Privacy & market concentration: Intended & unintended consequences of the GDPR

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Abstract

We show that the European Union's General Data Protection Regulation (GDPR) reduced data sharing online, but had the unintended consequence of increasing market concentration among web technology vendors. We collect panel data on the web technology vendors selected by more than 27,000 top websites internationally. The week after the GDPR's enforcement, website use of web technology vendors for EU users falls by 15%. Websites are more likely to drop smaller vendors, which increases the relative concentration of the vendor market by 17%. Increased concentration predominantly arises among vendors that use personal data such as cookies, and from the increased relative shares of Facebook and Google-owned vendors, but not from website requests to process personal data. This suggests that increases in concentration are driven by website vendor choices rather than changes in user behavior.

Keywords: Privacy, GDPR, Competition, Web technology

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1 Introduction

Academics and policymakers worry that privacy regulation could harm competition. Large firms could have more technical and financial resources to comply with regulation (Brill, 2011; Phillips, 2019). Further, where regulations require consent for personal data processing, large firms could leverage firm recognition to more easily obtain individual consent (Campbell et al., 2015). We suggest that policies limiting business-to-business data sharing could also benefit large firms. Potential business partners could favor large vendors because they may offer a better product or better regulatory compliance, thereby limiting legal risk. In this paper, we provide novel empirical evidence of these tradeoffs between privacy and competition policy.

We examine website choices of web technology vendors in response to the European Union (EU) enforcing the General Data Protection Regulation (GDPR). Europe's GDPR serves as a model for privacy regulation in Brazil, Japan, South Korea and several American states. These state-level regulations, like the California Consumer Privacy Act, may herald privacy regulation at the federal level. Despite this policy momentum, a growing literature reveals unintended consequences of privacy policy. Privacy policy can slow technology diffusion (Miller and Tucker, 2009, 2017; Adjerid et al., 2016) and even increase data breaches (Miller and Tucker, 2011). The GDPR coincided with lower venture capital investment for EU technology firms (Jia et al., 2019), lower recorded web traffic and revenue (Goldberg et al., 2019; Aridor et al., 2020), but no change in Internet network interconnectivity (Zhuo et al., 2019). If privacy policy harms competition, this compounds concerns about market power in the economy (Council of Economic Advisors, 2016; Berry et al., 2019).

Both privacy and competition concerns are acute in web technology. We define web technology as vendors that provide support services to websites, including: raising ad revenue, hosting audiovisual content, measuring visitor activity, and facilitating social media sharing. Web technology is an area of concern for EU privacy regulators because of its large-scale personal data processing (Commission Nationale de l'Informatique et des Libertés, 2019; Information Commissioner's Office, 2019b). Web technology's largest companies—Google and Facebook—capture 56% of global digital advertising spend (WARC, 2019), and draw privacy and competition scrutiny from regulators on both sides of the Atlantic.

Online web technology interactions provide an opportunity to measure the otherwise opaque data transfers between firms that the GDPR seeks to limit. When users visit a website, their browsers also interact with the third-party domains of web technology vendors and often share user identifiers (e.g. stored on cookies) that the GDPR considers to be personal data. We exploit this behavior in our data collection, which periodically crawls a sample of websites and directly observes their web technology vendor usage. We examine a panel of over 27,000 websites drawn from the top 2,000 sites in each EU country, the US, Canada and globally.

We browse each site throughout 2018 using a specialized tool to record web technology vendor interactions, which yields an initial set of over 375,000 website-vendor ties. By viewing the data through an economic lens, we complement computer science research documenting the GDPR's impact on web technology (e.g. Libert et al., 2018; Sørensen and Kosta, 2019).

We find that the GDPR restricts website use of web technology vendors, while increasing the relative concentration among web technology vendors. The GDPR creates a steep but short-lived 15% drop in website-vendor relationships, which return to pre-GDPR levels by the end of 2018. We focus on the short run impact where the drop in website-vendor relationships is largest, because EU regulators have since criticized industry practices and intend to regulate the industry in 2020 (CNIL 2019; ICO 2019b). Though we do not observe market conduct (e.g. pricing) of web technology vendors, we document changes to the market structure of the industry. We find that relative market concentration increases 17% in aggregate in the short run, implying that the GDPR most reduces the market shares of small web technology vendors. Concentration also increases in the top four web technology categories that comprise 94% of categorized vendor ties: advertising, web hosting, audience measurement, and social media. Concentration is pronounced among web technology vendors that process personal information, so that personal data collection also becomes more concentrated after the GDPR. We find that concentration does not depend on whether websites elicit consumer consent for data processing, implying that website rather than user choices drive increases in concentration. Finally, we show that website choices entrench Google and Facebook, whose web technology offerings drive increased concentration.

Our study adds to a broader economic literature documenting the unintended consequences of legislation designed to promote consumer health or welfare. Prior studies have documented how restrictions on advertising led to increased market concentration in markets for cigarettes (Eckard JR., 1991; Gallet, 1999; Clark, 2007) and alcohol (Sass and Saurman, 1995). As with studies of restrictions on information flows from firms to consumers, we find anti-competitive effects from restrictions on information flows from consumers to firms. The rest of the paper explains the GDPR policy, then describes the data, empirical strategy, and results.

2 GDPR Background

The European Union's General Data Protection Regulation (GDPR) regulates the processing of personal data of EU residents. The regulation applies to both EU firms and non-EU firms that target EU residents. Though passed in April 2016, the GDPR delayed its enforcement until May 25, 2018 to allow stakeholders to adjust. GDPR fines can reach 4% of a firm's annual global revenue.

Though the GDPR is a multifaceted regulation, many of its elements support the key principle of data minimization: firms must limit the personal data that they process (collect and use). Firms are explicitly required to audit internal data processes, encrypt and anonymize personal data, and notify affected individuals and the regulator in the event of a data breach. Firms are also responsible for respecting the new data rights of EU residents under the GDPR, including the rights to: access personal data, correct data, erase data, transfer data and object to data processing. In sum, the GDPR incentivizes firms to limit personal data processing by increasing both its associated operational cost and legal liability.

EU regulators clarified in 2019 that "consent" is the most appropriate of the GDPR's legal bases for web technology vendors to process personal data for affiliated websites (Information Commissioner's Office, 2019b). Under GDPR, personal data includes identifiers like cookies and IP addresses used in web technology. Valid consent under the GDPR requires that individuals opt in to data processing, and that consent notices must list both the purposes of data processing (e.g., for advertising or site analytics) and all third parties processing the data. In 2018, most websites that sought consent did so by asking users to either click "OK" to accept all disclosed data processing, or by clicking "More Options" to opt out of specific usage categories or usage by specific third parties. The ICO, the UK's privacy authority, deems the industry's *de facto* opt-out approach to be non-compliant because declining data processing should be as easy as accepting (Information Commissioner's Office, 2019a).

3 Data

3.1 Data description

We collect panel data on the web technology vendors employed by thousands of top websites to study the GDPR's impact on the web technology industry. Websites rely on inputs from specialized vendors to provide various services. For instance, many websites engage "audience measurement" vendors to record user site visits and generate statistics on user characteristics, onsite activities, and referral channels. Websites can choose the category's dominant vendor—Google Analytics—and/or competitors like Adobe Audience Manager. When a user visits a website, their browser interacts with third-party domains owned by those vendors: `google-analytics.com` (Google) and/or `demdex.net` (Adobe). By recording these third-party domain interactions, we can observe whether the website employs Google Analytics, Adobe Audience Manager, both, or neither.

We collect third-party domain data using the "webxray" tool developed by Libert (2019) and first used in Libert (2015). For each website in our panel, webxray opens an instance of the Chrome browser and

records all interactions with third-party domains. Third-party cookies are the best known form of third-party domain interactions, but webxray also records third-party domain interactions arising from http and Javascript requests. To capture the experience of an EU user, we use a VPN service to represent the browser as originating from France. Note that webxray does not interact with the website in any way, so we measure web technology vendor interactions arising *without* user consent.

To construct our sample, we use Amazon's Alexa service to identify the top 2,000 websites in each of the 28 EU countries as well as in each of the US, Canada and globally. These lists overlap such that our panel includes 28,227 unique sites. For our baseline, we collect data in the two days leading up to the GPDR's enforcement deadline. Similar data in WhoTracks.me (2018) and Sørensen and Kosta (2019) suggests that website use of third-party domains was relatively stable leading up to the deadline. Beginning on the May 25 deadline, we collect data weekly for six weeks, bi-weekly for the next six weeks, then every four weeks through the end of 2018.

As Libert (2015) explains, webxray sometimes fails to scan a site. When this happens, we make at least three attempts to scan the site. Note that 3.25% of sites never scan, perhaps because the sites block VPN users or potential bots. For the remaining 27,311 sites, the panel is 96.36% complete.

3.2 Vendor classification

A central challenge in measuring concentration is to appropriately define the market. We define markets by classifying web technology vendors into broad purposes like advertising and audience measurement. Measuring market concentration requires not only classifying vendors by purpose, but also linking third-party domains to vendors. To solve both challenges, we use a third-party domain database by Libert (2019).[1] This database clarifies when vendors use a third-party domain without the vendor's name and when vendors use multiple third-party domains. For instance, Google's advertising category offering uses the `doubleclick.net` domain (a past acquisition) and the `2mdn.net` domain.

The Libert (2019) database groups vendors into nine categorizes. By unique vendors in our data, the top categories are advertising (165 vendors), hosting (25), audience measurement (24), and social media (11). The "advertising" category includes full service ad vendors (e.g. Google Marketing Platform/Ad Manager, Xandr) and different ad intermediaries. These include ad exchanges (e.g. OpenX, Index Exchange); demand side platforms (The Trade Desk, AdForm); supply side platforms (Rubicon, PubMatic); and data management platforms (Oracle Bluekai, Lotame). "Social media" includes social platforms like Facebook

[1] We re-label some categories and omit the subcategories of the "hosting" category: "general", "code", "font", and "video." We combine Google's ad vendor offering ("Google Marketing Platform/Ad Manager") as well as its video offering ("Google Video/YouTube"). We combine "TrustArc" & "TRUSTe" (a rebranding) and "Are You a Human" & "Distill Network" (a 2017 merger).

and Twitter as well as social sharing tools like AddThis and ShareThis. "Hosting" is a broad category for vendors that host websites or site content elements. The category contains webhosts (Amazon Web Services, Cloudflare); tag management (Google Tag Manager only); website code (Google APIs, jQuery Foundation); video serving (Google Video/YouTube, Vimeo); and fonts (Typekit, Fonts.com). "Audience measurement" includes vendors that focus on reporting for the site's internal purposes (Google Analytics and Adobe Audience Manager) as well as vendors that focus on external reporting (Comscore and Alexa). Smaller categories include website security and bot detection ("security"), customer service chat widgets ("CRM": customer relationship management), platforms for "native ads", and "privacy compliance." Appendix C lists the top five vendors in each category.

We use the Libert (2019) database because it provides an independent and reasonable categorization that covers the majority of our data. Categorization is challenging even for broad categories because vendors can offer multiple services that straddle multiple categories. For instance, the "audience measurement" and "design optimization" categories differ by whether they offer advanced services like experiments and user session recording. Vendors such as Hotjar, which offers both types of services, appear in both categories under the Libert (2019) classification.

3.3 Descriptive statistics

In Table 1, we provide descriptive statistics for the websites and associated web technology vendors in our data. Table 1 focuses on the 26,127 websites that we scan both before the GDPR and one week post-GDPR, since our concentration estimates focus on those periods.

We use vendors as the unit of analysis rather than third-party domains. Before the GDPR, our data contain means of 16.3 third-party domains and 14.4 web technology vendors per site. These differ because a single vendor may use multiple third-party domains. For instance, Google Video/YouTube uses the domains `googlevideo.com`, `youtube.com`, and `ytimg.com`. Websites have a median of 9, a minimum of 0, and a maximum of 188 vendors. On average, 7.3 (50.3%) of these vendors place a third-party cookie on the browser. The Libert (2019) database categorizes 8.4 vendors per site on average, representing 58.2% of the 377,269 website-vendor ties in the baseline data.

The median global Alexa rank for these sites is #58,227. The data contain the top ranked site (`google.com`) and the lowest ranked site is #6,589,497. Our site selection emphasizes top sites in the EU and an average of 70.0% of all site traffic is generated by EU users. Across sites, the EU user share of site traffic covers the full range of 0% to 100%, with a median of 89.9%.

Table 1: Descriptive statistics

Variable	Obs.	Mean	St. Dev.	Min.	Med.	Max.
Third-party domains	26,127	16.3	18.0	0	11	199
Vendors	26,127	14.4	16.6	0	9	188
Vendors using third-party cookie	26,127	7.3	12.2	0	3	135
Categorized vendors†	26,127	8.4	10.3	0	5	87
First party cookie	26,127	0.92	0.28	0	1	1
Alexa rank	26,105	155,961.8	291,834.5	1	58,227	6,589,497
EU user share (%)	26,127	70.0	34.5	0	89.9	100

Notes: Website sample is scanned both pre-GDPR and one week later. †Libert (2019) categorization

4 Empirical strategy

Our empirical strategy for estimating the effect of the GDPR on web technology concentration relies on a simple before and after difference in market concentration metrics, where market definitions follow the vendor classification discussion in the previous section. We consider three concentration metrics below. Our concentration metrics require vendor market shares as an input. Our data allow us to observe website-vendor links, but not the size of associated economic benefits or costs. We rely instead on a vendor's reach as the basis of our concentration metrics, where reach is defined as the number of websites using one or more of a vendor's third-party domains.

We define vendor i's *relative* market share s_i to be i's reach divided by the total reach of all N vendors in the category:

$$s_i = \frac{reach_i}{\sum_{j=1}^{N} reach_j}$$

Normalizing by total reach provides a sense of relative concentration and ensures that the vendor shares sum to one. Note that the absolute market share (normalizing by the total number of sites instead), would not sum to one because websites often use multiple vendors in a category. Also, absolute market concentration trivially falls because most vendors lose reach post-GDPR. The relative market share is compressed in categories like advertising where sites employ multiple vendors each (4.3 on average). For example, 78.3% of sites use Google Marketing Platform/Ad Manager, but its relative market share is only 14.5%.

For a robust quantification, we examine three concentration metrics:

- *Herfindahl–Hirschman Index (HHI)*: HHI summarizes market concentration as the sum of the squared market shares:

$$HHI = \sum_{i=1}^{N} s_i^2$$

- *Concentration ratios (CR)*: The total market shares of the top M firms:

$$CR(M) = \sum_{i=1}^{M} s_i$$

- *Head-to-head win rate*: We propose a simple metric to quantify which vendor sites are more likely to drop. In particular, conditioning on websites that drop one of two vendors they employed prior to the GDPR, we quantify how often the sites drop each vendor. We examine the win rate of each category's dominant vendor to provide an intuitive explanation for changes in concentration.

HHI is our primary concentration metric due to its simplicity and broad use by regulators. We complement HHI with concentration ratios and head-to-head win rates as the latter metrics can be more intuitive. The United States Department of Justice and Federal Trade Commission (US Department of Justice and the Federal Trade Commission, 2010) use HHI to evaluate proposed horizontal mergers. HHI uses market shares on a 0 to 100 scale as an input, so that HHI varies from 0 (perfectly competitive) to 10,000 points (monopoly). For instance, a market with an equal duopoly would have $HHI = 50^2 + 50^2 = 5,000$ points. Though some models of competition (e.g. Cournot) link market structure to market conduct, we do not observe conduct like pricing, so we restrict our analysis to market structure.

We emphasize that we measure *relative* concentration. As we will see, vendors fall on average in all but one web technology category. We seek to measure whether websites favor vendors with large or small ex-ante market shares when websites limit vendors. In other words, we measure whether the larger vendors get a bigger slice of the smaller pie. Note that both the HHI and CR metrics are invariant if all vendors fall by the same percentage.

5 Results

5.1 GDPR impact on web technology vendors

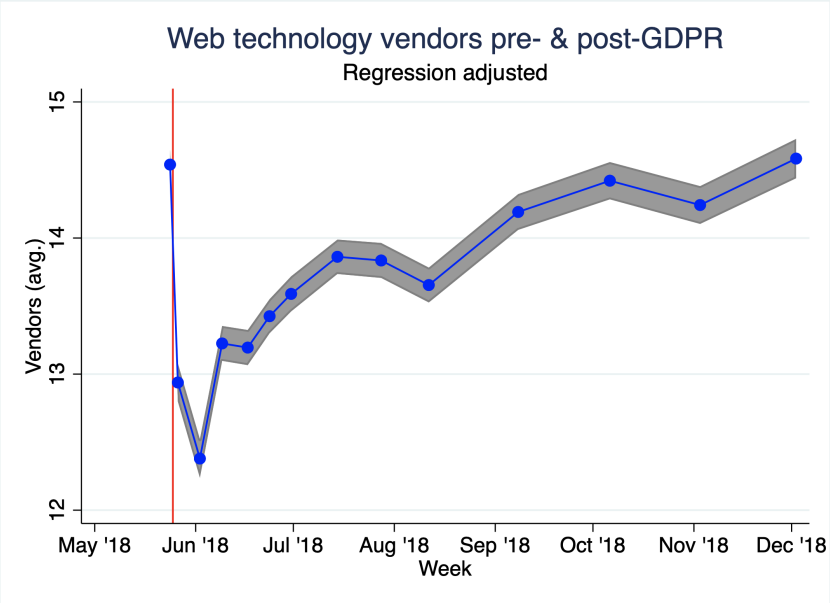
We begin by showing how website use of web technology vendors evolves over 2018. Figure 1 plots our regression estimates for this evolution.[2] We see that average web technology vendor use drops sharply after GDPR enforcement on May 25, 2018 (denoted by the vertical red line). Vendor use reaches its minimum

[2]Figure 1 plots the estimates of the fixed effects regression

$$y_{it} = \beta_0 + \sum_{t=1}^{T} \beta_t \cdot GDPR_t + \theta_i + \varepsilon_{it}$$

where y_{it} is site i's number of web technology vendors at time t, $GDPR_t$ is an indicator for the post-GDPR week $t > 0$, θ_i is a site fixed effect, and ε_{it} is the error term. Figure 1 plots the pre-GDPR average web technology vendors (β_0) and subsequent weeks ($\beta_0 + \beta_t$), and confidence intervals use the standard error for β_t.

Figure 1: Evolution of average web technology vendors per EU website



one week later – we refer to the baseline versus one week later comparison as the *short-run* GDPR impact estimate. The short-run estimate shows that sites reduce web technology vendors 14.9% from an average of 14.5 to 12.4 vendors. Most of this reduction happens right after the enforcement deadline as the number of vendors falls 11.0% between the initial scan on May 23-24 and the second scan on May 25-28. This suggests that most publishers waited until the last minute to adjust the vendors on their site. Though we only have one directly-collected pre-GDPR observation, in Appendix B we use related data from WhoTracks.me (2018) to establish a flat pre-trend for 1,322 of our sample sites. Third party vendor usage is steady between March and April 2018 (+0.04%) and declines only 0.67% in May 2018, which includes nearly a full week post-enforcement. Results from Sørensen and Kosta (2019) also suggest a relatively stable pre-trend in third-party domain usage.

Our findings emphasize the short run impact of the GDPR on web technology, where the potential influence of confounding unobserved trends is minimized. One of our starkest findings is that the short-run GDPR effect erodes over time: the effect on web technology vendors dissipates by the end of 2018. Two weeks after the GDPR, web technology vendors increase by 0.85 vendors on average over the previous week and continue to grow thereafter. The post-GDPR growth in vendors could arise from the web technology sector's dynamism, website fear of regulatory penalties falling over time due to a lack of enforcement, or some other explanation. Given that EU regulators signaled they will intervene in this industry (Information Commissioner's Office, 2019b, Commission Nationale de l'Informatique et des Libertés, 2019), we theorize the maximal impact of the GDPR in 2018 is more indicative of the industry under future enforcement.

Table 2 shows the short-run change in web technology vendors by category among the 26,127 sites that we scan both before the GDPR and one week after. We see that web technology vendors fall 14.5% in the short run and the subset of categorized vendors falls 17.7% from 8.4 to 6.9. The category-level results in Table 2 reveal that the average number of vendors falls for all but one category in the short run. The exception is the "privacy compliance" category, which we expect would benefit from the GDPR. However, few sites use vendors in the privacy compliance category, as these increase from only 0.017 to 0.021 vendors on average. Advertising is both the largest category and the category that falls the most (24.3%), from 4.35 to 3.29 average vendors. Hosting, audience measurement, and social media are the next largest categories and these categories fall by 9.7%, 10.9%, and 11.5% respectively. The remaining categories appear infrequently with means of at most 0.22 vendors per site.

In Appendix A, we provide evidence that the reduction in web technology vendors reflects the technology supplier decisions of websites. We first show that no vendor of consequence chooses to completely exit the EU. We identify only 42 websites that block EU users post-GDPR and only 12 of these sites reduce the number of vendors below 10 in the short run. Finally, we show that sites that request consumer consent do not block third-party domains, as we see no short run change in sites loading at least one third-party domain. Sanchez-Rola et al. (2019) also find that third-party domain interactions precede consent.

5.2 GDPR impact on concentration

To examine the effect of the GDPR on market concentration, our empirical strategy focuses on the short-run comparison of the web technology industry where the GDPR impact was greatest.

Table 2 shows the baseline HHI and concentration ratios for the top two vendors (CR2) in every category. We see that all categories but advertising and hosting have HHI's above the 2,500 point threshold that American regulators define as a "highly concentrated market" (US Department of Justice and the Federal Trade Commission, 2010). We also compute an aggregate HHI metric among all vendors that ignores categories. Aggregate HHI is only 146 points and aggregate HHI among all classified vendors is 308 points. Table 2 only includes a single concentration ratio (CR2), though the total shares of the top two firms exceed 50% in all categories but advertising. Advertising has the lowest HHI (348 points) and CR2 (0.187) because our relative market reach definition compresses these measures. Advertising contains 165 vendors and sites use 4.3 ad vendors on average, so that even the dominant vendor (Google Marketing Platform/Ad Manager) has a relative share of only 14.5% although it reaches 78.3% of sites.

Turning to the GDPR's short run impact on market structure, Table 2 shows that aggregate HHI increases 17.3% among all vendors and 17.8% among all classified vendors. The top four vendor categories represent

Table 2: Short run GDPR impact on concentration

	Avg. vendors			HHI			Concentration ratio (CR2)			Head-to-head competition	
Category	Pre	Post	Diff. (%)	Pre	Post	Diff. (%)	Pre	Post	Diff. (%)	Win (%)	Dominant firm
All vendors	14.44	12.35	-14.5%	146	171	17.3%	0.098	0.105	7.0%		
All categorized vendors[†]	8.40	6.91	-17.7%	308	363	17.8%	0.168	0.187	11.3%		
Advertising	4.35	3.29	-24.3%	348	436	25.3%	0.187	0.217	15.8%	98.9%	Google ad platform[††]
Hosting	1.78	1.61	-9.7%	1,892	1,936	2.3%	0.569	0.578	1.7%	74.3%	Google APIs
Audience measurement	1.25	1.11	-10.9%	4,116	4,355	5.8%	0.697	0.719	3.1%	93.5%	Google Analytics
Social media	0.79	0.70	-11.5%	4,251	4,412	3.8%	0.775	0.791	2.1%	87.2%	Facebook
Design optimization	0.22	0.20	-10.5%	2,874	2,861	-0.5%	0.720	0.716	-0.6%	50.0%	Hotjar
Security	0.15	0.12	-17.8%	8,926	9,722	8.9%	0.998	0.998	0.0%	94.7%	Cloudflare
Native ads	0.078	0.066	-14.8%	4,229	4,024	-4.8%	0.849	0.845	-0.5%	21.7%	Taboola
CRM	0.022	0.019	-9.6%	6,408	6,119	-4.5%	0.982	0.980	-0.2%	.	Zendesk Chat
Privacy compliance	0.017	0.021	23.2%	3,925	4,116	4.9%	0.838	0.865	3.2%	25.0%	TrustArc

Notes: [†]Libert (2019) classification. [††] Google ad platform includes Google Marketing Platform & Google Ad Manager.

94.3% of categorized vendors pre-GDPR, and HHI increases post-GPDR in each of these categories. The advertising category sees the largest increase in HHI, growing 25.3% from 348 to 436 points. The increase in HHI among the next three top categories is more moderate: 2.3% in hosting, 5.8% in audience measurement, and 3.8% in social media. Beyond the top 4 categories, we see mixed results. Design optimization changes little (-0.5%), whereas HHI in security increases 8.9%. The native ads and CRM categories become less concentrated: HHI falls -4.8% and -4.5% respectively. Both categories are highly concentrated categories and so small that they represent only 1.1% of total categorized vendor reach. The increase in HHI in the advertising category (25.3%) is proportional to the decrease in the average number of vendors (24.3%), though this relationship is less than proportional in the remaining categories. Several categories see HHI increases near or above the 100 point threshold that American regulators use to scrutinize mergers: advertising gains 88 points, audience measurement gains 239 points, social media gains 161 points, and security gains 796 points.

As the total share of the top two firms, CR2 can be a more intuitive metric than HHI. In Table 2, we see that the sign of the short run change in CR2 reflects the change in HHI in all categories but security, where the baseline CR2 of 0.988 creates a ceiling effect. In Appendix C, we provide the change in concentration ratios for different numbers of top firms and we see that the change in concentration ratios generally reflects the change in HHI until the concentration ratio exceeds 95% of the market. As with HHI, we see the largest increase in CR2 in the advertising category with a relative increase of 15.9% from a CR2 of 0.187 to 0.217. For the remaining top 4 categories, the relative increase in CR2 lies between 1.7% and 3.1%. The decreases in CR2 for design optimization, native ads, and CRM are small at -0.6%, -0.5% and -0.2% respectively.

Finally, Table 2 shows the head-to-head win rate of the dominant firm in each category. Recall that this metric reflects the probability that a publisher keeps the dominant category vendor over a competitor post-GDPR, conditional on employing both vendors pre-GDPR. The top 4 categories suggest that the increase in concentration is in part a story of Google and Facebook's dominance in this metric. In advertising, Google Ad Manager wins an exceptional 98.9% of these head-to-head battles. Google also wins in hosting (Google APIs) 74.3% of the time and in audience measurement (Google Analytics) 93.5% of the time. For its part, Facebook wins 87.2% of its head-to-head battles in social media. Further down the category list, we see that the dominant firm's win rate helps to explain the change in HHI. Hotjar wins only half of its head-to-head battles in the design optimization category, which helps explain why the category's HHI is flat. In the security category, Cloudfare wins 94.7% of the time, which helps to explain why that category sees the second largest increase in HHI. Taboola wins only 21.7% of the time in the native ads category, which helps to explain why that category sees a 5.2% reduction in HHI.

In sum, the GDPR coincided with a short run increase in aggregate web technology concentration. While

market concentration does not always follow data minimization, the largest web technology categories become more concentrated. Many of these categories are highly concentrated initially and several categories exhibit significant increases in concentration both relative to the underlying change in category use and relative to the 100 point threshold that regulators use to scrutinize mergers. Three different concentration metrics paint a consistent picture of these results. Appendix D considers a second third-party domain classification scheme by Karaj et al. (2018), which broadly replicates our findings. WhoTracks.me (2018) also show that small ad vendors fall by more than top vendors among the top 2,000 EU sites the month after GDPR. Appendix E shows that the evolution in aggregate concentration mirrors the evolution in average vendor use through the end of 2018. Though aggregate HHI returns to pre-GDPR levels, concentration in the advertising category remains at 6.3% higher than the pre-GDPR baseline.

5.3 Extensions

Below, we consider three extensions that reexamine changes in aggregate concentration by cutting the data in three different ways.

5.3.1 Personal data concentration

We examine whether data minimization is accompanied by data concentration for personal data in particular. We wish to classify which vendor interactions contain personal information, though we do not directly observe this in our data. We classify web technology vendors as likely using personal data if they employ a cookie or if they are categorized as either "audience measurement" or "design optimization." While a cookie can contain non-personal information, cookies typically contain a user identifier, which is considered personal information under the GDPR. On the other hand, vendor interactions can still contain personal data without a cookie. For instance, Google Analytics relies on the unique user ID assigned by the website, which is transmitted by a http request to `google-analytics.com`. Since the "audience measurement" and website "design optimization" categories require a user ID to function, we classify those vendors as likely using personal data.

We find that data minimization led to increased concentration of personal data among top vendors. We split the vendor interactions in the data sample by whether they are likely to contain personal data and calculate the relative concentration using the aggregate HHI metric that ignores categories, as in Table 2. We report the results of this exercise in the first two rows of Table 3, where we see that relative concentration increases 23.8% among vendor interactions that likely involve personal data, but only 5.0% among interactions that likely do not.

Table 3: GDPR & aggregate concentration: Three extensions

	HHI			
Data samples	Pre	Post	Diff.	Diff. (%)
Role of personal data				
Likely personal data	187.0	231.5	44.5	23.8%
Unlikely personal data	360.0	378.1	18.1	5.0%
Role of consent				
Sites with privacy extension	100.1	117.9	17.8	17.8%
Sites without privacy extension	153.6	179.4	25.8	16.8%
Role of top 2 companies (Google & Facebook)				
All vendors	145.7	171.0	25.2	17.3%
All but top 2 companies	46.0	43.2	-2.8	-6.2%

The pool of online personal data thus became more concentrated in the hands of the largest vendors, which is another unintended consequence of the GDPR. To the extent that vendors can generate value from personal data, data concentration can further strengthen the market position of large vendors.

5.3.2 Consent

Past work has theorized a role for user privacy consent in increasing market concentration (Campbell et al., 2015). Under the GDPR, websites should obtain user consent for sharing personal data with vendors and list all these vendors. As a result, websites may reduce the number of listed vendors and favor large vendors familiar to consumers. Although sites may create their own systems to process user consent, many sites adopt third party consent management platforms (CMPs) in an effort to comply with the GDPR. Using data from `builtwith.com` described in Appendix A.2, we split the sample by whether sites implemented a known consent management platform (7.1% of sites) by the week after the GDPR. In rows 3 and 4 of Table 3, we report that the relative increase in concentration is similar whether the site implements a CMP (17.8%) or not (16.8%). We therefore conclude consent-related effects have limited influence on our market concentration results.

5.3.3 Google & Facebook

We provide more evidence that Google-owned vendors and Facebook play an important role in increasing relative market concentration. These two companies dominate digital advertising, collecting 56% of global spending (WARC, 2019). In our pre-GDPR baseline, Google's many vendors represent 28.8% of all website-vendor pairs and Facebook represents 3.4%. The companies top the four largest web technology categories and Table 2 shows that sites keep the dominant vendor over a competitor the majority of the time post-GDPR.

The final two rows (5 and 6) of Table 3 compare the pre/post-GDPR change in aggregate HHI with and

without the big two companies. Row 5 of Table 3 replicates the "all vendor" aggregate HHI measures in Table 2, showing that relative vendor concentration among all vendors rises 17.3% from an HHI of 146 to 171. The final row excludes the big two companies from the HHI measures, revealing that relative concentration *falls* 6.2% in their absence (from 46 to 43). Note also that HHI is much lower without the big two companies, because the remaining vendors have smaller relative market shares even without the dominant companies. This difference arises because Google-owned vendors grow from 28.8% to 31.9% of site-vendor pairs in the short run and Facebook grows from 3.4% to 3.6%.

Despite relative market share gains, the absolute position of the two companies is weaker after the GDPR. The share of sites working with each top vendor falls one week post-GDPR: Google Marketing Platform/Ad Manager falls from 62.8% to 57.2% of sites, Google APIs falls from 55.6% to 50.9%, Google Analytics falls from 78.3% to 72.0%, and Facebook falls from 49.8% to 45.0%.

Google's ad platform plays an important role in the advertising category, which has the greatest increase in concentration. Google did not join the industry standard (IAB Europe, 2018) for sharing user consent choices. These dueling standards put pressure on publishers to choose between Google's ad platform or the rest of the industry. From Table 2, we see that websites retained Google over another competing vendor in 98.9% of such choices. Though abstaining from the industry standard may have increased Google' relative share of the ad market, the British regulator also criticized the industry standard approach as being inadequate (Information Commissioner's Office, 2019b).

6 Conclusion

This paper provides novel empirical evidence of a potential tradeoff between privacy regulation and market concentration. We study the EU's GDPR, which serves as a global model for privacy policy. We examine the web technology industry, which attracts attention both for its permissive privacy practices and its high concentration. We examine over 27,000 top websites with a baseline of over 375,000 website-vendor ties. We show that websites reduce their web technology vendor use by 15% immediately after the GDPR enforcement deadline in response to the GDPR's data minimization mandate, but these compliance gains erode over time. In the short run, we see that concentration increases 17% in aggregate and in each of the top four web technology categories that together represent 94% of website-vendor ties: advertising, hosting, audience measurement, and social media.

In evaluating the GDPR, we see that the policy initially succeeded in its data minimization goal in the data-intensive web technology industry. Though these gains eroded over time, renewed criticism of the industry by EU regulators (Information Commissioner's Office, 2019b, Commission Nationale de l'Informatique

et des Libertés, 2019) potentially signals future reductions in the industry. Despite data minimization successes, the GDPR had the unintended consequence of increasing the industry's relative concentration. We show that this tradeoff between data minimization and concentration is not mechanical: some niche categories become less concentrated. However, relative concentration increases in the top web technology vendor categories that represent most of the industry. The increase in concentration is highest among the web technology vendors that process the personal data, which the GDPR targets. Though requiring consumer consent could favor large vendors, the increase in concentration appears to be independent of consent. Instead, our evidence suggests that concentration increases because websites were more likely to drop smaller vendors. As policymakers wrestle with how to protect individual privacy, they should balance the risk of increasing concentration of personal data ownership and increasing market power. More research is needed to determine how policymakers could mitigate these unintended policy consequences.

This paper shows how market structure evolves post-GDPR, but ignores market conduct. Future research can further explore the consequences of greater relative concentration for market conduct such as vendor pricing. Vendor revenue and cost data would further elucidate the economic magnitude of the concentration effect. For instance, if ad vendors with greater reach are associated with greater ad revenue share, then our findings could understate the increase in concentration. Defining the market remains a central challenge for measuring market concentration. Our current classification scheme employs broad categories. For instance, the advertising category contains subcategories like ad exchanges, demand side platforms, and supply side platforms. From the perspective of evaluating the impact on competition, investigating these subcategories may provide further insight into the role of privacy regulation.

For regulators examining competition in technology industries, the GDPR presents nuanced effects. Most web technology vendors—including Google and Facebook—are worse off post-GDPR in that they lose website partners. However, the relative market shares of the largest vendors—particularly Google and Facebook—increase post-GDPR. This does not itself imply anti-competitive conduct by the large vendors. Rather, our evidence suggests that increased relative concentration results from website choices and not from vendor or user choices. We speculate that increased concentration could simply result from the large vendors offering a better product or better compliance with the regulation.

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Appendix

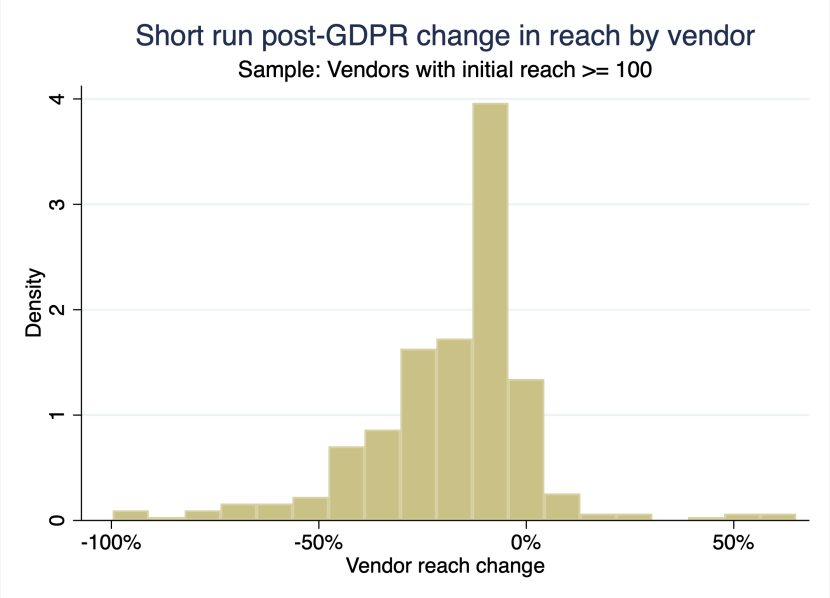
A Compliance approaches

A.1 Vendor compliance

Our data indicates that the observed reduction in web technology vendors post-GDPR reflects publisher rather than vendor decisions. Web technology vendors like Kargo, Verve, Drawbridge, and Factual—most of which provide mobile ad services—indicated that they were exiting the EU as a result of the GDPR. Nonetheless, no vendor of consequence drops out of our data after the GDPR.

While the main results examine vendor adoption at the website level, here we consider the results at the vendor level. Figure 2 presents a histogram for the relative short run change in reach by vendor, for the 361 vendors with baseline reach over 100 sites—0.38% of our site sample. Among these vendors, reach falls an average of -17.9% and a median of -12.7%. 92.8% of these vendors see their reach fall one week post-GPDR. The reduction in vendors is thus spread out among vendors, and no vendor of consequence removes itself from the site-vendor pair data. The largest vendor whose reach falls to 0 only has initial reach of 78 sites (0.30%). This evidence suggests that the websites rather than the vendors are the principal decision-makers in the market.

Figure 2: Histogram: Short run change in vendor reach



A.2 Website compliance

The GDPR creates unusual challenges for empirical investigation because the regulation can potentially affect both the data collection process and the underlying data generating process (Goldberg et al., 2019). Of particular interest is the role of user consent compliance and its potential to censor the automated collection of data. Since our data collection process does not interact with sites, all third-party domain (3PD) interactions in our data arise without consent, implying that consent compliance mechanisms could introduce empirical measurement issues.

We explore the role of consent compliance on our concentration measures by augmenting our sample with data from `builtwith.com`, which tracks website adoption of known consent management platforms (CMPs). Using data from `builtwith.com` from August 2019, we find that only 24.4% of sites in our sample at some point employ a third-party consent management platform, and only 7.1% of sites do so by July 4, 2018. However, regardless of CMP usage, sites in our sample do not appear to wait for consent before initiating interactions with third parties. We see no reduction in sites that load zero 3PD content among sites using CMP's by July 4, 2018. Instead, we see no change (s.e. .0011) in sites with zero third parties – in other words, the change in 3PD is all on the intensive margin. The surprising irrelevance of consent is supported by Sanchez-Rola et al. (2019), who found that 92% of the sites they scan in July 2018 set at least one identifier cookie without consent. Further, only 4% of sites provide a clear cookie opt-out option and only 2.5% of sites erase cookies after opt-ing out.

We further examine the incidence of sites blocking users as a compliance strategy, which could also have implications for measurement. Though some sites block EU users post-GDPR, this approach is rare in our data. We compare our sites to a list of 1,361 blocking sites compiled by O'Connor (2019), and only 13 of these sites appear in our list of 27K scanned sites. We found another 29 blocking sites in our data manually, by visiting sites with unusual post-GDPR changes. Notably, only 12 of the 42 blocking sites reduce vendors to fewer than 10 vendors by the week post-GDPR. Only 21 of these sites reduced their 3PD at all in this period. The 12 blocking sites of interest include chicagotribune.com and latimes.com, which reduced 3PD from 55 and 63 to a single third-party domain post-GDPR (their parent company's domain).

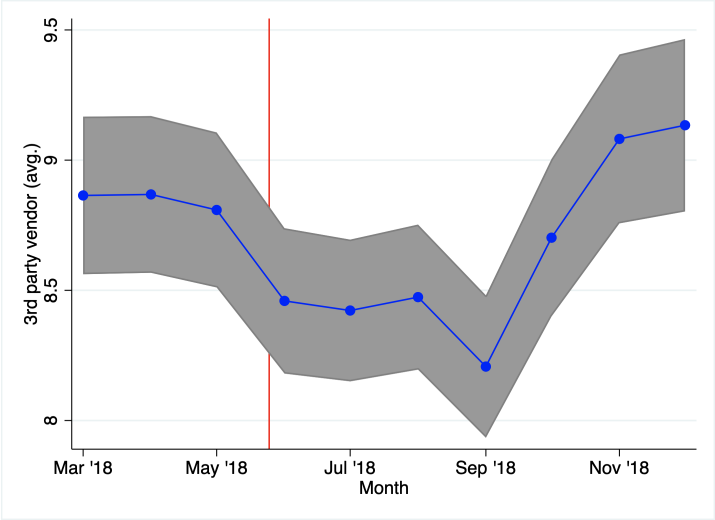
In sum, neither consent compliance nor user blocking appears to be a significant concern for our data collection process in terms of observing site-vendor relationships.

B Pre-GDPR trend in web technology vendor usage

We use external data from WhoTracks.me (2018) to examine the trend in web technology use prior to GDPR enforcement. We do not see evidence of anticipatory compliance in these data.

WhoTracks.me (2018) released public data on the monthly web technology use of the 1,500 top EU websites beginning in March 2018. Karaj et al. (2018) describe the data collection methodology, which employs a large panel of consumers to measure third party domain usage on websites. Karaj et al. (2018) argue that their approach has several advantages, such as extensive sampling coverage of consumer browser and operating system set-ups, as well as the ability to view non-public websites (e.g., sites requiring user authentication). However, the WhoTracks.me (2018) data is dynamically selected because it evolves with the composition and preferences of its participating users, complicating site-level inference. The WhoTracks.me (2018) data includes the third party vendors associated with the top 1500 sites, as determined by their panel of users residing in the EU. Although these top sites vary over time, a complete panel is available for 1,452 sites between March 2018 and December 2018. We analyze the 1,322 sites (91.0%) that also appear in our sample data.[3] Karaj et al. (2018) also map third-party domains into vendors (referred to as "trackers") using their own database (see also Appendix D). Figure 3 shows the evolution of average third party vendor

Figure 3: 3rd party vendors pre-post GDPR: Sites in WhoTracks.me (2018) & our data



usage for the 1,322 WhoTracksMe sites that are also in our data. Figure 3 plots the mean number of third party vendors by data collection month and 95% confidence intervals around each mean. The data reveal that third party vendor usage increased only 0.04% on average between March and April 2018. Third party usage on average fell -0.67% in May 2018, though this includes several days (May 25-31) after GDPR

[3]Results using the full sample of 1,452 sites are essentially the same. See footnote 4.

enforcement.[4] Thus, the WhoTracks.me (2018) data suggests a flat pre-trend in third party usage leading up to enforcement, which is also supported by Sørensen and Kosta (2019). Post-GDPR, Figure 3 shows a similar trend to Figure 1 as the number of vendors increases to pre-GDPR levels by the end of 2018.

To summarize, we do not find evidence of a pre-GDPR trend in web technology vendor use, which is consistent with sites delaying compliance until the May 25th enforcement deadline.

C Top vendors & concentration ratios

We explore the top firms in the nine Libert (2019) vendor categories and examine how their cumulative market shares evolve post-GDPR. Table 4 below lists the top five firms in each category as well as the number of vendors per category.

To further unpack the changes in HHI, we examine the changes concentration ratios. The concentration ratio is the total market share of the top M companies in the category. For instance, CR4 gives the total market share of the top 4 firms in the category. We see that the changes in CR(M) are typically the same sign as the change in HHI: this is by construction, but concentration ratios provide a more intuitive explanation.

In Table 5, we show the short run change in concentration ratios for the top {1, 2, 3, 4, 5, 8, 10} firms. Note that not all categories have sufficient firms to fill out the table.

D Robustness: WhoTracksMe classification

We rely on an independent categorization of third-party vendors by Libert (2019). However, we also consider a second vendor categorization which we refer to "WhoTracksMe" after the project developed by Karaj et al. (2018). The WhoTracksMe project is a large-scale monitoring initiative for online tracking. WhoTracksMe defines the equivalent of the advertising and audience measurement/website analytics categories more broadly so that these categories include an average of 6.9 and 1.9 vendors rather than 4.3 and 1.3 vendors respectively. The closest equivalent to the webxray hosting category is the content delivery network (CDN) and hosting categories in Karaj et al. (2018), which collectively have the same average size of 1.8 vendors per site. Karaj et al. (2018) also has a social media category, but this excludes Facebook as Karaj et al. (2018) instead classified Facebook as advertising. The Karaj et al. (2018) social media category thus has only 0.2 rather than the 0.8 vendors on average in Libert (2019). Note that the baseline average vendors is slightly lower under the WhoTracksMe classification: 14.1 vendors in Table 6 versus 14.4 in Table 2. This difference arises from defining uncategorized third-party domains as separate vendors and because WhoTracksMe categorizes

[4]For the full sample of 1,452 sites, the number of third party vendors rises by only 0.08% in April and falls -0.63% in May.

Table 4: Web technology categories & top vendors

Category†	Vendors	Top Vendors				
		#1	#2	#3	#4	#5
Advertising	165	Google ad platform††	Xander	AdForm	The Trade Desk	Rubicon Project
Hosting	25	Google APIs	Google Tag Manager	Amazon Web Services	Cloudflare	Google Video/YouTube
Audience measurement	24	Google Analytics	Hotjar	ScorecardResearch	Adobe Audience Manager	Quantcast
Social media	11	Facebook	Twitter	AddThis	LinkedIn	Share This
Design optimization	8	Hotjar	New Relic	Optimizely	Visual Website Optimizer	Crazy Egg
Native ads	4	Taboola	Outbrain	nscontext.eu	ContentStream	
Security	3	Cloudflare	Distil Networks	Knownsec		
CRM	3	Zendesk Chat	liveperson.net	Salesforce		
Privacy compliance	3	TrustArc	Evidon	iubenda		

Notes: Vendor ranking based on pre-GDPR baseline. †Libert (2019) classification. ††Google ad platform includes Google Marketing Platform & Google Ad Manager.

Table 5: Short run change in concentration ratios

	Difference in Concentration Ratios						
Category†	CR1	CR2	CR3	CR4	CR5	CR8	CR10
Advertising	0.0293	0.0297	0.0314	0.0299	0.0300	0.0302	0.0325
Hosting	0.0043	0.0097	0.0096	0.0058	0.0028	0.0026	0.0018
Audience measurement	0.0207	0.0218	0.0189	0.0130	0.0006	0.0004	0.0009
Social media	0.0132	0.0162	0.0090	0.0091	0.0085	0.0000	-0.0001
Design optimization	0.0042	-0.0046	-0.0039	-0.0026	0.0001		
Security	0.0428	-0.0004					
Native ads	-0.0354	-0.0046	-0.0003				
CRM	-0.0262	-0.0019					
Privacy compliance	0.0248	0.0268					

Notes: †Libert (2019) classification.

more of the vendors in the data.

Our concentration results are broadly robust to the WhoTracksMe classification in Table 6. The aggregate increase in relative HHI is higher for both all vendors (22.3%) and WhoTracksMe categorized vendors (23.5%). The WhoTracksMe classification results replicate the increase in HHI for advertising (29.0%), audience measurement/website analytics (6.7%) and hosting (5.1% for CDN and 0.1% for hosting). However, the social media HHI declines slightly (-0.5%), which confirms that Facebook plays a critical role in increasing HHI in the Libert (2019) social media category. As with the Table 2, the picture outside of these top categories is more mixed as several small vendor categories exhibit a decrease in HHI. Still, the top three categories here represent 84.6% of categorized vendors and the social media category represents an additional 1.8%.

E Post-GDPR evolution of concentration

The GDPR's impact on concentration follows its impact on web technology vendors. Figure 4 plots the evolution in relative concentration over 2018, as measured by aggregate HHI. Aggregate HHI ignores category information and defines the relative share as vendor reach over total vendor reach. Aggregate HHI is 146 points before the GDPR and HHI reaches its maximum one week post-GDPR. As with average vendor use, Figure 4 reveals that web technology concentration returns to its pre-GDPR level by the end of 2018. Figure 4 shows that the evolution of aggregate HHI over time is the mirror image of the evolution of the average number of vendors in Figure 1. We see that both the post-GDPR increase in concentration and its relationship with average vendors persist.

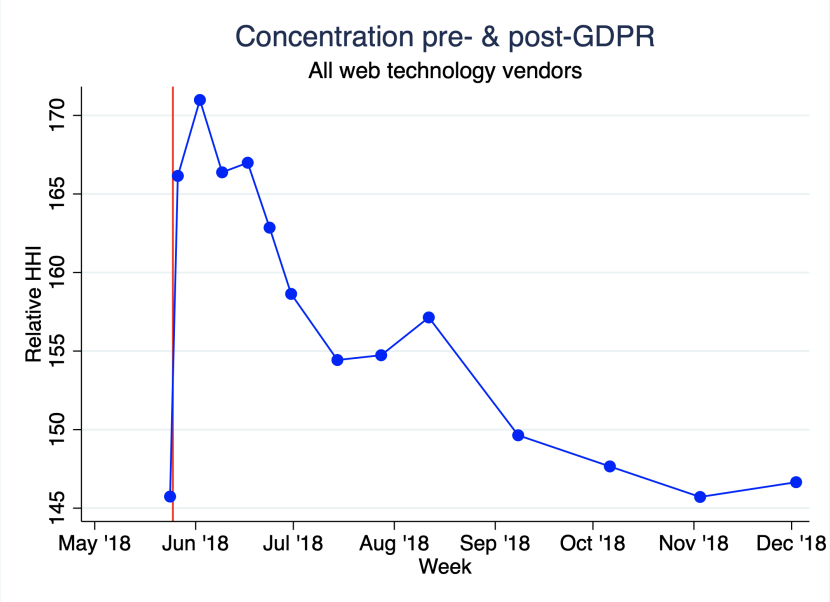
Our concentration findings emphasize the short-run impact of the GDPR, though here we also examine concentration levels at the end of 2018. Table 7 explores the change in concentration by category 28 weeks

Table 6: Robustness: GDPR impact on concentration using WhoTracksMe classification

	Avg. vendors			HHI			Concentration ratio (CR2)			Head-to-head competition	
Category	Pre	Post	Diff. (%)	Pre	Post	Diff. (%)	Pre	Post	Diff. (%)	Win (%)	Dominant firm
All vendors	14.10	12.04	-14.6%	185	226	22.3%	0.137	0.158	15.6%		
All categorized vendors[†]	12.26	10.42	-15.0%	244	302	23.5%	0.157	0.183	16.2%		
Advertising	6.90	5.55	-19.6%	282	364	29.0%	0.182	0.219	20.7%	95.4%	Google ad platform[††]
Website analytics	1.85	1.64	-11.4%	1,903	2,030	6.7%	0.483	0.490	1.4%	94.1%	Google Analytics
Content delivery network	1.59	1.50	-5.6%	2,459	2,585	5.1%	0.676	0.698	3.2%	45.1%	Google APIs
Essential	0.65	0.62	-3.5%	5,041	4,611	-8.5%	0.764	0.726	-4.9%	67.9%	Google Tag Manager
Miscellaneous	0.28	0.24	-17.3%	485	403	-17.0%	0.226	0.190	-15.9%	27.6%	Walmart
Social media	0.22	0.20	-9.4%	3,106	3,091	-0.5%	0.625	0.624	-0.1%	75.9%	Twitter
Hosting	0.20	0.18	-9.9%	8,385	8,390	0.1%	0.949	0.949	0.0%	88.2%	Amazon Web Services
Customer interaction	0.20	0.17	-10.8%	366	361	-1.3%	0.182	0.168	-8.0%	20.0%	bidr.io
Audio-Visual player	0.19	0.16	-13.0%	4,070	3,998	-1.8%	0.689	0.673	-2.3%	64.9%	Google Video/YouTube
Comments	0.084	0.075	-11.1%	701	731	4.2%	0.250	0.243	-2.7%	0.0%	Yadro
Pornvertising	0.054	0.048	-10.1%	4,702	4,795	2.0%	0.920	0.917	-0.3%	66.7%	exosrv.com

Notes: [†]Karaj et al. (2018) classification. [††]Google ad platform includes Google Marketing Platform & Google Ad Manager.

Figure 4: Evolution of web technology vendor concentration (HHI)



after the GDPR by replicating the calculations in Table 2 for the later time period. While aggregate HHI returns to baseline levels (0.6% higher), the aggregate HHI among vendors whose purpose is classified is still 3.9% higher than the baseline. The largest category (advertising) remains 6.3% more concentrated than the pre-GDPR baseline, while the next three categories see small decreases. Average vendors in the native ads category remains lower than the pre-GDPR baseline at -13.2% (versus -14.8% one week post-GDPR), though the sign on HHI has reversed to 10.3% from -4.8% one week post-GDPR. Given the industry's extreme dynamism, after 28 weeks and perhaps outside of advertising, the magnitude of changes in HHI and average vendors are sufficiently small that we do not wish to over-interpret changes in concentration.

Table 7: Post-GDPR change in concentration (end of 2018)

	Avg. vendors			HHI			Concentration ratio (CR2)			Head-to-head competition	
Category	Pre	Post	Diff. (%)	Pre	Post	Diff. (%)	Pre	Post	Diff. (%)	Win (%)	Dominant firm
All vendors	14.52	14.57	0.3%	145	146	0.6%	0.098	0.094	-3.3%		
All categorized vendors[†]	8.46	8.22	-2.8%	307	319	3.9%	0.167	0.167	-0.2%		
Advertising	4.38	4.10	-6.4%	345	367	6.3%	0.187	0.191	2.3%	98.5%	Google ad platform[††]
Hosting	1.79	1.88	5.0%	1890	1862	-1.5%	0.568	0.566	-0.3%	69.0%	Google APIs
Audience measurement	1.26	1.24	-1.6%	4099	4093	-0.2%	0.696	0.699	0.5%	93.0%	Google Analytics
Social media	0.80	0.77	-3.2%	4258	4103	-3.6%	0.774	0.754	-2.7%	86.1%	Facebook
Design optimization	0.22	0.22	-2.7%	2880	3009	4.5%	0.721	0.740	2.6%	65.8%	Hotjar
Security	0.15	0.15	0.1%	8936	9426	5.5%	0.998	0.999	0.1%	90.2%	Cloudflare
Native ads	0.078	0.068	-13.2%	4226	4661	10.3%	0.851	0.879	3.3%	55.6%	Taboola
CRM	0.021	0.021	-3.6%	6346	6245	-1.6%	0.982	0.975	-0.6%	100.0%	Zendesk Chat
Privacy compliance	0.017	0.038	127.5%	3825	5985	56.5%	0.829	0.924	11.4%	0.0%	TrustArc

Notes: [†]Libert (2019) classification. [††]Google ad platform include Google Marketing Platform & Google Ad Manager.