, eliminating the expenses associated with legal battles. This affordability makes it an attractive option for copyright holders seeking to protect their rights. Finally, it is a

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scalable and ongoing approach – once the legal framework is established, it facilitates large-scale and continuous efforts to combat piracy.

However, it is crucial to acknowledge the limitations of this intervention. DNS-based website blocking does not impose sanctions on copyright infringers, allowing pirate websites to persist by creating new domains or shifting existing ones. Furthermore, the ease and speed with which users can circumvent the blocks using methods like VPNs, proxies, or DNS server changes pose challenges to the intervention's effectiveness. As the extent of circumvention determines the blocks' overall impact, the effectiveness of this approach must be empirically assessed.

Our analysis leverages a unique large-scale household-level dataset on media consumption from a telecom provider involved in the website-blocking partnership. Using a difference-in-differences estimator with household fixed effects, we compare the behavior of households that engaged in digital piracy before the blocks (the "treated" group) with households that did not engage in piracy (the "control" group).

We measure the impact of the DNS blocks on digital piracy activity, which we proxy by downstream and upstream Internet traffic, and the use of legal alternatives not previously covered by the literature – TV viewership, video-on-demand, and the subscription to paid TV channels. Despite finding some descriptive evidence of block circumvention, our findings reveal a significant decrease in Internet traffic, both in downloads and uploads, of digital pirates following the implementation of the blocks. However, we find no statistically significant effect on the set of paid legal alternatives considered except for a slight increase in TV viewership. Additionally, we explore how household characteristics moderate the effectiveness of the DNS blocks, finding that households with teenagers exhibit a weaker response to the intervention.

This research contributes to the existing literature by examining the efficacy of a DNS-based batch website blocking intervention using disaggregated observational household-level data. Investigating the heterogeneity in households' responses provides valuable insights that can inform policy design. Furthermore, our study adds to the broader understanding of the relationship between digital piracy and legal consumption alternatives, shedding light on the effectiveness of piracy control measures.

This paper is structured as follows. Section 2 lays out the empirical context of this study. Section 3 reviews the empirical literature on piracy control strategies and the demographics of digital pirates. Section 4 describes the data sets used, and section 5 details our empirical strategy. In section 6, we present our results, and, in section 7, we summarize our findings and contribution and discuss the main limitation of our work.

2. Background

2.1. Piracy control strategies

Various strategies are employed to combat digital piracy, targeting the providers or consumers of copyright-infringing content through private or public initiatives. Legal actions against providers include litigation and website blocking, while users may face graduated response laws like the three strikes law in the United States. Technological solutions, such as digital rights management (DRM), versioning, and network pollution, also aid in curbing piracy. Channel competition among media and cultural content providers is another approach. Copyright enforcement agencies also resort to public awareness campaigns (e.g., "You wouldn't steal a car") and collaborate with ISPs and search engines to block or demote infringing content. (Online Appendix A provides an overview of commonly used anti-piracy approaches.)

Our study focuses on website blocking, a targeted approach restricting consumer access to copyright-infringing content. Various methods, including IP address and DNS-based filtering, can be employed for implementing blocks. Detailed explanations of different website-blocking methods, including DNS filtering, are provided in Online Appendix B.

Unlike strategies relying solely on provider-directed technological measures (e.g., versioning or DRM), website blocking typically requires legal permission or court orders (the specific legal requirements for website blocking will vary by jurisdiction). Although this introduces potential challenges in terms of cost and time, it ensures compliance with the law and provides legitimate means for protecting copyright holders' rights.

Unlike more punitive interventions like website shutdown, website blocking does not eliminate infringing content or subject providers to legal prosecution. While this may reduce its effectiveness and allow providers to remain operational, it also enables scalability. Once the legal framework is established, website blocking can become a large-scale, ongoing effort.

However, website blocking has two notable weaknesses. Tech-savvy users can easily circumvent blocks using VPNs, proxies, or DNS server changes. If widely adopted, this inexpensive and quick circumvention undermines the effectiveness of blocks. Additionally, blocks can trigger a cat-and-mouse game as targeted websites adapt by creating new domains or mirror sites.

In summary, the effectiveness of website blocking hinges on factors such as the legal framework, cooperation between copyright holders and ISPs, enforcement resources, circumvention levels, and the prevalence of cat-and-mouse scenarios.

2.2. Website blocking agreement

We study the impact of a website blocking agreement for regulating copyright infringement in the digital context by implementing DNS-based website blocks. The initiative was a joint effort between the local copyright protection agency, representatives of the various creative industries, consumer associations, and Internet service providers. It established a monitoring agency responsible for compiling lists of copyright-infringing websites based on predefined criteria and sending them to ISPs. ISPs were given a short time window to make the blocks effective via DNS filtering.

This cooperation was founded within the existing legal framework and established an administrative procedure for blocking copyright-infringing websites. By eliminating the judicial process, the agreement allowed for a much faster and broader anti-piracy effort, adding to the inherent speed and cost benefits of DNS-based blocks (Ofcom, 2010). In the first year after the agreement, block waves occurred frequently, often once or twice per month. Blocks were implemented at various times, with no observable pattern on block order dates. From the user's standpoint, the timing of forthcoming blocks could not be anticipated, as they could happen at different times of the month, not at all, or more than once per month. Additionally, the exact timing of the block would differ for clients of different ISPs, as ISPs could implement the blocks at different times within the allowed time window.

Mandated blocks targeted various types of pirate websites – streaming sites, cyberlockers, P2P, linking sites, and torrent sites – hosted domestically or abroad, providing illegal video or music content. Using Internet Archive Wayback Machine, we crawled the homepages of the blocked websites at the time their respective block was implemented and flagged the presence of the keywords *torrent*, *stream*, *streaming*, *download*. Overall, 35% of the blocked websites had the word *torrent*, 42% had the words *stream* or *streaming*, and 54% had the word *download*. Most block waves contained a somewhat balanced mix of the different types of sites. Once websites became blocked, visitors were presented with a message saying the site was unavailable, not found, or that it had been blocked for copyright infringement.

2.3. Local media and video entertainment market

At the time of implementation of the DNS blocks, access to Broadband Internet was not sold as a stand-alone product by the country's telecommunications providers (at least not at competitive prices). Over two-thirds of households had an Internet connection, most of which subscribed to a multiple play[1] telecommunications service. The most popular bundle was triple-play (3P), with about three-quarters of subscribers opting for a 3P or higher bundle. A few prominent players, including our industry partner, dominated the market. Our industry partner's customer base reflected the market's preference for multiple-play bundles.

Legal online streaming platforms such as Netflix, Hulu, or Amazon Prime had either limited availability or low market penetration in the region. We verified this by examining Alexa's Top Websites per country using the Internet Archive Wayback Machine for the month preceding the implementation of the blocks. None of the legal streaming sites were listed among the country's top 250 websites (excluding platforms like YouTube), while six pirate sites were. Consequently, consumers had limited options for switching from online piracy to online legal channels. Given this specific context, our study focuses on the legal alternatives to piracy that were most accessible to the average household: digital TV and Video-on-Demand (VoD) services.

As far as our knowledge extends, the website blocking agreement examined in our study was the only concerted effort by authorities specifically targeting digital piracy, aside from an educational campaign in primary schools.

3. Literature review

There are two distinct streams of literature closely aligned with our research topic. Firstly, the works focusing on the impact of shutting down and blocking pirate websites. Secondly, the work on the demographics of digital pirates. We review these two streams of literature in the two following subsections. For a broader understanding of piracy control strategies, please refer to Online Appendix C, where we provide an overview of relevant works categorized by intervention type.

3.1. Effectiveness of website shutdown and blocking

Most closely related to our research are studies investigating the impact of shutting down and blocking pirate websites on piracy activity and the use of legal alternatives to piracy. Prior works on website shutdown have analyzed the cases of Megaupload (Danaher and Smith, 2014; Peukert et al., 2017) and kino.to (Peukert et al., 2017), while previous works on website blocking have analyzed the impact of blocking The Pirate Bay (Poort et al., 2014; Danaher et al., 2020) and other popular pirate websites (Danaher et al., 2020).

In a country-level analysis, Danaher and Smith (2014) measured the impact of shutting down Megaupload on digital movie sales and rentals. The authors found that some users turned to these legal channels after the shutdown. Additionally, Peukert et al. (2017) conducted a country-level analysis on the impact of Megaupload's shutdown on box office revenues. They found that only wide-release movies benefited from the shutdown, and the overall effect was negative on average. Furthermore, Aguiar et al. (2018) found that the shutdown of kino.to, a popular illegal streaming website in Germany, reduced piracy activity, but the effect was short-lived.

Studies on website-blocking interventions have produced mixed results. Poort et al. (2014) used a consumer survey and observational BitTorrent activity data to investigate the impact of blocking *The Pirate Bay* in the Netherlands. Although some survey respondents reported reducing their digital piracy activity, the authors found no impact on the share of the population using BitTorrent. Danaher et al. (2020) examined the blocking of *The Pirate Bay* in the UK in 2012 and found that it did not increase the use of legal sites. Using a household-level panel of 10 consumer segments, the authors analyzed the impact of website blocks on visits to pirate websites and websites providing paid legal alternatives, such as Netflix. Following the blocks on *The Pirate Bay*, the UK courts

[1] A multiple-play service is a bundled package that includes two or more services like Internet, TV, and phone. For example, a 2P (dual-play) bundle might include Internet and phone, while a 3P (triple-play) bundle might include Internet, TV, and phone.

ordered the blocking of 19 other major piracy sites in 2013 and an additional 53 sites in 2014. Danaher et al. (2020) found that the 2013 blocks significantly reduced piracy and caused a 12% increase in visits to paid legal streaming sites. The 2014 blocks resulted in a 90% drop in visits to these sites, leading to a 22% reduction in piracy activity for the affected households, a 6% increase in visits to paid streaming sites, and a 10% increase in visits to ad-supported streaming sites (Danaher et al., 2019).

Unintended consequences of website blocking or shutdown may include users of blocked or closed websites redistributing themselves across several new smaller websites. Aguiar et al. (2018) have observed this phenomenon in Germany, and Danaher et al. (2020) observed it in the UK. Furthermore, public disclosures or announcements with lists of blocked websites may inadvertently serve as advertisements for such websites (Clemente, 2015).

Our research is most closely related to the work of Danaher et al. (2020) on the impact of court-ordered website blocking in the UK. However, in addition to focusing on a different country, we focus on a much larger scale ongoing intervention (hundreds of blocks) that relies on a swift administrative procedure that does not require a court order for a block to be issued. As such, this intervention is distinct from those previously analyzed. We also consider a set of legal alternatives not previously covered by the literature – TV viewership, video-on-demand, and subscription to paid TV channels.

3.2. Demographics of digital pirates

Previous research has consistently highlighted the influence of demographic factors on piracy behavior. Studies examining software piracy (Al-Rafee and Cronan, 2006) and music piracy (Gopal et al., 2004) have found that age significantly shapes individuals' attitudes and behaviors towards piracy. These findings align with the existing ethics literature, which suggests that ethical standards tend to be higher among older individuals (Ruegger and King, 1992; Allmon et al., 2000; Ford and Richardson, 2013).

Studies focusing on the prevalence of digital piracy among young people have shed light on the extent of the issue. For instance, Gunter et al. (2010) studied the prevalence of digital piracy among adolescents and found that more than half of 8th graders had engaged in piracy, with 44% reporting piracy in the previous year and 35.1% in the previous month. These statistics increased to 72.3%, 63.8%, and 52.8% among 11th graders, respectively.

Additionally, Mateus and Peha (2011) characterized and quantified worldwide BitTorrent traffic and discovered that content appealing to teenagers and young adults had disproportionately higher ratios of BitTorrent transfers to sales compared to titles targeting older demographics.

Younger demographics, in particular, demonstrate greater familiarity with tools that facilitate circumvention, as evidenced by VPN and proxy server usage statistics. Specifically, millennials account for 32% of VPN and proxy server users among Internet users worldwide, followed by Generation X at 27% and baby boomers at 13% (Statista, 2014). The motivations behind VPN use vary, with millennials primarily seeking access to restricted content and social networks, while Generation X aims to maintain international connections and access restricted sites. Based on this evidence, teenagers and young adults in a household are likely to moderate the household's response to the website blocks.

4. Data

4.1. Media consumption data

We collaborate with a multinational telecommunications provider of pay-TV, broadband and mobile Internet, and fixed and mobile telephony. We were granted access to 15 months of media consumption records for a random sample of 100K subscribers selected from those active (i.e., had a working 3P or 4P service) for the whole period. 64% of the households in this sample subscribed to the premium[2] service bundle, and the remaining households subscribed to the standard bundle. In our analysis, we focus on the subscribers of the premium bundle for whom we can track both Internet and TV viewing activity. The data extends from four months before website blocking to ten months after.

Each household in our dataset is uniquely and anonymously identified. For each month of our period of analysis, we have information on the households' aggregate download and upload Internet traffic (in MB), paid VoD expenditure (in cents), aggregate TV viewership time (in minutes), and number of days observed using BitTorrent. We assign households into one of two groups – BitTorrent users and non-users, corresponding to whether they used BitTorrent at least once in the four months preceding the blocks. Due to limitations in our data set, we were restricted to using BitTorrent[3] activity as a measure of digital piracy since other web browsing behaviors, including illegal and legal streaming, remained invisible to us.

Our main dataset also includes information on the additional services purchased by each household including the subscription of our industry partner's Video-on-Demand (VoD) service and of paid TV channels (e.g. sports and entertainment), and on the household's monthly bill value and whether it opted for electronic billing. Online Appendix D provides a detailed description of all household level variables used in our analysis.

[2] The *premium* service bundle differs from the *standard* bundle in the number of TV channels offered, Internet speed, and VoD credits offered. The type of equipment used is also different, which has implications for data collection. Specifically, we cannot observe TV consumption for households subscribing to the standard service bundle.

[3] The BitTorrent protocol can be used for legal and illegal purposes. However, previous work suggests that most of the content exchanged via this protocol is illegal (Watters et al., 2011; House, 2011). BitTorrent file-sharing traffic has been previously used in piracy research as a measure of digital piracy by Danaher et al. (2010), Godinho de Matos et al. (2017), and Poort et al. (2014).

Table 1
Summary Statistics for BitTorrent users.

Statistic	N	Mean	St. Dev.	Min	Max
N Torrent days (in month)	6,622	1.311	2.833	0	27
Download (Mb/day)	6,622	2,458.162	2,302.212	0.000	23,326.560
Upload (Mb/Day)	6,622	628.567	1,194.947	0.000	23,958.230
VoD (cents/month)	6,622	17.986	128.090	0.000	4,130.400
TV Total (min/day)	6,622	253.467	173.389	0.000	1,124.500
TV Entertainment (min/day)	6,622	63.329	72.177	0.000	618.367
TV Video-on-Demand (min/day)	6,622	1.667	7.004	0.000	118.467
Month Bill (USD)	6,598	71.897	20.379	14.300	152.737
TV Service Tenure (month)	6,622	101.513	59.461	3.290	248.903
Internet Service Tenure (month)	6,622	74.206	35.839	3.290	188.645
Set-Top-Box Tenure (month)	6,622	53.904	22.345	0.710	88.387
Flag Entertainment-Bundle	6,622	0.264	0.441	0	1
Flag Sports-Bundle	6,622	0.172	0.378	0	1
Flag Electronic Receipt	6,622	0.423	0.494	0	1
Flag Bank Transfer	6,622	0.342	0.474	0	1
Flag Active Contract	6,622	0.891	0.312	0	1

Table 2
Summary Statistics for Non-BitTorrent users.

Statistic	N	Mean	St. Dev.	Min	Max
N Torrent days (in month)	57,550	0.000	0.000	0	0
Download (Mb/day)	57,550	1,049.417	1,503.382	0.000	47,257.730
Upload (Mb/Day)	57,550	162.193	554.680	0.000	22,730.020
VoD (cents/month)	57,550	21.992	151.508	0.000	5,926.800
TV Total (min/day)	57,550	245.949	177.542	0.000	1,157.000
TV Entertainment (min/day)	57,550	48.517	64.850	0.000	940.800
TV Video-on-Demand (min/day)	57,550	1.220	5.973	0.000	190.800
Month Bill (USD)	57,370	66.893	19.487	14.300	167.037
TV Service Tenure (month)	57,550	79.417	65.809	3.129	250.161
Internet Service Tenure (month)	57,550	48.632	39.295	0.000	188.871
Set-Top-Box Tenure (month)	57,550	37.508	25.416	0.000	88.387
Flag Entertainment-Bundle	57,550	0.188	0.391	0	1
Flag Sports-Bundle	57,550	0.167	0.373	0	1
Flag Electronic Receipt	57,550	0.343	0.475	0	1
Flag Bank Transfer	57,550	0.346	0.476	0	1
Flag Active Contract	57,550	0.917	0.276	0	1

Tables 1 and 2, provide summary statistics for the main variables used in our analysis for both BitTorrent users and non-users, respectively, for the month just before the implementation of the website blocks. From our sample of 64K households, about 10.3% were observed using BitTorrent at least once in the 4 months before the blocks. On average, BitTorrent users consumed 2.5 GB of download traffic and 0.6 GB of upload traffic per day. These users spent an average of 18 cents/month on our industry partner's VoD and watched an average of 4.2 hours of TV per day, of which 63 minutes were dedicated to entertainment. 26.4% of BitTorrent users subscribed to paid entertainment channels. Non-users of BitTorrent, consumed on average 1 GB and 0.16 GB of daily download and upload traffic, respectively. These users spent an average of 22 cents/months on our industry partner's VoD and watched an average of 4 hours of TV per day, of which 48 minutes were devoted to entertainment. Finally, 19% of them subscribed to paid entertainment channels. These statistics show clear differences in media consumption between BitTorrent and non-BitTorrent users, particularly in what concerns Internet use.

Fig. 1 plots the fraction of households observed using BitTorrent during the full period of analysis for both our treated and control groups. The figure shows a clear drop in BitTorrent activity immediately after the start of the blocks, marked by the vertical dashed line. Despite some early recovery, the figure shows a continuous decline in BitTorrent activity after the start of the intervention.

4.2. Household demographics and media consumption

We were also granted access to the results of an online survey ran by our industry partner inquiring about subscribers' media preferences, consumption habits, and household demographics. The survey, which was unrelated to this project, was sent by email to a sample of around 42K triple and four-play subscribers, out of which approximately 4% responded. The survey results of households subscribing to the premium service bundle were matched with media consumption data for the 15 months under analysis resulting in

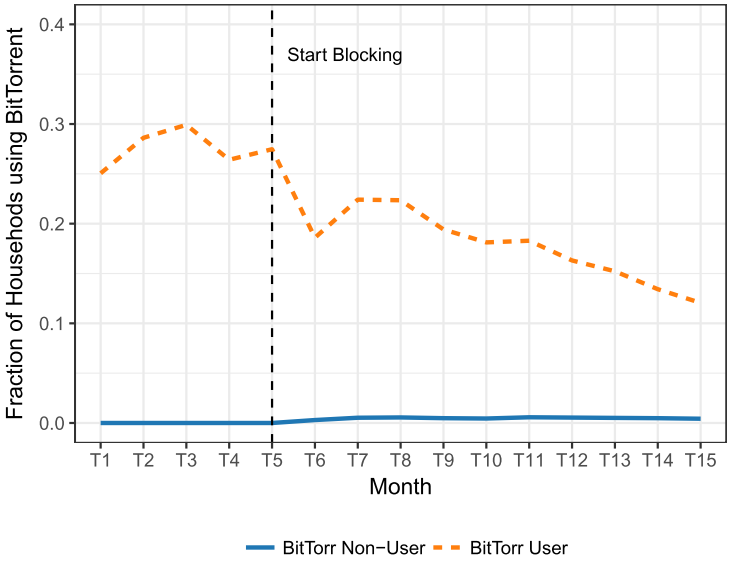

Fig. 1. Fraction of households using BitTorrent per month.

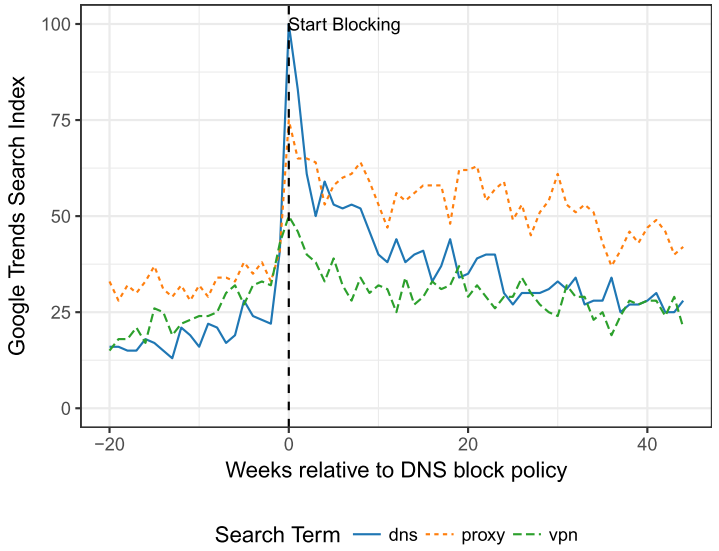

Fig. 2. Google search index for keywords DNS, PROXY and VPN.

a final sample of 1,407 households.[4] Although not perfectly representative of the population of subscribers of our industry partner, these data allow us to investigate how households' demographic profile moderates their response to DNS blocks.

4.3. Google search data

Finally, we collected data on online searches for keywords likely used by Internet users attempting to bypass DNS blocks, namely "DNS," "Proxy," and "VPN." These data were obtained from Google Trends. The search interest for a specific term is the share of searches for that term relative to all Google searches in the same region during the same period. The search peak for a given term in a given location during a specified period is indexed to 100. Fig. 2 shows that Google searches for keywords related to block circumvention, such as "DNS", "VPN" and "Proxy" spiked right when the blocks were first issued and remained roughly twice as large after the blocks compared to before. Together, Figs. 1 and 2 suggest that although website blocking seems to have been effective in leading some households away from piracy, some users learned how to circumvent the DNS blocks and likely continued downloading content from the blocked websites.

[4] Online Appendix E provides descriptive statistics for this sample.

5. Empirical strategy

Our household-level analysis aims to compare the media consumption activity of subscribers who used BitTorrent before the website blocks, our *Treated* group of households, to those who did not, our *Control* group. We expect that blocking copyright-infringing websites impacts the behavior of BitTorrent users but not that of non-users. We use difference-in-differences to estimate the change in Internet download and upload traffic that resulted from the blocks. Following, Adermon and Liang (2014), we use Internet traffic as a proxy for digital piracy. As peer-to-peer sharing of media files generates significant upload and download traffic, using Internet traffic as a measure of piracy activity should allow us to capture piracy while also allowing us to keep track of 'hidden' piracy activities (BitTorrent traffic hidden through VPN or proxy servers). We also measure the blocks' effect on households' expenditure on our industry partner's VoD, subscriptions to paid entertainment channels, and TV viewership.

Our classification of households as BitTorrent users is a conservative definition of "digital pirates," which leaves out households who engage in all other types of illegal consumption of copyrighted content that we cannot measure. Therefore, our control group might include, alongside BitTorrent non-users, digital pirates whose pirating behavior we cannot observe (e.g., streamers). The implication for our analysis is that some households in our control group may have been affected by the treatment and, as a result, reduced the amount of internet traffic they consume. Thus, our difference-in-differences estimators do not provide us with the average treatment effect but instead with a conservative estimate of the effect of treatment.

The equation presented below summarizes our general difference-in-differences specification for estimating the effect of website blocking:

$$Y_{it} = \beta_0 + \beta_1 BitTorrentUser_i \times After_t + \alpha_i + \tau_t^T + \epsilon_{it} \tag{1}$$

where $BitTorrentUser_i$ is a dummy variable indicating whether household i used BitTorrent prior to the blocks and $After_t$ indicates a period after the blocks started. τ^T are time dummies and α_i the household level fixed effects. β_1 measures the impact of website blocking on the outcome variable of interest. The outcome variables considered include two proxies for piracy activity – $Log(Downloads\ Mb/Day)$ and $Log(Uploads\ Mb/Day)$ – and the consumption of three legal alternatives to piracy – $VoD\ Expenditure$, $Paid\ Entertainment\ Channels$, and $TV\ min/Day$. We also look at the total time people spend watching movie channels on TV, represented by $TV\ Mov.\ min/Day$. We estimate this specification using OLS, adjusting standard errors for heteroskedasticity, serial correlation, and clustering them at the household level. We expand this model to test the moderating role of household demographics by including two triple interaction terms between our BitTorrent indicator, the *after* policy indicator, and indicators for the presence of teenagers and young adults, respectively.

Our difference-in-differences approach rests on the fundamental assumption that, without the intervention, the treatment (BitTorrent users) and control (BitTorrent non-users) would follow parallel trends in their Internet, VoD, and TV consumption. We formally test this assumption following Pischke (2005) and Autor (2003) by interacting the treatment indicator $BitTorrentUser_i$ with the time dummies as shown in the equation below.

$$Y_{it} = \beta_0 + \gamma_j^T BitTorrentUser_i \times \tau_t^T + \alpha_i + \tau_t^T + \epsilon_{it} \tag{2}$$

The vector of coefficients γ_j^T captures the difference in behavior across groups (BitTorrent users and non-users) over time. According to Pischke (2005), a test of the parallel trends assumption is $\gamma_j = 0\ \forall j < 0$, that is, "the coefficient on all leads of the treatment should be zero" (Pischke (2005), p. 7). This specification also allows us to study how the impact of the blocks evolved over time.

6. Results

6.1. Impact of website blocking on household behavior

We start by visually inspecting the results of our formal test for the common trend assumption. Fig. 3 plots the γ_j^T coefficients of equation (2) for all dependent variables of interest and their respective 95% confidence interval. Confidence intervals containing 0 indicate no difference between treatment and control groups. We can thus verify the parallel trends assumption and visualize the blocks' cumulative effect.

The top plots in the first row of this figure show that the trend of downloads and uploads was similar across BitTorrent users and non-users before the DNS blocks. It also shows that BitTorrent users reduced their Internet usage substantially after the blocks' start. Furthermore, these plots highlight that the effect of the DNS blocks continued to increase over time, which can be explained by the regular and ongoing blocks. The gradual decrease in internet usage also indicates that the threat of block circumvention and the possible dissemination of circumvention methods was insufficient to offset the blocks. The second row of plots provides insight into the effects of the blocks on our industry partner's VoD and premium TV channels. These plots also show that BitTorrent users and non-users followed a common trend before the blocks' implementation. However, unlike Internet traffic, the blocks did not impact the consumption of these two media products. Finally, the last two figures in the bottom row of Fig. 3 show that the common trend assumption also holds for total TV viewership but not for view time of entertainment channels, for which we observe significant differences between the treated and control groups for the first two periods. We address this violation of the parallel trends assumption by re-running our analysis using a matched sample of households (section 6.2).

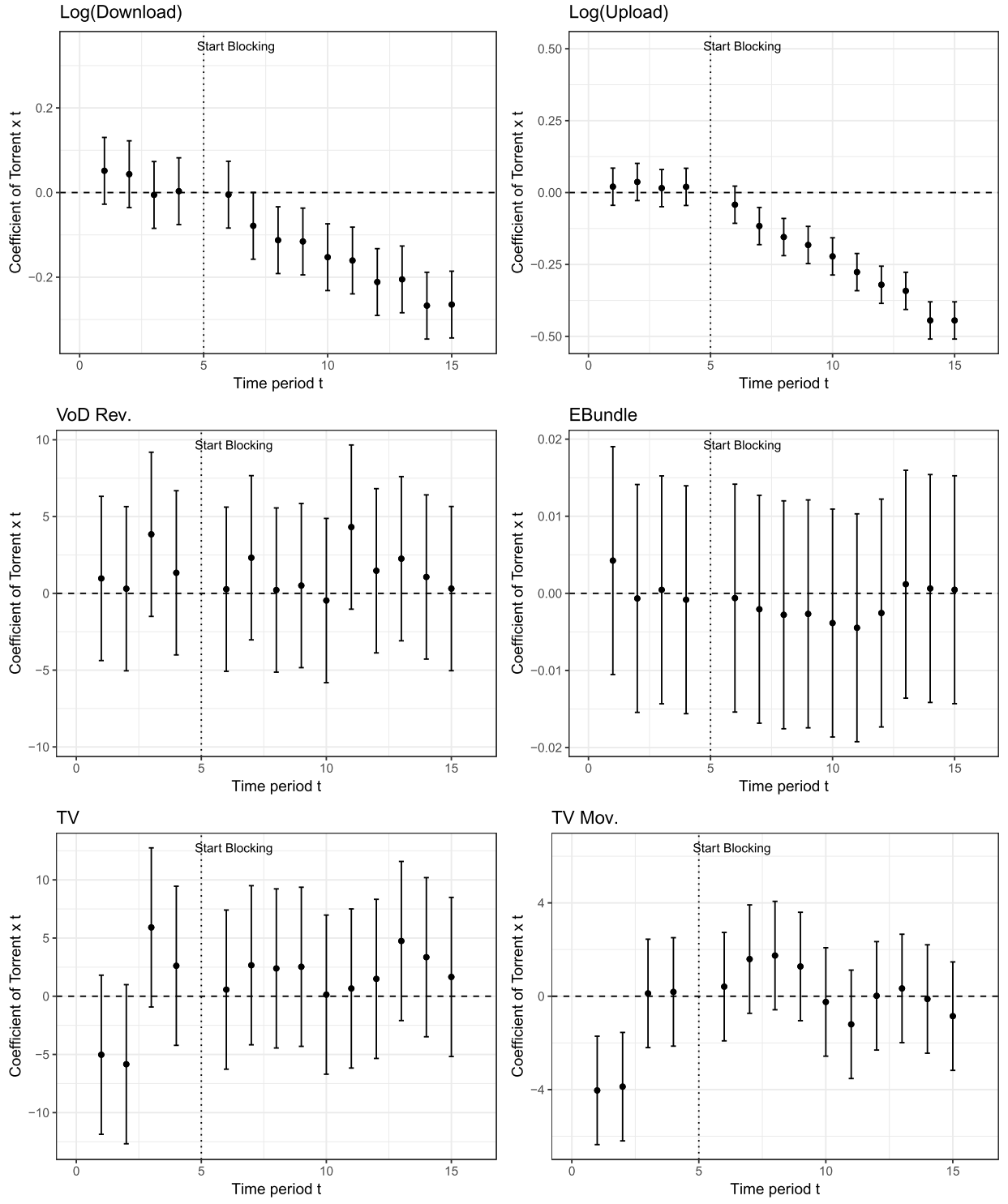

Fig. 3. Impact of DNS blocks on downloads, uploads, video-on-demand expenditure, subscription of premium TV channels and TV viewership over time. Error bars are the 95% confidence intervals.

Table 3 presents our main difference-in-differences estimates. Columns (1) and (2) show the impact of treatment on download and upload traffic, respectively. The results show that after the start of DNS blocks, the daily download traffic of BitTorrent users decreased by $100 \times (exp(-0.176) - 1) = -16.1\%$ ($p < 0.01$) and upload traffic decreased by roughly $100 \times (exp(-0.273) - 1) = 24.9\%$ ($p < 0.01$). This evidence suggests that DNS blocks effectively decreased BitTorrent users' piracy activity. The observed asymmetry

Table 3
Effect of DNS blocks on Internet traffic and use of legal alternatives.

	Dependent variable:					
	Log(Download) (1)	Log(Upload) (2)	VoD Rev. (3)	EBundle (4)	TV Mov. (5)	TV (6)
After x BitTorrent User	−0.176***	−0.273***	−0.065	−0.002	1.816***	2.488*
	(0.010)	(0.012)	(1.019)	(0.003)	(0.479)	(1.376)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	962,580	962,580	962,580	962,580	962,580	962,580
R^2	0.840	0.797	0.261	0.839	0.730	0.710
Adjusted R^2	0.829	0.782	0.209	0.827	0.710	0.689
Residual Std. Error	0.928	0.874	132.275	0.171	34.956	106.296

Note: *p<0.1; **p<0.05; ***p<0.01.
Cluster robust standard errors in ().
Clustering at individual level.
All models estimated with individual fixed effects.

Table 4
Heterogeneous effect of DNS blocks on Internet traffic and use of legal alternatives - Pre-blocks BitTorrent usage intensity.

	Dependent variable:					
	Log(Download) (1)	Log(Upload) (2)	VoD Rev. (3)	EBundle (4)	TV Mov. (5)	TV (6)
After x N. torrent days [1-2]	−0.118***	−0.105***	−0.860	−0.005	1.133*	2.709
	(0.014)	(0.015)	(1.538)	(0.004)	(0.661)	(1.937)
After x N. torrent days]2-5]	−0.197***	−0.257***	−0.296	−0.007	2.131**	2.672
	(0.021)	(0.025)	(2.003)	(0.006)	(1.043)	(2.842)
After x N. torrent days]5-10]	−0.223***	−0.398***	2.077	0.008	1.434	−1.845
	(0.026)	(0.034)	(2.091)	(0.007)	(1.298)	(3.471)
After x N. torrent days]10+]	−0.276***	−0.675***	0.737	0.004	3.686***	5.229
	(0.023)	(0.035)	(2.173)	(0.007)	(1.092)	(3.206)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	962,580	962,580	962,580	962,580	962,580	962,580
R^2	0.840	0.797	0.261	0.839	0.730	0.710
Adjusted R^2	0.829	0.782	0.209	0.827	0.710	0.689
Residual Std. Error	0.928	0.873	132.275	0.171	34.956	106.296

Note: *p<0.1; **p<0.05; ***p<0.01.
Cluster robust standard errors in ().
Clustering at individual level.
All models estimated with individual fixed effects.

in the two coefficients suggests that some households substituted illegal BitTorrent activities with other over-the-top illegal or legal streaming services, such as Netflix. Video streaming entails little upload traffic but keeps the download link busy and could thus account for the observed asymmetry. This behavior would be consistent with the results of Danaher et al. (2020), which found increased visits to legal online streaming sites (e.g., Netflix) due to website blocking. Unfortunately, our data does not allow us to test this hypothesis.

Columns (3), (4), (5), and (6) measure the impact of the blocks on VoD expenditure, subscription to paid entertainment channels, unpaid viewership of TV channels devoted to movies and TV shows, and unpaid overall TV consumption. We find no significant impact on VoD expenditure or subscriptions to paid entertainment channels. Columns (5) and (6) show a small but statistically significant effect of TV viewership – a 2.5-minute increase in total TV time ($p < 0.1$) and a 1.8-minute increase in view time of channels dedicated to movies and TV shows ($p < 0.01$). Even though we focus on an empirical setting in which online legal alternatives were limited and, consequently, where this set of legal alternatives was most likely to benefit from an anti-piracy intervention, we still observe only a very modest effect on TV consumption. This evidence suggests some stickiness to the online channel, highlighting that the gains accruing right holders from this sort of intervention depend highly on the specific types of available legal alternatives.

Next, we investigate the role of pre-block BitTorrent usage intensity on the household's response to the blocks. For this analysis, we assigned BitTorrent users into four groups based on the total number of days we observed them using BitTorrent in the pre-block period. The first group includes households that used BitTorrent only once or twice (N = 3,165), the second group includes households who used BitTorrent between 2 and 5 times (N= 1,438), the third group includes those who used BitTorrent between 5 and 10 times (N= 918), the fourth group includes households who used it for ten or more days (N=1101). We then interact each group's indicator with the *After* dummy variable. The results are presented in Table 4 and provide additional insights into who

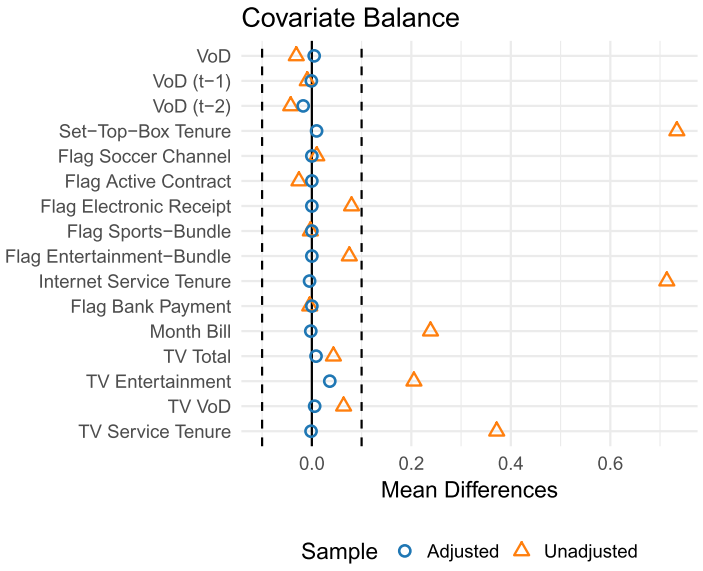

Fig. 4. Covariate balance before and after Coarsened Exact Matching.

was affected by the intervention and how. Considering columns (1) and (2) jointly, we can observe that the higher the pre-block usage of BitTorrent, the higher the post-block reduction in both download and upload traffic. Naturally, the higher the BitTorrent pre-block use, the higher the bandwidth use resulting from this activity. Thus, if a light user (for whom only a small percentage of bandwidth use comes from BitTorrent activity) stops pirating, this will only represent a slight percentual reduction of internet traffic. However, if a heavy user (for whom a large percentage of bandwidth use comes from BitTorrent activity) stops pirating, this will necessarily entail a very large percentual drop in bandwidth use. Interestingly, the asymmetry in the reduction of downloads and uploads also increases with usage intensity – from nearly no asymmetry for the first group to coefficients that are over twice as large for upload traffic than for download traffic for the last two groups. Again, this asymmetry suggests a substitution of BitTorrent for online streaming. A possible explanation for this result is that heavy BitTorrent users will be more motivated to continue to consume media content through the digital/online channel than light users.

6.2. Robustness checks

To assess the robustness of our findings, we re-ran our analysis using a matched sample of BitTorrent users and non-users. We matched households using Coarsened Exact Matching (CEM). CEM is a monotonic imbalance bounding matching method, which is more suitable for estimating causal effects than propensity score matching (Iacus et al., 2012; King and Nielsen, 2016). CEM is typically used in k-to-k matches such that different numbers of treated and control units are matched to each other. CEM uses weights to compensate for the differential strata sizes that result from this procedure. For additional details on how CEM works, see Iacus et al. (2009).

Fig. 4 provides balance statistics for the covariates we used to match BitTorrent users and non-users before and after the match. It is clear from this figure that the matched households are highly similar on all these covariates. Fig. 5 replicates Fig. 3 for the matched households only. The figure shows that BitTorrent users and non-users in the matched sample exhibited similar trends in all the dependent variables of interest. The disadvantage of matching is that, out of the initial 64,172 subscribers in our data set, we are left with only 4,688 (of which 3,481 are controls and 1,207 are treated). Table 5 replicates the analysis of Table 3 with the matched dataset. Columns (1) and (2) show again that download and upload traffic reduced quite significantly after the DNS blocks – a 14.4% ($p < 0.01$) and 20.3% ($p < 0.01$) reduction, respectively. These coefficients are slightly smaller but consistent with those presented in Table 3, and the asymmetry observed in our main analysis (greater percentual reduction in upload traffic than download traffic) remains present. Also consistent with our main analysis, the coefficients of models (3) and (4) are not statistically significant, suggesting no take-up in paid legal alternatives resulting from the blocks' implementation. Finally, contrary to our main results, we find no statistically significant effect on total TV time but a marginally significant ($p < 0.1$) increase of 1.9 minutes in viewership of entertainment channels.

Table 6 replicates the models presented in Table 4 using the matched sample. Overall, the results are consistent with those using the full sample – a higher usage intensity of BitTorrent prior to the blocks is associated with a higher reduction in both downloads and upload traffic and a greater asymmetry between the two. In short, our matched sample analysis supports the robustness of our findings regarding the effect of DNS blocking on piracy activity and on the two paid legal alternatives to piracy considered. Our findings on the effects of the blocks on total TV time are not robust to matching. However, a marginally significant effect (similar to that found in our main analysis) is still found for viewership of channels broadcasting only movies and TV shows. Our findings of the role of usage intensity on the households' response to the blocks are also robust to matching.

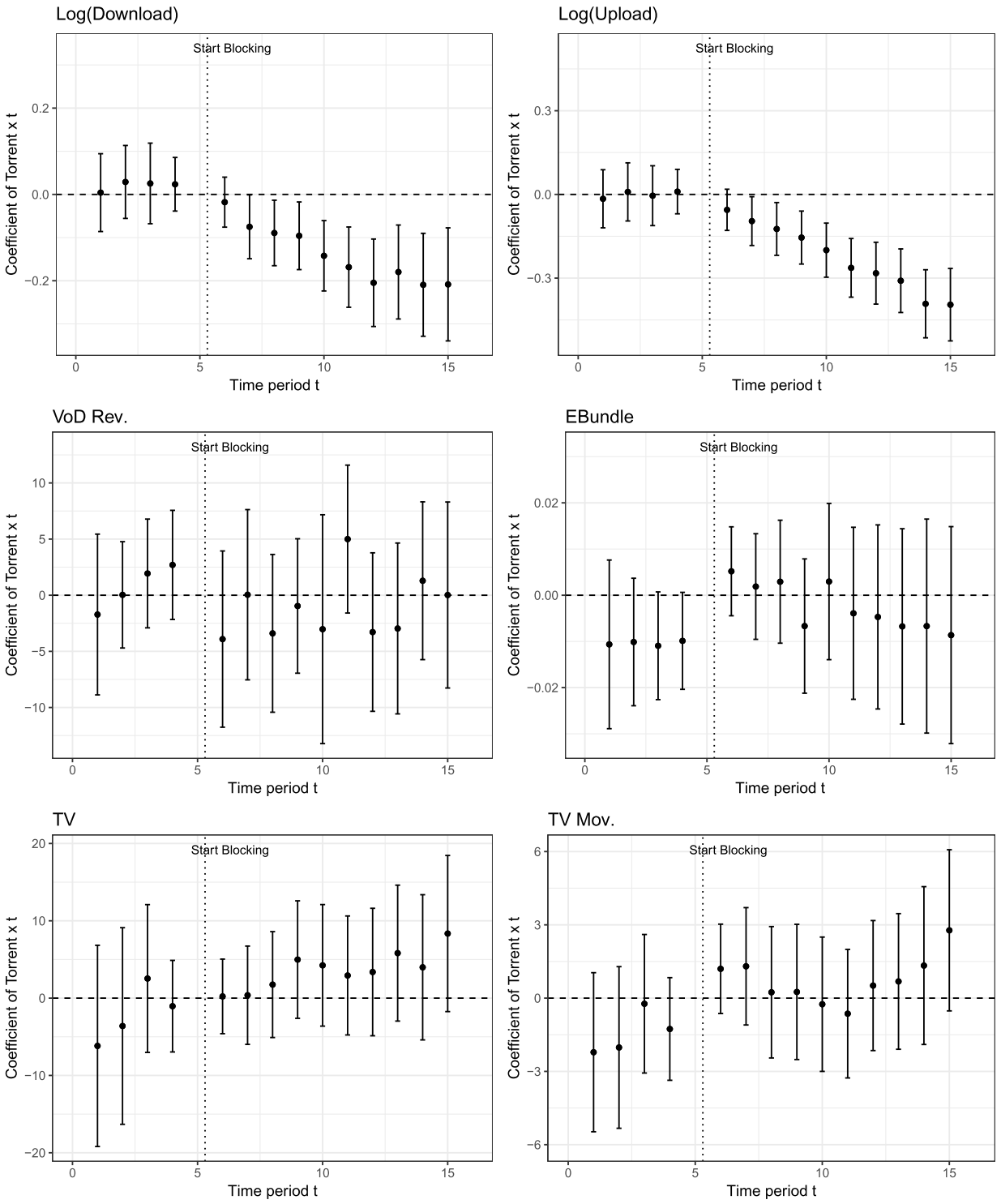

Fig. 5. Impact of DNS blocks on downloads, uploads, video-on-demand expenditure, purchase of premium channels and usage of TV over time for households in the matched sample. Error bars are the 95% confidence interval.

6.3. Demographic moderators of the effectiveness of DNS blocks

In this section, we investigate the role of household demographic characteristics in moderating the household's response to DNS blocking. To this purpose, we use data from a separate sample of households that responded to an online survey run by our industry

Table 5
Effect of DNS blocks on Internet traffic and use of legal alternatives (matched sample).

	Dependent variable:					
	Log(Download) (1)	Log(Upload) (2)	VoD Rev. (3)	EBundle (4)	TV Mov. (5)	TV (6)
After x BitTorrent User	−0.156***	−0.227***	−1.708	0.006	1.887*	5.261
	(0.033)	(0.035)	(1.619)	(0.008)	(1.015)	(3.508)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	70,320	70,320	70,320	70,320	70,320	70,320
R^2	0.775	0.749	0.181	0.756	0.662	0.666
Adjusted R^2	0.759	0.731	0.123	0.739	0.638	0.642
Residual Std. Error	0.900	0.908	76.515	0.163	26.241	89.109

Note: *p<0.1; **p<0.05; ***p<0.01.
Cluster robust standard errors in ().
Clustering at individual level.
All models estimated with individual fixed effects.

Table 6
Heterogeneous effect of DNS blocks on Internet traffic and use of legal alternatives - Pre-blocks BitTorrent usage intensity (matched sample).

	Dependent variable:					
	Log(Download) (1)	Log(Upload) (2)	VoD Rev. (3)	EBundle (4)	TV Mov. (5)	TV (6)
After x N. torrent days [1-2]	−0.074*	−0.091**	−0.149	0.001	0.857	3.104
	(0.038)	(0.039)	(1.908)	(0.008)	(1.108)	(4.046)
After x N. torrent days]2-5]	−0.255***	−0.310***	−3.391**	−0.011	1.418	4.143
	(0.061)	(0.066)	(1.458)	(0.012)	(1.523)	(6.004)
After x N. torrent days]5-10]	−0.229***	−0.276***	−2.550	0.010	1.916	12.184*
	(0.060)	(0.078)	(2.155)	(0.017)	(2.307)	(7.055)
After x N. torrent days]10+]	−0.249***	−0.583***	−1.128	0.030	3.842	0.753
	(0.062)	(0.085)	(3.308)	(0.019)	(2.415)	(6.536)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	70,320	70,320	70,320	70,320	70,320	70,320
R^2	0.784	0.757	0.174	0.720	0.641	0.670
Adjusted R^2	0.768	0.739	0.115	0.700	0.615	0.647
Residual Std. Error	0.958	0.940	72.359	0.154	24.416	85.464

Note: *p<0.1; **p<0.05; ***p<0.01.
Cluster robust standard errors in ().
Clustering at individual level.
All models estimated with individual fixed effects.

partner. The descriptive statistics in Online Appendix E show that this household sample is more interested in TV, entertainment, and VoD than the average household in the original sample. Therefore, we start by replicating the analyses provided in section 6.1 over this sub-population. We present the results in Table 7. We find that the estimated reductions in download and upload traffic are much larger for this sample – 19.6% ($p < 0.01$) and 38.4% ($p < 0.01$), respectively. The asymmetry between the two coefficients is also much larger – the percentual reduction in upload traffic is twice as large as the percentual reduction in download traffic. Compared to our original analysis, these two differences are likely explained by the fact that treated households in this sample are heavier BitTorrent users than those in our main sample. On average, survey respondents used BitTorrent on 2.8 days in the month before the blocks, while households in our main sample used BitTorrent on only 1.3 days in the month before the blocks. Moreover, as shown in 4, both the magnitude of the coefficients and the asymmetry between them increases with pre-blocks BitTorrent usage intensity. Also consistent with our main results, we find no statistically significant effect on the paid legal alternatives considered. However, unlike our main results, we find no statistically significant effect on total TV time or the time spent viewing entertainment channels on TV.

Table 8 presents our analysis of the heterogeneity in the households' response to DNS blocks using the survey sample. Regarding the moderator role of teenagers, the results show that the coefficient of interest – the triple interaction *BitTorrent User x After x Teens* – is positive and statistically significant (p<0.1 and p<0.01, respectively) in columns (1) and (2). Thus, the presence of teenagers in the household reduced the blocks' effectiveness in limiting piracy activity. This constitutes valuable insight for policymakers interested in complementing current DNS-blocking policies with educational programs targeting schools and high schools. Surprisingly, the triple interaction term *BitTorrent User x After x N. Young Adults* is not statistically significant in any of the models suggesting that the response of BitTorrent users from this demographic group was no different from that of adults.

Table 7
Effect of DNS blocks on Internet traffic and use of legal alternatives (sample of households that answered the media survey).

	Dependent variable:					
	Log(Download) (1)	Log(Upload) (2)	VoD Rev. (3)	EBundle (4)	TV Mov. (5)	TV (6)
After x BitTorrent User	−0.218***	−0.484***	0.831	−0.018	2.579	7.479
	(0.045)	(0.054)	(4.535)	(0.016)	(2.128)	(5.538)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,105	21,105	21,105	21,105	21,105	21,105
R^2	0.796	0.743	0.287	0.798	0.709	0.690
Adjusted R^2	0.781	0.725	0.236	0.783	0.688	0.667
Residual Std. Error	0.822	0.979	143.764	0.227	41.026	103.584

Note: *p<0.1; **p<0.05; ***p<0.01.
Cluster robust standard errors in ().
Clustering at individual level.
All models estimated with individual fixed effects.

Table 8
Moderators of the effect of DNS blocks on Internet traffic and use of legal alternatives (sample of households that answered the media survey).

	Dependent variable:					
	Log(Download) (1)	Log(Upload) (2)	VoD Rev. (3)	EBundle (4)	TV Mov. (5)	TV (6)
BitTorrent User x After	−0.227***	−0.535***	3.868	−0.032*	2.626	11.794*
	(0.051)	(0.063)	(5.270)	(0.019)	(2.167)	(6.533)
BitTorrent User x Teens	0.069	−0.020	12.995*	−0.009	12.115***	9.627
	(0.070)	(0.068)	(7.853)	(0.023)	(2.962)	(8.166)
BitTorrent User x Young Adults	−0.002	0.014	2.201	−0.038	5.446	−8.858
	(0.072)	(0.087)	(8.383)	(0.024)	(3.674)	(9.638)
BitTorrent User x After x Teens	0.173*	0.354***	−14.926	0.023	−0.786	−9.709
	(0.098)	(0.112)	(11.740)	(0.035)	(4.714)	(12.651)
BitTorrent User x After x Young Adults	−0.115	−0.112	0.508	0.052	7.841	−6.266
	(0.119)	(0.138)	(9.694)	(0.037)	(5.623)	(13.780)
Month Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,105	21,105	21,105	21,105	21,105	21,105
R^2	0.035	0.054	0.003	0.029	0.280	0.072
Adjusted R^2	−0.034	−0.014	−0.069	−0.041	0.228	0.005
F Statistic	38.044***	59.306***	2.843***	31.187***	403.633***	80.825***

Note: *p<0.1; **p<0.05; ***p<0.01.
Cluster robust standard errors in ().
Clustering at individual level.
All models estimated with individual fixed effects.

7. Conclusion

Our study focuses on the effectiveness of DNS-based website blocking as a means to combat digital piracy and encourage the use of legal alternatives for media consumption. We contribute to the existing literature by examining a public-private partnership that established a quick administrative procedure for blocking copyright-infringing websites without needing a court order. This approach allowed for regular and cost-effective blocking of infringing websites.

We take advantage of a unique dataset on household-level media consumption to measure the impact of this intervention on piracy and the use of a set of legal alternatives – TV viewership, Transactional VoD, and paid TV channel subscriptions. Our findings reveal that DNS blocking successfully reduced piracy activity, as indicated by decreased download and upload traffic. However, contrary to our expectations, there was no significant observable uptake of the legal alternatives, except for a slight increase in TV viewership. Despite initial concerns that digital pirates would find ways to circumvent the blocks and thus render the intervention ineffective, our results suggest this was not a significant issue.

Our analysis also demonstrates that the effectiveness of the intervention varied based on household characteristics. Heavier users of BitTorrent prior to the blocks experienced more considerable reductions in traffic, with a more prominent asymmetry between download and upload reductions. This asymmetry suggests that there was an uptake of online streaming services (legal or illegal) due to DNS blocking. Additionally, the presence of teenagers in a household appeared to diminish the effectiveness of the intervention.

Overall, our work expands the understanding of piracy control strategies by examining the effectiveness of an increasingly popular anti-piracy intervention. We assess its impact on piracy activity and legal alternatives not previously explored in the literature. Our findings offer valuable insights for policymakers, researchers, and industry practitioners, shedding light on the benefits and

limitations of DNS blocking as a piracy control measure. Additionally, our results raise considerations regarding the incentives for Internet service providers to participate in implementing such measures. Specifically, the fact that the services offered by ISP did not benefit from this intervention may negatively impact their willingness to collaborate on similar anti-piracy initiatives or imply that a careful allocation of costs among different industry stakeholders needs to be determined beforehand.

7.1. Limitations

This work has its limitations. First, all analyses pertain to a specific geography, which means attitudes towards piracy and the observed responses to regulatory changes might be specific to local culture and context. Second, we know that a household in our sample was affected by the DNS blocks if we observed it using BitTorrent prior to the blocks. However, we do not know which households were using illegal streaming services and were thus also affected by the blocks. Therefore, the treatment may have affected some households in the control group. This effect (unobserved streamers or low-intensity BitTorrent users in the control group stopping to use online piracy) should dominate any increase in piracy levels that could occur among the control group due to media coverage of the policy. For these reasons, our estimates are lower bounds for the average effect of treatment. Third, the survey data analyzed pertains to a different household sample than our primary analysis. The households that responded to this survey have self-selected to do so and, therefore, are not a representative sample of the households included in the main analysis. Still, for some households, the survey provides valuable demographic information that allows us to identify heterogeneous responses to website blocking that prior research had not yet been able to produce. Fourth, the matched sample used in the robustness check drops much of the original sample. However, this is an inherent trade-off between the quality of the match and the resulting matched sample size. Finally, this work relies on observational data, and even if pre-intervention trends are similar across treated and control households, we can only partially rule out such trends could have diverged after the DNS blocks for reasons unknown to us.

Disclaimer

During the preparation of this work the authors used *Grammarly* in order to improve the language and readability of the paper. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

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Data availability

The data that has been used is confidential.

Appendix. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jebo.2023.12.005.

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