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Abstract

We evaluate the welfare effects of the Roam-Like-At-Home regulation, which drastically reduced the price of accessing the mobile internet for EU residents when traveling abroad in the European Economic Area. Estimates from individual-level usage data suggest that consumer surplus increased by 2.77 EUR/user/travel day. A decomposition shows the heterogeneous impact of the regulation on different user segments. We estimate that around half of the gains stem from a reduction in deadweight loss, i.e., new users accessing the mobile internet. We further show that the impact of the regulation varies with usage intensity abroad and at home, by the nature of the trip (leisure vs. business), and by content type. We discuss implications for content providers and other policy areas such as net neutrality.

JEL-Codes: L960, L510, O330, D620.

Keywords: Telecom, mobile data, roaming, regulation, consumer surplus.

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1 Introduction

It is now widely known that digitization, and the internet in specific, are associated with firm productivity, innovation, employment, and, more broadly, economic growth (Czernich et al., 2011; Cardona et al., 2013; Hjort and Poulsen, 2019). The literature has started to develop a deeper understanding of the channels through which digitization generates value, mostly highlighting lower costs on the demand- and supply-side (Goldfarb and Tucker, 2019), translating into greater product variety and more efficient entry, which creates substantial welfare effects (Brynjolfsson et al., 2003; Aguiar and Waldfogel, 2018).

However, the bottleneck to participate in the value gains caused by digitization is unrestricted access to the internet. Evidence from within and across countries documents a *digital divide* in terms of income, education and geography (Schleife, 2010; Viard and Economides, 2015; Silva et al., 2018). Most research in this literature is focused on fixed-line internet technology, while device usage and applications are increasingly shifting towards mobile (Einav et al., 2014). According to data from Statcounter, the majority of web traffic in 2021 came from mobile devices.[1] Mobile broadband can be complementary to fixed-line broadband, not only in closing the gap in internet access between rural and urban areas (Prieger, 2013), but also in individual-level adoption decisions (Xu et al., 2019). Not having access to the mobile internet can have meaningful economic implications. Evidence shows that mobile devices are linked to different internet consumption and e-commerce behavior, and that consumers interact more with geographically local content on mobile devices (Ghose et al., 2013; Fong et al., 2015; Mang et al., 2016; Xu et al., 2017).

Policy measures to increase internet penetration include the forced unbundling of infrastructure (Nardotto et al., 2015), subsidies for infrastructure investments (Briglauer et al., 2019), minimum coverage requirements (Fabrizi and Wertlen, 2008), and price regulation (Vogelsang, 2003; Spruytte et al., 2017). An important aspect of price regulation concerns *roaming*.

Within the limits of regulatory frameworks, network operators may charge different prices for using voice or data services on networks owned by other operators (Zucchini et al., 2013), especially across national borders. Depending on a consumer's physical location, the price to access the mobile internet can be prohibitively high. For example, the average price per megabyte (MB) used abroad for consumers from OECD countries was at least 2.5 USD in 2010. Such

[1] See https://gs.statcounter.com/platform-market-share/desktop-mobile-tablet/worldwide/.

prices were many times more expensive than comparable domestic use (OECD, 2011). There are several examples of consumers being billed enormous sums for casual mobile internet usage while on vacation.[2] Starting in 2007, European regulators imposed rules that gradually lowered the price-based gap in mobile telecommunication between locals and visitors within the European Economic Area (EEA), i.e., in all EU member states, Iceland, Liechtenstein and Norway. However, survey evidence suggests that most consumers still chose not to use the mobile internet while traveling abroad in 2012 and 2013 (Mang et al., 2016). In the last phase of the regulation, effective June 15th, 2017, telecommunication providers in the EU were no longer allowed to charge for mobile voice and data services when consumers use networks in foreign countries within the EEA. Coined *Roam-Like-At-Home* (RLAH), the regulation promised EU residents that the price for mobile telecommunication services is the same as at home when traveling in the EEA. Travel outside the EEA was not affected.[3]

Imposing a price cap on network operators can have intricate welfare effects (Spruytte et al., 2017), not only by transferring surplus from network operators to consumers, but also by redistributing surplus across consumer types (e.g., Chillemi et al., 2019; Maillé and Tuffin, 2017), and by increasing surplus of content providers through increased demand (e.g., Greenstein et al., 2016). In this paper, we aim to empirically evaluate some of these welfare effects in the context of the RLAH regulation. In particular, we focus on heterogeneity in consumer surplus effects.

We have access to an anonymous dataset from a network operator in a EU country. Our dataset tracks the aggregate daily mobile data usage of all clients who used their mobile phone at least once while traveling abroad between September 2016 and December 2017. We compare mobile data usage in the home country to mobile data usage when traveling in the EEA and outside of the EEA. Using a difference-in-differences set up, we show that the regulation increased mobile data usage of European travelling within EEA by approximately 170%. We estimate that this corresponds to an increase in consumer surplus of at least EUR 2.77 per user and travel day. Furthermore, our analysis highlights important heterogeneity in consumer surplus gains. We show that the impact of the regulation varies with usage intensity (before RLAH while traveling or at home) and the nature of the trip (leisure vs. business). This suggests that the regulation was partially effective in closing a digital divide between locals and visitors.

We then investigate heterogeneity by content type using an online experiment that further

[2]See, for example, https://www.theguardian.com/money/2012/may/25/data-roaming-smartphone-abroad.
[3]See https://europa.eu/youreurope/citizens/consumers/internet-telecoms/mobile-roaming-costs/index_en.htm

investigates how consumers allocate mobile data across different types of content providers. This analysis is informative about the distribution of consumer surplus across utility-generating activities and lets us speculate about the welfare effects of RLAH for content providers. We show that while music/video consumption and review platforms are the services that experience the highest growth in usage, communication, social media, and internet search activities explain more than half of the consumer surplus gains.

Finally, we perform a rough estimation of the average change in network operator surplus in the EEA. We show that losses to network operators are smaller than our estimates of consumer surplus gains, depend on tourism flows, and come from the decrease in the marginal revenue from incoming tourists.

While the detailed disaggregated analysis of consumer surplus effects is the main focus of our paper, the related literature is highly complementary to paint a complete picture of the welfare effects of RLAH for consumers, network operators and content providers. For example, Canzian et al. (2021) assess the total welfare impact of the regulation with aggregate data from a range of countries. They arrive at remarkably similar estimates of the total consumer surplus effects. The paper further supports our conclusion that consumer surplus gains largely out-weight the profit loss of network operators. In addition, we shed light on heterogeneity in consumer surplus and content consumption, which lets us discuss content provider surplus as the third dimension of welfare effects in the evaluation of RLAH. While very rich, a shortcoming of our observational data is that we do not observe individual-level prices for accessing the mobile internet. Hence, when calculating consumer surplus, we assume that prices for using the mobile internet abroad have changed due to RLAH, whereas domestic prices remain stable. This assumption is backed by evidence in Grzybowski and Munoz-Acevedo (2021), showing that domestic prices and revenues of network operators do not change with RLAH.

More generally, we also add to the mostly theoretical literature on telecommunication regulation (Genakos and Valletti, 2011; Chillemi et al., 2019), including the distribution of rents between internet service providers and content providers (Easley et al., 2018). Finally, we contribute to the related literature on the welfare effects of digitization and the mobile internet (Brynjolfsson et al., 2003; Aguiar and Waldfogel, 2018; Ghose and Han, 2011; Ghose et al., 2013; Xu et al., 2019).

2 Regulation of roaming charges in Europe

The mobile internet dates back to the introduction of second-generation mobile networks in the early 1990s and has since diffused widely. According to data from the International Telecommunications Union (ITU), global mobile broadband penetration increased from 4% in 2007 to 70% in 2018. More than 90% of the world population is covered by at least a third-generation mobile network in 2018. Access to the mobile internet is extraordinarily convenient, as it grants the ability to consume or provide information outside the reach of a fixed-line internet connection at home or work. By the early 2000s, many countries had privatized the telecommunications sector (Waverman and Sirel, 1997), and mobile telecommunication networks are now typically operated by several firms that compete for consumers (Li and Xu, 2004). Interconnection between networks, which enables termination of voice calls across networks and internet access through a competitor's infrastructure, is governed by regulation, mostly concerning network access fees (Vogelsang, 2003; Jullien et al., 2013). Within the regulatory frameworks, network operators may pass on some of those fees (wholesale roaming fee) to consumers for using off-network telecommunication services in the same country and when crossing national borders (retail roaming fee). While national roaming charges often only translate into differentiated price structures for on-net and off-net voice calls (Zucchini et al., 2013), international roaming charges frequently translate into a differentiated price structure for national and international data services. Historically, retail roaming fees have been above cost, despite efforts of wholesale regulation (Infante and Vallejo, 2012). High roaming charges have been among the most significant deterrents of mobile data usage for international travelers. In a Eurobarometer survey from 2014, 52% of respondents who travel to other EU countries said that they switch off their phone and never use it or switch off the data roaming capabilities of their phone when traveling.[4]
Starting in 2007, roaming regulation in the EU had four major regulatory rounds that gradually introduced wholesale and retail price caps for voice, text and mobile data services (see Infante and Vallejo, 2012; Spruytte et al., 2017 for a detailed discussion).

Figure 1 shows the evolution of the regulated wholesale and retail price caps for mobile data services in the EU. The wholesale price cap for data services reduced from €c100/MB in July 2009 to €c5/MB before the implementation of RLAH rules. Finally, in June 15, 2017, RLAH rules stipulated the end of retail roaming charges for EU residents that travel to countries within

[4] See https://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_414_en.pdf.

the EEA. However, prices did not go down to zero for everyone. Wholesale prices were reduced to €c0.77/MB for 2017 while retail price for in-plan roaming were capped to a minimum of half the wholesale price (hence €c0.385/MB for 2017) and to the wholesale price for out-of-plan roaming within Europe. This means that EU users with plans at a mobile data domestic price higher than €c0.385/MB would enjoy their entire data allowance when roaming within EEA. Conversely, users with plans in which the domestic data price is lower than €c0.385/MB would found their data allowance reduced to match the retail price cap. In 2018, 2019 and 2021, price caps for wholesale and retail prices continued to decline.

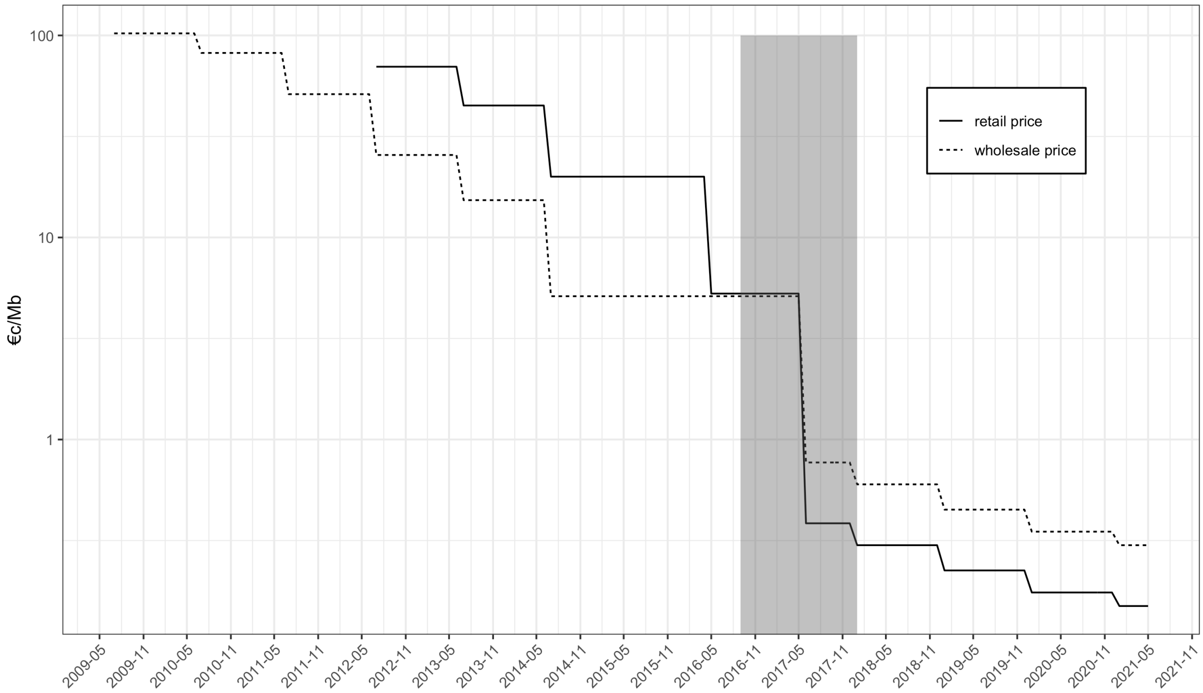


Figure 1: Evolution of retail and wholesale caps. The focus of our study is the highlighted period.

3 Methodology

We follow Brynjolfsson et al. (2003), Hausman (1981) and Hausman and Leonard (2002) to estimate the effect of RLAH on consumer surplus.

We start with a simple model where consumers draw utility from accessing the internet at a price p_m, and from consuming and providing content at a price p_c. We model RLAH as a change in prices between periods $t \in \{0, 1\}$. We express the consumer surplus effect of RLAH as the compensating variation (CV). In our case, CV measures the payment that a consumer would require to remain in their (lower) initial level of utility after the price reduction.

Considering the utility level of period $t = 1$, we can write the consumer surplus change as

$$CV = e(p_{m0}, p_{c0}, u_1) - e(p_{m1}, p_{c1}, u_1) \tag{1}$$

where p_{mt} captures the price per MB purchased from the network operator, and p_{ct} captures the price per MB of content, where t is equal to 0 before RLAH and 1 after RLAH.

We assume that demand follows a standard log-linear form:

$$q(p_m, p_c, y) = A(p_m + p_c)^{\epsilon} y^{\sigma} \tag{2}$$

where A is a shift parameter, y denotes income, σ the income elasticity, and ϵ the total price elasticity. For the case of international roaming, y acts as the travel budget. The income elasticity σ is the elasticity of demand for megabytes when roaming within a certain travel budget. Our demand specification captures that consumers purchase a data allowance from the network operator and spend MBs on content. That is, consumers are sensitive to the total price per MB consumed, i.e. $p_m + p_c$.

Like Hausman (1981), we use Roy's identity, the indirect utility function and the expenditure function, to rewrite the compensating variation such that:

$$CV = \left[\frac{1-\sigma}{1+\epsilon} y^{-\sigma} \big((p_{m0} + p_{c0})q_0 - (p_{m1} + p_{c1})q_1\big) + y^{1-\sigma}\right]^{\frac{1}{1-\sigma}} - y \tag{3}$$

Prior studies on the welfare effects of telecommunication technology such as Brynjolfsson (1996) and Hausman (1997) suggest that CV measures are not very sensitive to the estimated income elasticity. In the case of international data roaming, the constraint is the consumer's travel budget, which is a small fraction of the consumer's annual income. This is in line with the idea that we can ignore income effects when purchase amounts are a small fraction of the consumer's annual income (Willig, 1976). Hence we assume $\sigma = 0$, which allows us to arrive at a Marshallian expression of consumer surplus change:[5]

[5] We relax this assumption in appendix A.7. We show that the estimates with no income effect provide a lower bound because the consumer surplus change increases with positive average income (y) and positive income elasticity of demand (σ).

$$CV = \frac{(p_{m0} + p_{c0})q_0 - (p_{m1} + p_{c1})q_1}{1 + \epsilon} = \frac{p_{m0}q_0 - p_{m1}q_1}{1 + \epsilon} + \frac{p_{c0}q_0 - p_{c1}q_1}{1 + \epsilon} \tag{4}$$

We make the additional assumption that prices of online content do not change across time $p_{c0} = p_{c1} = p_c$. This assumption is reasonable because a large part of online content, such as internet search, is free. Furthermore, travelers are a relatively small share of overall internet users and are unlikely to change content providers' pricing choices.

$$CV = \frac{p_{m0}q_0 - p_{m1}q_1}{1 + \epsilon} + p_c \frac{q_0 - q_1}{1 + \epsilon} \tag{5}$$

To compute expression (5), we need estimates for p_{m0}, p_{m1}, q_0, q_1, p_c and ϵ. Estimating ϵ is challenging because we do not observe a continuous exogenous variation in prices. However, we exploit the discrete exogenous change in prices induced by RLAH. That is, we approximate ϵ as the mid point arc-elasticity of demand (Allen and Lerner, 1934), such that

$$\epsilon = \frac{(q_1 - q_0)}{(p_{m1} + p_c) - (p_{m0} + p_c)} \times \frac{(p_{m1} + p_c) + (p_{m0} + p_c)}{(q_1 + q_0)}. \tag{6}$$

This simplifies (5) to

$$CV = (p_{m0} - p_{m1}) \times \frac{q_0 + q_1}{2}. \tag{7}$$

Figure 2 illustrates that the approximation of ϵ as the arc elasticity can lead to an overestimation of the consumer surplus gains. The latter is small in the presence of large differences in prices, as is the case with RLAH.

To compute the compensating variation from the regulation, we need to find empirical estimates of q_1, q_0, p_{m1}, and p_{m0}. As we are specifically interested in the effect of the regulation we will focus on estimating the share of q_1 that can be attributed to RLAH.

The following section describes the data sources and empirical strategies that we use to calibrate the consumer surplus calculations laid out above.

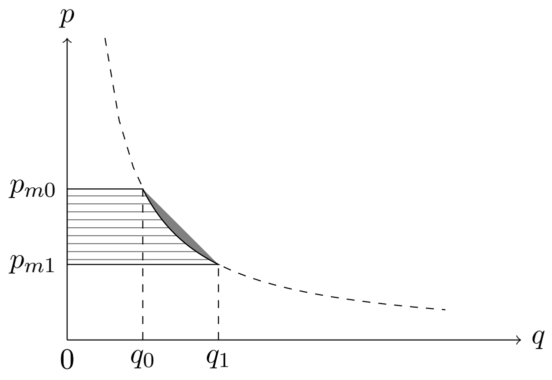


Figure 2: Consumer surplus calculation
Note: The hatch grey area captures the change in consumer surplus while the filled grey area represent overestimation from use of the arc-elasticity.

4 Data and Empirical Strategy

4.1 Quantities and Prices

To estimate quantities q_1 and q_0, we access an anonymized panel dataset from an European network operator, from now on called MOBILE.[6] Our sample includes anonymized information from all clients who used their mobile phones at least once while traveling abroad between September 2016 and December 2017.[7] These clients represent 5% of domestic clients which is a similar number to the one reported in the official Eurobarometer statistics on roaming usage during that time period (European Commission, 2017). We observe the average daily number of MBs downloaded and uploaded – while abroad – for each mobile phone number and week. We also observe from which country the mobile internet traffic originated.

Our sample includes users who traveled at least once before and once after the regulation, no matter the destination.[8] Table 1 provides some descriptive statistics of mobile internet usage of MOBILE's clients. There is an overall increasing trend in mobile internet usage. Mobile Internet traffic while traveling within the EU increased by 170 percent from an average of 31 MB/day in the period before RLAH (average from week 39 of 2016 to week 23 of 2017) to 84 MB/day

[6] MOBILE is a large Mobile Network Operator (MNO) that had more than a third of the local market in 2017. It entered the mobile telecommunications business in this geographical market about twenty years before the 2017 RLAH regulation entered into effect. Like many other European MNOs, MOBILE faced direct and fierce competition from two other prominent players operating in the same region.

[7] Demand for mobile internet while traveling may be seasonal. Since we do not have data for the summer of 2016, we can only check for seasonality outside of summer. We repeat our baseline analysis to the sub-sample that includes the months of September-2016 to December-2016 as the before period, and the months of September-2017 to December-2017 as the after period. Estimates are between 7% and 9% larger than our baseline specification (see Appendix A.4, Table A.4).

[8] In Appendix A.2, we show that our results are robust to different approaches of sample selection.

Table 1: Descriptive statistics for mobile internet use, data from MOBILE

	Location	Period	Variable	#Countries	Avg.	Std.	MED
1	Home	Before RLAH	Total internet traffic	1	84.220	136.362	38.985
2	Home	Before RLAH	Number of days	1	5.416	2.029	7
3	Abroad within EU	Before RLAH	Total internet traffic	29	31.520	76.538	10.297
4	Abroad within EU	Before RLAH	Number of days	29	2.212	1.652	2
5	Abroad outside EU	Before RLAH	Total internet traffic	104	7.069	26.112	1.715
6	Abroad outside EU	Before RLAH	Number of days	104	1.678	1.220	1
7	Home	After RLAH	Total internet traffic	1	100.285	152.354	48.629
8	Home	After RLAH	Number of days	1	5.384	2.076	7
9	Abroad within EU	After RLAH	Total internet traffic	29	86.294	164.409	32.344
10	Abroad within EU	After RLAH	Number of days	29	2.752	1.996	2
11	Abroad outside EU	After RLAH	Total internet traffic	106	6.911	27.237	1.773
12	Abroad outside EU	After RLAH	Number of days	106	1.583	1.138	1

in the period after RLAH (average from week 24 of 2017 to week 52 of 2017). In contrast, the average mobile data usage while being abroad in a country outside the EEA remained stable at around 7 MB/day.

Travelers in our sample are likely different from the average traveler residing in the EU. Consequently, the results that we get for our sample of users may not represent the entire population of travelers in the EU. Using EUROSTAT data, we compare country characteristics of the market in which MOBILE is active relative to the European country distribution for each variable. The country of MOBILE exhibits higher domestic tourism and lower outbound tourism relative to other EU countries.[9]

After estimating quantities q_0 and q_1, we need to recover prices p_{m0}, and p_{m1} to compute the consumer surplus gains from the regulation. We do not have access to individual-level price data from MOBILE. However, they provided us with historical documents for 2016-2017, which underline that MOBILE followed exactly the rule laid out by the European Commission (EC) to determine the retail price of roaming. They priced roaming mobile data using the binding constraint on the retail cap described in section 2. Applying this rule, we can approximate average values of p_{m0} and p_{m1}. The maximum price per MB that operators could charge for roaming was established at the domestic price (p_h) augmented by €c5 before the regulation and decreased to €c0.385 after.[10] In practice, this means that if a consumer pays a domestic price that is lower than the price cap for roaming, the operator can reduce the roaming data allowance to match the regulated roaming price per MB. However, if a consumer pays a higher price at home than the regulated roaming price, they will enjoy their entire domestic data allowance

[9]See Appendix A.1. To preserve country anonymity required by our non-disclosure agreement, for each variable, we compute its mean across all countries, including the country of MOBILE. We then calculate the Z-score for each variable associated with the focal country in the sample.

[10]See section 2 and https://ec.europa.eu/digital-single-market/en/roaming-tariffs.

while roaming.

Hence, the price per MB p_{mt} paid by users in period t can be defined as the maximum between price per MB at home p_h and the regulated price p_{rt}. Hence $p_{m0} = \max(p_{r0}, p_h) = \max(0.05 + p_h, p_h) = 0.05 + p_h$ and $p_{m1} = \max(p_{r1}, p_h) = \max(0.00385, p_h)$.

We also do not observe individual-level domestic prices per megabyte (p_h). As we discuss in detail in Appendix A.8, we rely on information from the EC to compute the average price per MB for domestic mobile data in countries similar to the one where MOBILE operates. This boils down to a domestic price of $p_h = 0.0015$ and the following roaming retail prices:

$$p_{m0} = 0.05 + 0.0015 = 0.0515$$
$$p_{m1} = \max(0.00385, 0.0015) = 0.00385$$

4.2 Empirical Strategy

We use the dataset described above to estimate the quantity effect of RLAH via difference-in-differences (DiD). We compare an individual i's demanded quantity of mobile data when traveling in the EEA and outside of the EEA, before and after RLAH:

$$MobileData_{ijt} = \delta After_t \times RLAH_{ijt} + \mathbf{\Psi}_{ijt} + v_{ijt} \quad (8)$$

where $MobileData_{ijt}$ is the daily average mobile data consumption (sum of download and upload traffic in MBs) initiated by individual i, in country j, in week t. $RLAH_{ijt}$ indicates whether individual i is consuming mobile data while abroad in a country of the EEA where RLAH rules apply. $After_t$ is a dummy variable equal to one throughout the period for which the RLAH policy is in effect. $\mathbf{\Psi}_{ijt}$ is a vector of fixed effects and trends that we further specify below. We cluster standard errors at the individual level to allow for arbitrary serial correlation.[11]

The identifying assumption of DiD requires that without RLAH, the mobile data consumed by the treatment group (travelers subject to RLAH) and those in the control group (travelers not subject to RLAH) follow similar trends. While this is not testable, we provide evidence that at least the necessary condition – similar trends before RLAH – holds (see right panel of figure 3).

[11] We also provide regressions with clustered standard errors at the level of the destination country. In such specification, standard error estimates for our baseline specification (see column (1) of Table 2) increase about 40%, but with no impact on statistical significance of the results at the 1% significance level.

In the specification of equation 8, the estimation of δ that we denote by $\hat{\delta}$ measures the change in megabyte consumption due to the regulation. Our consumer surplus estimation requires estimating q_0 and q_1. We recover q_0 from the sample mean of RLAH travel activity before the regulation $\hat{q_0}$, and compute $\hat{q_1} = \hat{q_0} + \hat{\delta}$.

Plugging quantity estimates $\hat{q_0}$, $\hat{\delta}$, and prices information p_{m0}, p_{m1} into equation (7), we compute consumer surplus as:

$$CV = (0.0515 - 0.00385) \times \frac{2\hat{q_0} + \hat{\delta}}{2} \tag{9}$$

In the following sections, we first report the results of the estimation for $\hat{q_0}$ and $\hat{\delta}$, and then compute the corresponding consumer surplus gains.

5 Estimates of Changes in Data Consumption

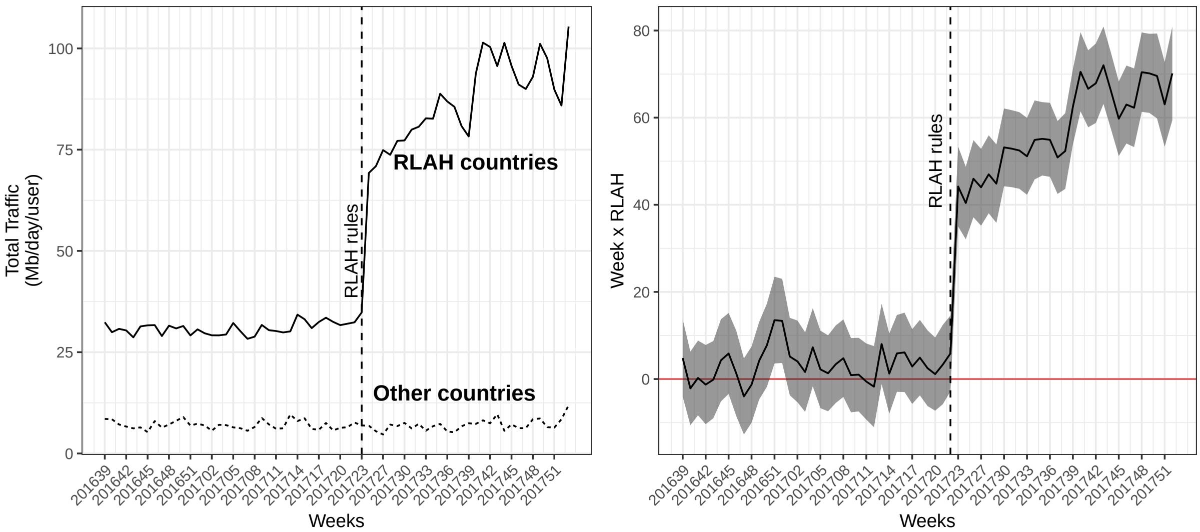
5.1 Average Changes in Data Consumption

We start with a descriptive analysis of the data. The left panel of Figure 3 shows the average daily mobile data consumption (sum of uploads and downloads) while abroad in a given week. We distinguish between data consumption abroad in EEA countries, where RLAH rules apply, and non-EEA countries, where the regulation does not apply. The figure highlights that travelers' traffic patterns were stable before introducing the RLAH rules and that trends were similar across country groups. The right panel of figure 3 tests for linear trends, and plots the difference in mobile data consumption between RLAH-countries and non-RLAH countries after controlling for user and country fixed effects. There is no significant difference in the trends before RLAH comes into effect, but after RLAH, travelers' consumption patterns in countries affected by the regulation more than triples, while mobile data consumption for those traveling to countries not affected by RLAH remains unchanged.[12]

Turning to the econometric estimation of quantity changes, we report the results of a range of models with different fixed effects included. We do so to underline our choice of the preferred specification given the specifics of the data, which highlights substantial heterogeneity in the

[12] Figure 3 indicates that there is an increasing trend in the period after RLAH. We take this into consideration when we repeat our baseline regression of column (1) in Table 2 including time trends. Overall, we find that the regulation stimulated a short-term immediate increase of 39.98MB per user per traveled day, which rises to 69.5MB (39.98+29×1.021) by the end of 2017. See Table A.3 in Appendix A.3.

Figure 3: Impact of RLAH rules on mobile data usage



Note: 95% confidence interval for the parallel trend test on the right plot are computed using results from equation (8).

Table 2: Impact of roaming like at home on mobile data consumption.

	Dependent variable:			
	Total (Mb)			
	(1)	(2)	(3)	(4)
After × EUtravel	54.205***	49.431***	39.512***	20.005**
	(0.943)	(0.866)	(4.591)	(7.357)
Country × Users FE	No	Yes	No	Yes
Week × Users FE	No	No	Yes	Yes
User FE	Yes	Yes	Yes	Yes
Week FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Observations	787,835	787,835	787,835	787,835
R^2	0.385	0.534	0.940	0.969
Adjusted R^2	0.305	0.349	0.251	0.252
Residual Std. Error	108.942	105.503	113.124	113.077
Note:	+ p<0.1; * p<0.05; ** p<0.01; *** p<0.001 Errors clustered by user in ()			

impact of RLAH.

Our preferred specification is column (1) of Table 2. The point estimate suggests that RLAH increased daily mobile internet usage by 54.205MB ($CI_{95\%}[52.319, 56.091]$). In relative terms, this is a 170% increase from the baseline of 30MB when traveling in Europe before the regulation. Column (2) includes user-country fixed effects and controls for systematic individual- and destination-specific consumption behavior. In this specification, the point estimate is about

9% smaller than the estimate in column (1), which is a significant difference at the 95% level. Column (3) includes user-week fixed effects, excluding user-country fixed effects. It singles out the seasonal travel choices of users without controlling for the actual destination country. Note that both will intertwine for users who travel to a single destination in a single week – which is the vast majority of observations. These fixed effects capture the change in consumption of users that travel multiple times within a calendar week across years, hence demeaning heavy data consumption weeks from our estimate. Peaks in data consumption might be related to the type of trip, e.g., business or leisure. The point estimate is about 27% significantly lower than the baseline of column (1), and about 20% lower, but not significantly different at the 95% level, than the estimate in column (2).[13] Column (4) includes both user-week and user-country fixed effects. The coefficient in column (4) reports a result demeaned of heavy user-specific consumption weeks and the impact of the specific country destination of users. The point estimate is about 63% lower than our baseline (significantly so) and about 49% lower, but not significantly different, than the estimate in column (3). Put together, this exercise highlights substantial heterogeneity in the consumer response to RLAH. Heterogeneity seems to come from differences in mobile data usage across country destinations and perhaps types of trips.

5.2 Heterogeneity Analysis

To provide additional insight into how RLAH affected the demand for mobile internet, we estimate quantity effects separately for different users and travel types.

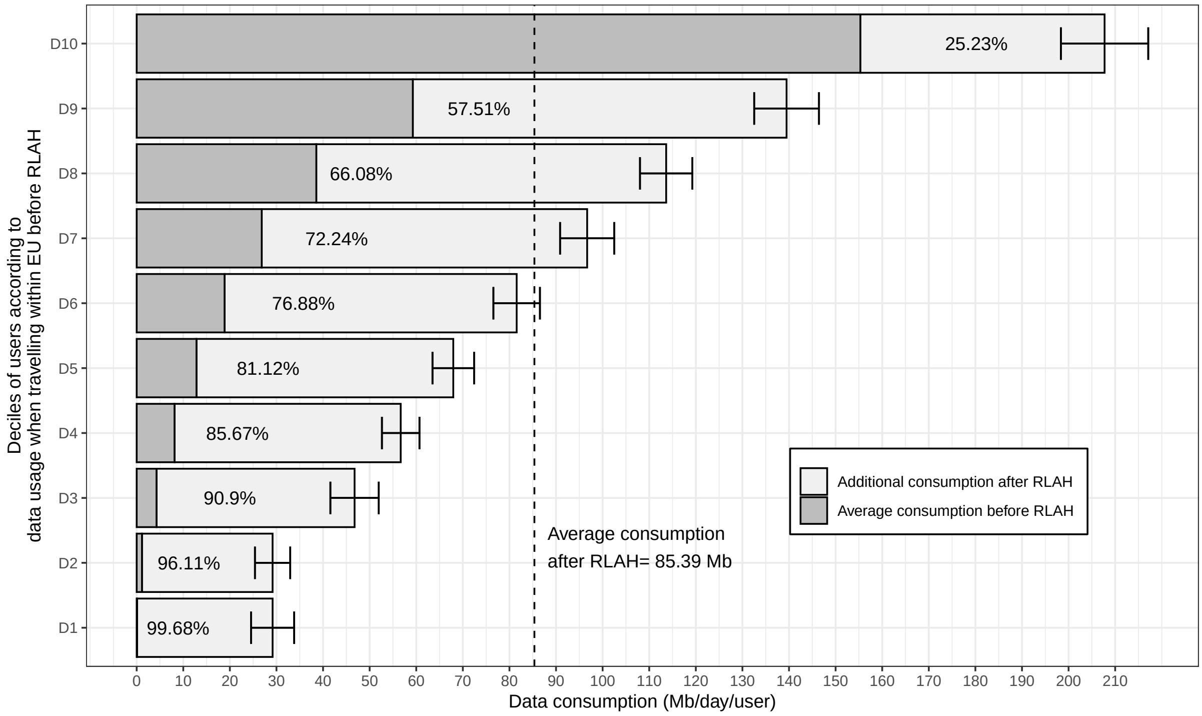
5.2.1 By Consumption Intensity: Abroad and at Home

First, we classify users in deciles according to their pre-RLAH consumption intensity when they are travelling within the EEA. We present the results of this estimation in Figure 4, where D1 captures users with the lowest intensity.[14] The analyses show that the relative increase in data usage from the regulation was higher for the lower deciles than the upper deciles. In the first decile, 99.7% of post-RLAH consumption is new, while for the tenth decile, only 25.2% of megabytes consumed would not have been used absent RLAH. This suggests that the regulation had very different effects for different types of users.

[13] If our model was non-linear, the specification in column (3) would have us drop most of the sample because of the perfect separability of outcomes (most users cannot have this fixed effect estimated for them).

[14] Regression results can be found in Appendix A.5, Table A.5.

Figure 4: Quantity Changes by Deciles of Usage Intensity Abroad



Note: 95% confidence intervals for the additional effects are computed using results from equation (8) for each decile. D1 (D10) captures users with the lowest (highest) average daily data consumption while roaming in the EU before RLAH

We perform the same decile decomposition by data consumption intensity at home. Results are reported in Figure 5, where D1 captures users with the lowest average daily data consumption at home.[15] The analyses show that the relative increase in data usage from the regulation was smaller for the lower deciles than the upper deciles. In the first decile, around 50% of post-RLAH consumption is new, while for the tenth decile, 66% of megabytes consumed would not have been used absent RLAH.

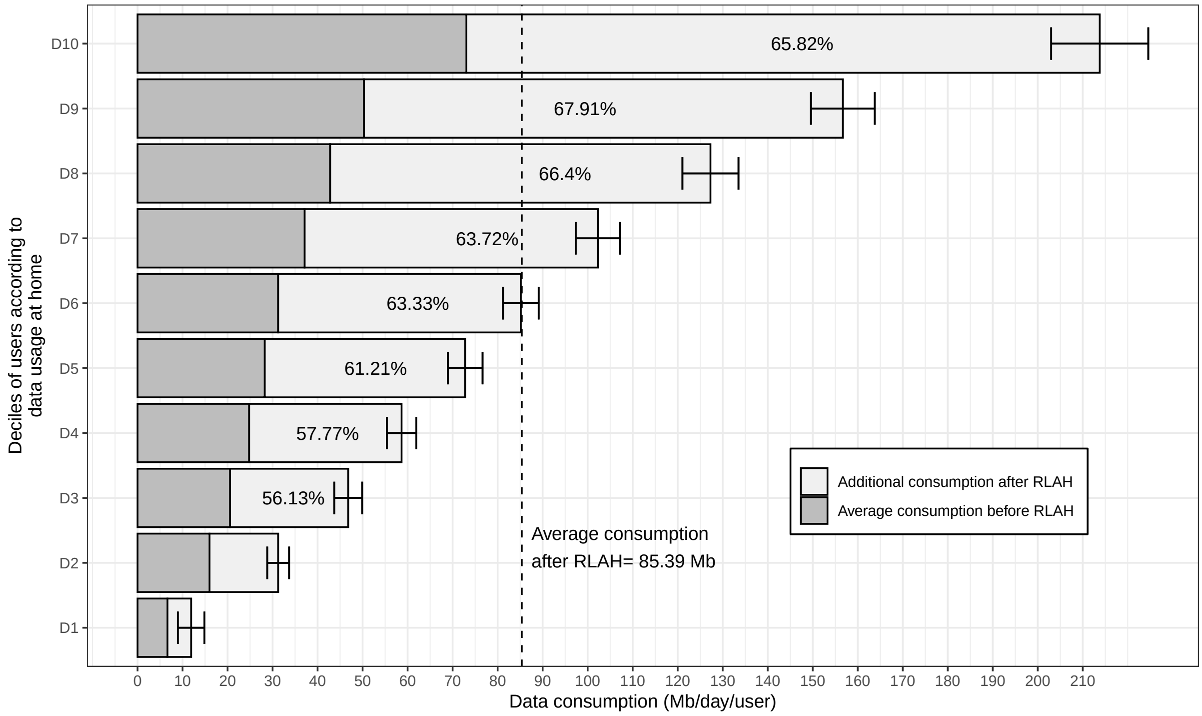
5.2.2 By Travel Intensity

Next, we classify users into deciles according to the number of weeks they travel at least one day, abroad within the EEA. We report these results in Figure 6.[16] D1 captures users with the lowest number of abroad trips in the entire period. The analysis shows little differences in data consumption between deciles, underlining that the travel intensity is not the main driver of the effect of RLAH.

[15] Regression results can be found in Table A.6.

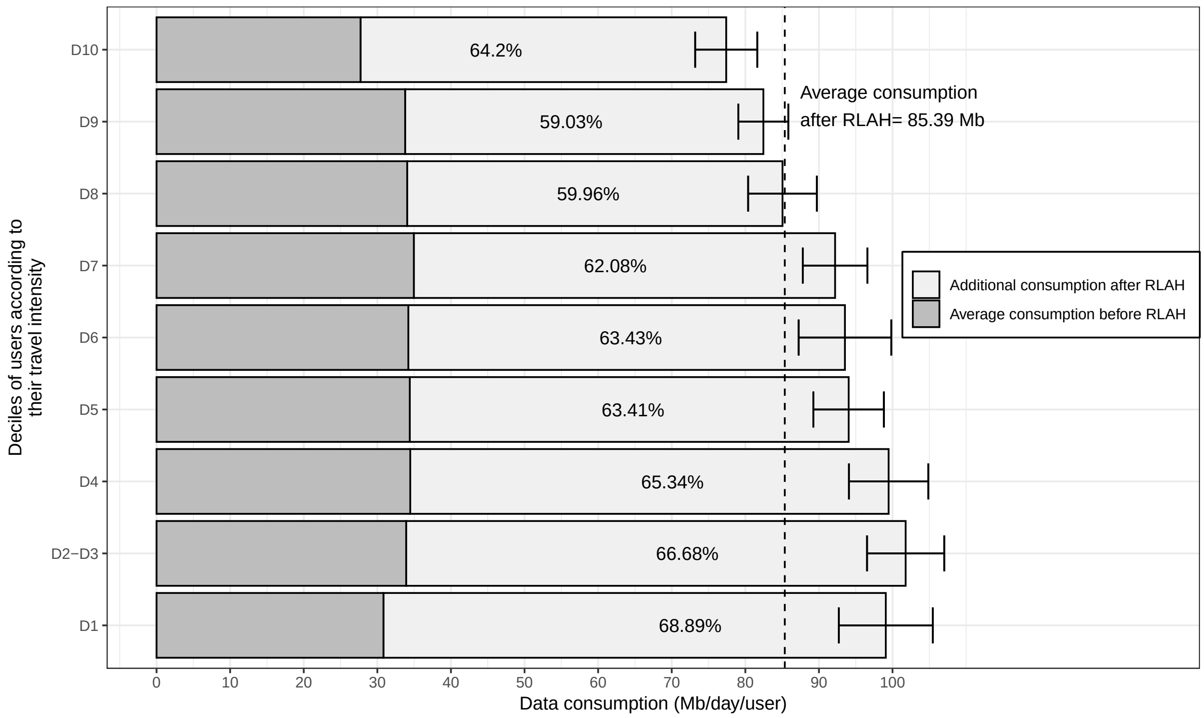
[16] We provide the corresponding regression in Table A.7.

Figure 5: Quantity Changes by Deciles of Usage Intensity at Home



Note: 95% confidence intervals for the additional effects are computed using results from equation (8) for each decile. D1 (D10) captures users with the lowest (highest) average daily data consumption at home.

Figure 6: Quantity Changes by Deciles of Travel Intensity



Note: 95% confidence intervals for the additional effects are computed using results from equation (8) for each decile. D1 (D10) captures users with the lowest (highest) travel intensity.

5.2.3 By Trip Type and Destination Country Characteristics

Finally, we aim to distinguish between business and leisure trips. Our definition of leisure trips includes trips with at least one weekend day, while we define business travel as trips that do not include weekends and holidays. In our classification, business trips exclude weekends, so they are always shorter than six days, whereas there is no limit in the number of days for leisure trips. Megabyte consumption may vary depending on the length of the journey, so we use the variable $Len.Trav$ to control for the duration of the trip in all regression models.

To enrich our analysis, we collect data about the number of arrivals across countries from the 2017 World Development Index Database.[17] We classify countries according to quartiles depending on their number of arrivals (a measure of tourism attractiveness). We then investigate differences in the effect of RLAH by characteristics of the destination country's telecommunication infrastructure. We do so by measuring a country's Internet coverage.[18]

Table 3 shows the results of an analysis of the entire sample together with a split sample analysis for leisure and business trips, where q_1 denotes the quartile with the lowest arrivals or lowest Internet coverage in 2017.

Column (1) reports the results of our baseline regression. Columns (2) and (3) decompose the effect of the policy across different levels of destination country characteristics. Non-EU countries serve as the reference category.

Results in column (2) classify the countries into quartiles depending on total inbound travel trips in 2017. Overall, the analysis shows that data consumption was higher in trips to countries with the highest number of arrivals.

Results in column (3) suggest that mobile data consumption increased less for trips to countries with a better Internet coverage (taking the average megabyte consumption in non-European countries before RLAH as counterfactual).

We report similar analyses in columns (4), (5), and (6) but focus only on leisure travel, i.e., trips that include at least one weekend day. Column (4) suggests that the impact of RLAH is larger for leisure travel. Interestingly, column (5) reports that when focusing on leisure travel, the regulation had a larger effect when roaming took place in more touristic EU countries, relative to non-EU countries. Columns (6) reports that the RLAH rules had a lower impact on countries

[17] See https://databank.worldbank.org/source/world-development-indicators

[18] We use information from the EC report (http://www.czechcompete.cz/files/uploads/News/7502/BroadbandCoverageinEurope2017_Final_Reportpdf.pdf). More precisely, Internet coverage captures the average operator LTE coverage for each country in percentage.

with the best Internet coverage when focusing on leisure trips.

Columns (7), (8), and (9) focus on business travels and exhibit slightly different results. Column (7) shows that the regulation had a lower impact on trips that exclude weekends and holidays relative to trips that include at least one weekend day. Column (8) shows that the impact of RLAH is more prominent in touristic countries than non-touristic ones but remains lower than for leisure trips. Finally, column (9) underlines that RLAH rules had the highest impact for trips to EU countries with lower Internet coverage relative non-EU countries.

5.3 Robustness and Limitations

A limitation of our analysis could be that consumers may have primarily used other means to access the internet to circumvent high roaming charges when traveling before RLAH. If that is the case, our estimates of increased mobile internet usage and consumer surplus are misleading. We cannot rule out this possibility entirely, but we find some evidence suggesting that such substitution appears to be marginal.

An important substitution scenario is a switch from public Wifi networks towards roaming access. To test this hypothesis, we obtained data from the number of connections to the Open Wifi Hotspot in Milano. Milano is one of Italy's most popular tourist destinations in Europe and collects data on tourists access to the city's public hotspot.[19] To access Milano's Wifi hotspot, users need to register using their mobile phone number, verified via an SMS code. Milano's Open Wifi Hotspot dataset records the tourists' country of origin based on the phone number, which allows us to separate EU visitors from non-EU visitors. We plot access data to the hotspot from June and July 2017 in figure A.1. Suppose that EU tourists substituted between Wifi usage and mobile data after RLAH rules. In that case, Milano's hotspot should have fewer users from EU countries relative to users from non-EU countries after RLAH. However, there seems to be no decrease in the usage of the Wifi hotspot of EU-users.

It may also be that consumers substitute cellular roaming on their smartphones with internet access via Wifi networks on their laptop devices. The Milano hotspot dataset does not have information for this robustness check. We also collected data from TripAdvisor and IVW (The German Audit Bureau of Circulation). These datasets allow us to distinguish between internet traffic originating from mobile devices (smartphones and tablets) and computer devices (laptops and desktop computers). Figures A.5 and A.4 show no changes in desktop usage when RLAH

[19] See Statista report.

Table 3: Quantity Changes by Travel Type and Destination Country Characteristics

	Dependent variable:								
	Total (Mb)								
	All			Leisure			Business		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Len.Tra	0.909*	0.913*	0.917*	0.852+	0.852+	0.864+	1.111	1.137+	1.130+
	(0.377)	(0.401)	(0.401)	(0.500)	(0.472)	(0.471)	(0.700)	(0.617)	(0.618)
After × Len.Tra	0.782	0.782*	0.780*	0.386	0.390	0.386	1.529	1.494	1.513
	(0.481)	(0.353)	(0.352)	(0.596)	(0.435)	(0.433)	(1.089)	(1.297)	(1.300)
EUtravel × Len.Tra	1.110**	1.073*	1.060*	0.892+	0.849	0.854	0.643	0.627	0.636
	(0.415)	(0.433)	(0.449)	(0.535)	(0.563)	(0.576)	(0.788)	(0.709)	(0.711)
After × EUtravel× Len.Tra	−1.645**	−1.567*	−1.545*	−2.863***	−2.784***	−2.801***	0.040	0.108	0.068
	(0.545)	(0.616)	(0.647)	(0.660)	(0.724)	(0.755)	(1.319)	(1.393)	(1.407)
After × EUtravel	56.668***			63.705***			51.827***		
	(1.337)			(2.213)			(2.634)		
After × N. arrival$_{q1}$		47.581***			52.056***			37.522***	
		(4.087)			(3.874)			(5.241)	
After × N. arrival$_{q2}$		46.336***			53.912***			39.798***	
		(2.580)			(3.247)			(2.504)	
After × N. arrival$_{q3}$		55.311***			61.001***			52.048***	
		(2.629)			(3.346)			(2.158)	
After × N. arrival$_{q4}$		57.723***			64.867***			52.939***	
		(1.838)			(2.170)			(2.713)	
After × Internet$_{q1}$			58.034***			66.066***			53.782***
			(2.870)			(2.932)			(4.285)
After × Internet$_{q2}$			58.763***			65.927***			52.312***
			(1.792)			(2.590)			(1.996)
After × Internet$_{q3}$			48.393***			54.555***			45.858***
			(2.557)			(2.930)			(3.152)
After × Internet$_{q4}$			52.514***			58.722***			49.177***
			(2.460)			(2.981)			(3.058)
Week FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
User FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	787,835	787,835	787,835	463,374	463,374	463,374	216,079	216,079	216,079
R^2	0.385	0.385	0.385	0.455	0.455	0.455	0.471	0.471	0.471
Adjusted R^2	0.306	0.306	0.306	0.340	0.340	0.341	0.273	0.273	0.273
Residual Std. Error	108.919	108.909	108.906	108.416	108.407	108.399	106.047	106.035	106.042

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001 | Errors clustered by mobile phone number in ()
q_1 (q_4) captures countries with the lowest (highest) arrival or Internet coverage

comes into effect, suggesting the absence of strong substitution patterns between mobile and desktop internet usage.

Another possibility is that before RLAH, consumers used cheap local prepaid SIM cards to access the mobile internet while traveling. However, data from the International Telecommunication Union (ITU) shows a consistent downward trend in the number of prepaid subscriptions in the EEA countries since 2011 (see figure A.2). Suppose there was a strong substitution between using the mobile internet within the domestic plan's roaming tariff and local prepaid SIM cards before RLAH. In that situation, we would expect to see a drop in the number of local prepaid SIM cards after RLAH. This does not seem to hold. Additionally, figure A.3 shows that the average domestic mobile broadband traffic in the EEA countries follows a similar trend as in non-EEA countries. If the effect of RLAH on tourists' use of domestic SIM cards was substantial, we expected to see a slower growth of domestic traffic in EEA than in non-EEA countries.

Taken together, the evidence that we collected suggests that it is unlikely that the results that we report are just a consequence of consumers switching between free and cheap means to access the internet while traveling towards roaming networks after the RLAH.

6 Welfare Effects

6.1 Changes in Consumer Surplus

6.1.1 Consumer Surplus per User and Travel Day

In this section, we use our quantity estimates and price calibration to establish how RLAH changed consumer surplus that we report in terms of average daily gains.

First, we use the results in column (1) of Table 2, and plug them in equation (9). We find that the average consumer surplus gain per user per travelled day increased about €2.77 ($CI_{95\%}[2.73, 2.82]$),[20] from which €1.49 (53.7%) comes from the revaluation of past consumption, while €1.28 (46.3%) stems from new consumption.[21]

When calculating the consumer surplus effects, we can of course also take user heterogeneity into account. Our results underline that a large share of consumer surplus from new data

[20] We use the causal estimates and standard errors from column (1) of Table 2 as an estimate of $\hat{\delta}$, which gives us $\hat{q_0} = 31.195$ and $\hat{q_1} = 31.19 + 54.2 = 85.39$. Overall we have $\hat{q_0} + \hat{q_1} = 116.59$ which leads or estimation of the compensating variation to $CV = (0.0515 - 0.00385) \times \frac{116.59}{2} = 2.77$. We also use the causal estimates and standard errors from column (1) of Table 2 to compute the confidence intervals.

[21] We show in Appendix A.7 that our estimation of the consumer surplus gains is higher when considering positive average income (y) and income elasticity (σ).

consumption stems from a) consumers with a large data consumption at home and b) consumers with low data consumption when roaming in the EU prior to the regulation. Conversely, and as shown in Figure 6, travel intensity heterogeneity seems to have a limited impact on consumer surplus generation heterogeneity.

6.1.2 Narrow Definition of Consumer Surplus: Leisure vs. Business Trips

One might argue that surplus changes with respect to business travel might not capture the precise definition of consumer surplus. Hence, we use the causal estimates and standard errors from column (4), and (7) to compute surplus changes separately for business and leisure trips. Overall we find that when focusing on leisure trips, the regulation generated an increase of €3.12 ($CI_{95\%}[3.01, 3.22]$) per user and travel day, from which €1.6 (51.2%) comes from the revaluation of past consumption, while €1.52 (48.8%) stems from new consumption. For business trips, we find that the surplus gain per user and travel day is about €2.56 ($CI_{95\%}[2.44, 2.68]$), from which €1.33 (52%) comes from the revaluation of past consumption, while €1.23 (48%) stems from new consumption.[22]

6.1.3 How Much did European Consumers Gain?

Using our estimation of €2.77 for the consumer surplus increase, we are able to better understand the overall gains of Europeans consumers.

We first compute the total consumer surplus increase of our sample. Users in our database traveled around 2.5m days in 2017 after RLAH within the EEA. Using our estimate of the average consumer surplus increase per traveled day, we compute the total consumer surplus gain from the regulation of our sample to be around €7m only for 2017.

Using external data on tourism, we can also compute the overall consumer surplus gains for the country of MOBILE. According to national tourism data, residents of the country where MOBILE operates spent around 50m days traveling in the EU between June and December 2017. In this case, the total consumer surplus gain from the regulation, and only for the country of MOBILE is around €140m only for 2017.

[22] For leisure trips we have $\hat{q}_0 = 33.633$ and $\hat{q}_1 = 33.633 + 63.705 = 97.338$. Overall we have $\hat{q}_0 + \hat{q}_1 = 130.971$ which leads or estimation of the compensating variation to $CV_{leisure} = (0.0515 - 0.00385) \times \frac{130.971}{2} = 3.12$. For business trips we have $\hat{q}_0 = 27.88$ and $\hat{q}_1 = 27.88 + 51.827 = 79.707$. Overall we have $\hat{q}_0 + \hat{q}_1 = 107.587$ which leads or estimation of the compensating variation to $CV_{business} = (0.0515 - 0.00385) \times \frac{107.587}{2} = 2.56$. We use the causal estimates and standard errors from columns (4) and (7) of table 3 to compute the confidence intervals.

Finally, EU countries' residents spent 846.32m nights traveling in the EU between June and December 2017 according to Eurostat.[23] Assuming that the quantity effects we estimate in section 5.1 are representative across the EU, the total consumer surplus gain of RLAH would be around €2.352B from June 2017 to December 2017.

While the assumption that users of MOBILE are representative of the entire EU is strong, several observations suggest that our estimates of consumer surplus effects might be lower bound.

First, we show in appendix A.1 that individuals from the country in which MOBILE operates tend to travel less outside the country relative to the average of other EU countries. In that case, our estimation for the overall EU consumer surplus is likely underestimated. Second, in a related research study, Canzian et al. (2021) show that the country where MOBILE operates has a lower consumer surplus change from data consumption than the average. In this case, we use our estimates to calculate a lower bound for the aggregate consumer surplus in the EU.

Third, the consumer surplus estimate that we obtain for 2017 would more than double in subsequent years. This is due to a longer time horizon, but also because of a change in the wholesale price cap - which determines the data allowance while roaming - that reduced from €c0.385/MB in 2017 to €c0.3/MB in 2018, €c0.225/MB in 2019 and EUR €c0.175/MB in 2020.

Finally, we do several simulations that relax our baseline assumption of null income elasticity of mobile data demand. We report the results in Appendix A.7. We find that the average consumer surplus gains are higher in scenarios with positive income elasticities than our baseline estimate. We report the results of this analysis in Table A.8.

6.2 Changes in Producer Surplus

After establishing estimates of the consumer surplus effects of RLAH, we now turn to a discussion of producer surplus effects. Here we distinguish between content providers and network operators.

6.2.1 Content Providers: Insights from an Online Experiment

The observational dataset obtained from MOBILE does not detail how users allocated their data allowances across content types. To provide suggestive evidence of how consumers distributed the additional megabytes they consumed after RLAH, we ran an online experiment on 2000

[23] See https://ec.europa.eu/eurostat/databrowser/view/TOUR_OCC_NIM__custom_61795/default/table?lang=en.

European consumers through the crowd-sourcing platform Clickworker.[24]

Experimental Setup We ask participants about their monthly data allowance and present them with two choice scenarios.[25] In each scenario, we ask participants to imagine that they are traveling abroad without access to Wifi or a desktop computer. We place our first scenario in the context before RLAH and give participants a data allowance of 140 MB.[26] Participants are then asked to allocate the MBs they have across six different content provider types: Communication, Search, Social Media, News, Music/Video, Review platforms, Transportation and none. For each category, we give examples of popular platforms (e.g., WhatsApp, Instagram, Spotify, etc.) and instructions on how units of consumption (messages, minutes of scrolling and posting, number of songs, etc.) translate into MBs. We place the second scenario after RLAH, and we tell participants that they have a mobile data allowance while traveling equal to the one they enjoy at home. We also ask them to allocate their allowance across content. In both scenarios, participants can leave unused MBs to a residual category.

Method For each respondent, we use their declared MB allowance and price paid at home to compute a hypothetical MB allowance when traveling abroad before and after the regulation.[27] Suppose a user pays more than the regulated price per megabyte (domestic price + €c5 before the regulation and €c0.385 after the regulation). In that case, she will benefit from her entire home allowance when traveling within the EU. However, if she pays less, she will have her MB allowance reduced to where her price per MB matches the actual regulated price.

After computing a users' roaming data allowance before and after RLAH, we determine consumption for each content provider by excluding the category that captures unused MBs. This category allows us to compute the average amount of MBs consumed per user per content-type:

[24] Our experimental data may not represent the population of European consumers affected by the RLAH regulation, so we compare the demographics of our online experiment participants to consumers in a Eurobarometer survey from August 2017 (see European Commission, 2017). We select the subsample of consumers in Eurobarometer that state that they have traveled at least once in the EU in the previous 12 months. Compared to this sample, our participants are more likely to be male (56% vs. 50%) and less likely to have tertiary education (54% vs. 87%). Still, our participants have a similar age profile (86% vs. 87% are younger than 35). Our sample consists of participants living in all EU countries except Luxembourg and Romania but is skewed towards Germany (43%), Spain (14%), Italy (13%), and France (7%).

[25] The questionnaires' details and descriptive statistics are reported in Appendix B.

[26] This is the average allowance we observe in pre-study data (N=400).

[27] To better match our MOBILE analysis, we keep users who have spent one or more MB in both scenarios. This decision trims our dataset to 1233 unique users and does not significantly affect our results.

$$MobileData_{ict} = \sum Content_{ict}(\gamma_c + \delta_c After_t) + a_i + v_{ict}, \quad (10)$$

where $Content_{ict}$ indicates respondent i's allocation of MBs to content of type c in scenario t, and the δ_c coefficients reflect the difference between scenarios. In this case $After_t$ is a dummy variable equal to 1 in the scenario that captures the RLAH rules. Since we have two observations per respondent, we also control for individual-fixed effects a_i. Using the estimation of each δ_c we denote by $\hat{\delta}_c$, we compute q_{0c} and q_{1c}. We set q_{0c} as the sample mean of data consumption before the price change $\hat{q_{0c}}$ for content type c, and $\hat{q_{1c}} = \hat{q_{0c}} + \hat{\delta}_c$. Then, we recover how much each content type weights in each individual's mobile data consumption (see equation (11)):

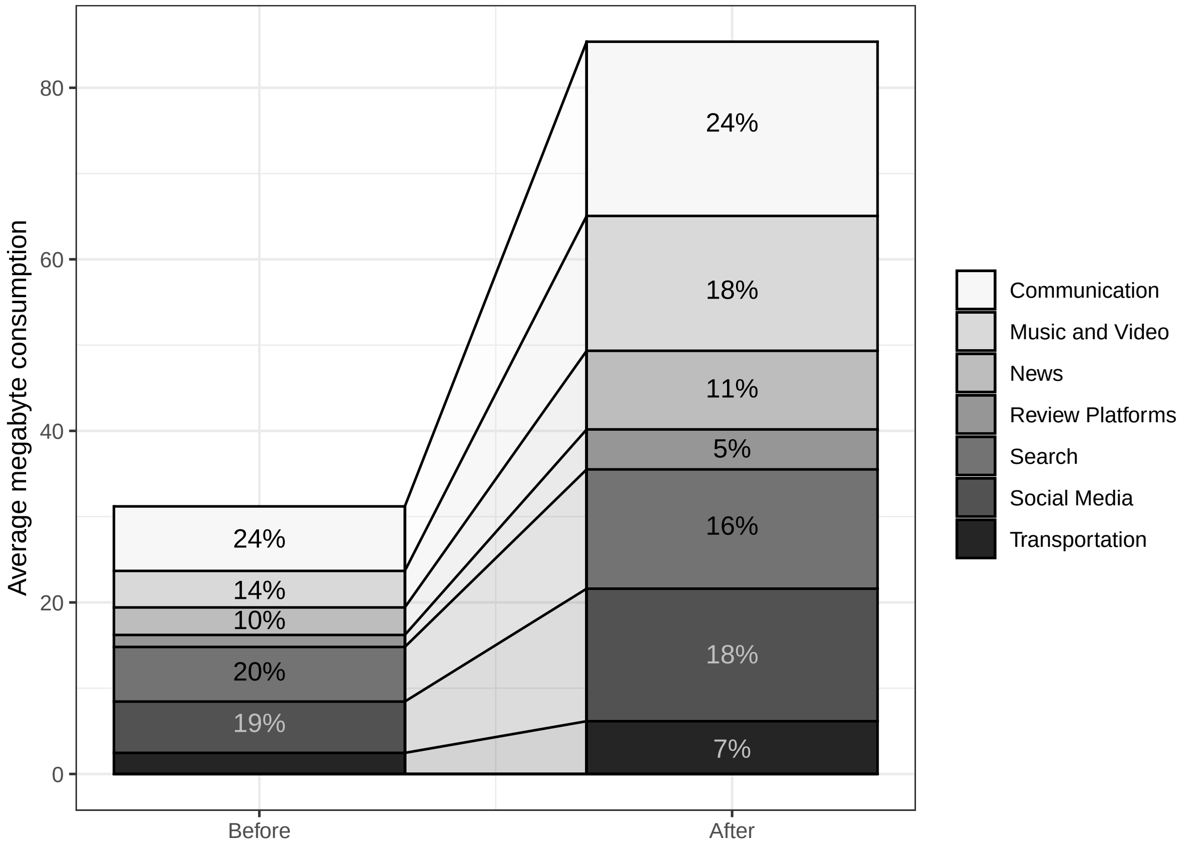
$$share_{0c} = \frac{\hat{q_{0c}}}{\sum_c \hat{q_{0k}}}, \qquad share_{\delta c} = \frac{\hat{\delta}_c}{\sum_c \hat{\delta}_c} \quad (11)$$

Results Table B.2 provides the descriptive statistics on respondents' mobile data choices. In Figure 7 we show average consumption in MB per day in the scenario that resonates the situation before RLAH and the scenario where RLAH rules apply. More precisely, we use our experiment to compute the average weight of each content type in the total data consumption before and after the regulation. We report the weights in Figure 7 and use them to decompose the additional MB per day that we estimated using the MOBILE database, before and after RLAH.

From the experiment, we take that communication is the content category with the most substantial increase. We can only speculate about the mechanism, but it seems reasonable that users expect to be sharing more data-heavy content such as photos and videos through messaging applications while traveling. The smallest increase is in the usage of review platforms, perhaps because there are decreasing returns to this type of information when traveling.

Table 4 shows the increase in the number of experimental subjects that would consume different content categories using mobile data because of the hypothetical price change.

Figure 7: Average Daily Consumption by Content Types



Note: Percentages capture (11), i.e. the share for each content type depending on the period. We multiply these shares by the quantities estimated by equation (8) in table 2 - column (1) to find the average daily MB usage for each content type. Before RLAH, percentage of Review Platforms and Transportation categories are respectively about 4.4% and 7.8%.

6.2.2 Network Operators: Insights from Aggregate Data

As a final exercise, we approximate the change in surplus for network operators after RLAH. Network operators draw two types of revenue from roamers. Roaming charges they levy on their customers during travels (national roamers) and wholesale costs they charge to other network operators because of visitors traveling to the operator's country (roaming visitors). Both these dimensions were affected by the new regulatory environment.

We focus on travelers to/from countries that were affected by the roaming like at home rules because we assume that these were the only group of individuals who affected the network operator's surplus. In that case, the total roaming profit of a network operator is determined by:

Table 4: Impact of RLAH rules on Activity of Content Providers

Content providers	**Change in unique users**
Communication	+40% CI[+35% ,+44%]
Search	+44% CI[+39% , +49%]
Social Media	+54% CI[+49% , +60%]
News	+57% CI[+50% , +64%]
Music & Video	+91% CI[+83% , +100%]
Transportation	+43% CI[+36% , +50%]
Review Platforms	+65% CI[+55% , +75%]

Note: we compute a ratio and its 95% confidence intervals of the additional unique users after RLAH divided by the number of users in a category before the regulation. Results for the online survey can be found in appendix B.2.

$$\begin{aligned}
\Pi_t^{nop} &= N_t^{nat.r}\pi_t^{nat.r} + N_t^{visitors}\pi_t^{visitors} \\
\pi_t^{nat.r} &= q_t^{nat.r} \times (p_{mt} - w_t) \\
\pi_t^{visitors} &= q_t^{visitors} \times (w_t - c_{ope})
\end{aligned}$$

π_t^{nop} denotes the average daily roaming profit of a network operator in moment $t \in \{0, 1\}$ with 0 marking the period before RLAH, and 1 marking the period after the regulation. $N_t^{nat.r}$ denotes the number of outgoing roamers that travel abroad and use roaming services. $N_t^{visitors}$ denotes the number of incoming visitors that use the network operator's infrastructure to access mobile data. $\pi_t^{nat.r}$ denotes the average daily roaming profit per national roaming customer, and $\pi_t^{visitors}$ denotes the average daily roaming profit per roaming visitor. $q_t^{nat.r}$ is the average amount of MBs that national roamers use per day while traveling and $q_t^{visitors}$ is the average amount of MBs that roaming visitors consume per day. p_{mt} is the retail price per megabyte for roaming nationals. w_t is the wholesale price per megabyte for both national roamers and roaming visitors. In our approximation, we assume that wholesale prices are the same for all network operators in all countries affected by RLAH. Finally, c_{ope} are operating costs per megabyte in €c.

We set w_t as the wholesale price cap before/after RLAH, the retail price using the same assumptions introduced in section 4.1, and quantity estimates based on table A.2.

With these parameters, we calculate the changes in marginal revenue from national roamers and roaming visitors.

For national roamers, the change in the marginal revenue ($\pi_0^{nat.r} - \pi_1^{nat.r}$) depends on the domestic price per megabyte. For domestic prices lower than €c0.385, the marginal revenue of national roamers decreased by $31.34p_h + 32.87$. When domestic prices higher than €c0.385, the marginal revenue from national roamers decreases by $65.75 - 54.05p_h$. For roaming visitors, the difference in marginal revenue ($\pi_0^{visitors} - \pi_1^{visitors}$) changed by $€c90.9 + 54.05 \times c_{ope}$.

Suppose RLAH change mobile data usage but not the likelihood of travel (which we think is a reasonable assumption). In that case, and with the parameterization we laid out above, the profit change for a network operator because of RLAH will be:

$$\Delta\Pi = \begin{cases} N_1^{nat.r} \times [31.34p_h + €c32.87] + N_1^{visitors}[€c90.9 + 54.05 \times c_{ope}] & \text{if } p_h \leq 0.385 \\ N_1^{nat.r} \times [€c65.75 - 54.05p_h] + N_1^{visitors}[€c90.9 + 54.05 \times c_{ope}] & \text{if } p_h > 0.385 \end{cases} \tag{12}$$

We can use equation (12) to map the 2017 post-regulation gains for any European network operator depending on their network operating cost (c_{ope}), their domestic price per megabyte p_h, the number of roaming visitors $N_1^{visitors}$ and number of national roamers $N_1^{nat.r}$.

According to the distribution of domestic prices and operating costs across European countries (see European Commission (2016)), operators' marginal profit decreased from visitors more than national roamers.

For the average operating cost c_{ope} and domestic price p_h across European countries in 2017 (c_{ope} =€c0.4/MB and p_h =€c0.15/MB),[28] the daily marginal revenue loss because of RLAH amounted to €c37.57 per national roamer and €c112.5 per visitor due to RLAH.

Operators in countries with a large number of incoming visitors lost more from the regulation. Additionally, network operators with higher operating costs were also more penalized by RLAH. These heterogeneous impacts are likely to have been substantial given the heterogeneity in roaming operating cost across countries in Europe (European Commission, 2016).

[28] See appendix A.8.

7 Discussion and Implications

The regulation's initial goal was to increase consumer surplus, reduce the digital divide for travelers, and make the first step toward a unified digital European market. Our results suggest that the regulation increased the total consumer surplus and allowed more travelers to access the Internet. However, our analyses also underline several other nuanced effects.

First, the impact on consumer surplus was heterogeneous across consumer types. Consumers who were intensive mobile internet users at home benefited the most when traveling abroad. Furthermore, our results also suggest that the regulation had lower consumer surplus effects on trips that exclude weekends and holidays relative to trips that include at least one weekend day. This result indicates that tourists rather than business users were the ones that benefited the most from the drop in roaming charges. We also showed that consumer surplus effects were more substantial in touristic countries than less touristic ones, reinforcing the point that the new roaming rules likely benefited travelers in their leisure activities.

While overall, these results shed good news for consumers, for network operators, they mean that the transfers that occur from firms to consumers are unevenly distributed across Europe. By the nature of the heterogeneous consumer behavior that we observe, these transfers likely penalized network operators based in countries with the most inflow of travelers and the highest levels of domestic use of mobile internet data.

Furthermore, our online experiments show that consumers do not value content homogeneously, and different content providers benefited differently from RLAH. These effects and surplus transfers are at the core of the net neutrality debate (Greenstein et al., 2016). With a net neutrality regime, policies like RLAH transfer ISP's revenue directly to other market agents, which triggers the possibility that the regulation could have an ambiguous mid-term effect on the digital divide. On the one hand, the RLAH might have reduced the digital divide between EU travelers, allowing more users to access the Internet. On the other hand, weakening ISP's revenue to the benefit of content producers may reduce ISP's incentives to invest in bandwidth quality in the future (Pil Choi and Kim, 2010).

As we have shown in section 6.2.1, consumers split their additional mobile internet allowance by different content providers online. According to our survey's results, search engines, social networks, and music and video services benefited the most from the added data allowances induced by RLAH.

In Europe, a few large firms dominate these content categories. For example, 90% of Europeans with access to the Internet use Google as a search engine,[29] making it likely that travelers' online search activity will benefit Google directly. If RLAH increases users' search behavior, Google certainly captured part of the enlarged pie. The immediate consequence is that it is likely that the RLAH regulation transferred surplus from European network operators towards multinational content providers such as Google, Facebook, Instagram, and other tech giants, that operate in the markets that travelers seem to value the most. So while the regulation increased consumer surplus, it also likely reinforced the non-EU platform position in the EU market.

8 Conclusion

Since the introduction of RLAH rules on the 15h June 2017, European citizens can enjoy free data roaming when traveling in the EEA. These rules are the outcome of several telecom regulation waves to provide users with more robust mobile data capabilities to reinforce the European digital single market. More precisely, the rules sharply reduced prices for mobile internet access and allowed a significant number of European citizens to access mobile data while traveling.

In this paper, we analyze the consumer surplus effects of such price decreases. We partner with a major European mobile carrier which gives us access to a dataset of mobile internet usage statistics for 90,000 anonymized users from September 2016 to December 2017. We show that the daily consumption of mobile data per user increased by around 170% because of Roam-Like-At-Home rules. We analyse the heterogeneity behind this increase and find significant differences depending on user and travel behavior. For example, we show that their prior habit of mobile data consumption substantially impacts a user's reaction to the price regulation. We also show that there is heterogeneity by types of travel. Slicing the data by measures of leisure and business trips, we find significantly different effects of the regulation on users' data consumption.

We use these quantity shifts to compute a consumer surplus gain from the regulation and find that users gained on average €2.77 per travel day. We then decompose this surplus gain and find that leisure trips generated a higher consumer surplus gain per user per travelled days (€3.12) than business trips(€2.56).

We also discuss the effect of RLAH rules with respect to different content providers. We do

[29]See https://gs.statcounter.com/search-engine-market-share/all/europe

so using an online experiment designed to study how consumers allocate the additional data allowance they obtained from roaming like at-home rules across different online content types. Our results suggest that consumer surplus gains from RLAH derive from a combination of new data consumption content types such as Music & video, and Review Platforms, and revaluation of previous consumption levels for other categories such as Communication, Social Media and Search.

Our results suggest that RLAH increased total consumer surplus and allowed more travelers to access the Internet. At the same time, content providers also benefited from RLAH. Such findings add to the emerging literature that evaluates telecom regulation and shows that the overall welfare effects can be intricate.

Our results have broad implications. Namely, we argue that the effects of RLAH link to net neutrality and the market position of non-EU services within the EU.

Our study has several limitations. First, we cannot rule out completely that EU citizens substituted other free means of accessing the Internet with roaming. Second, we cannot observe individual-level prices and we approximate the arc-elasticity of demand in our estimations. Finally, we do not observe actual internet use of clients of MOBILE and used online experiments to study how consumers spend the additional data allowance provided by RLAH.

Finally, we think our results may stimulate more research on the unintended effects of data access. For example, cities' shape and organization may have been impacted by users having easier access to both information platforms and transportation means . As places of interest can be more easily detected and reached when one has access to the Internet, firms may change their investment in quality and location choice accordingly (Donati, 2021). More broadly, if better access to information changed users' optimal choices, firms may also undertake different strategic decisions to adapt, which provides interesting avenues for future research.

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A Appendix: MOBILE dataset

A.1 Dataset representativeness

We compare characteristics of our focal country to other European countries using EUROSTAT data. We do so in a way that keeps the country in which MOBILE operates anonymous.

For each country variable we contrast, we compute its mean across all European countries. We then calculate the Z-score of our country for each variable.

We provide the results in table A.1. The table highlights that our country has higher domestic tourism (around 0.5 standard deviations from the mean) and lower outbound tourism (around one standard deviation from the mean) relative to other EU countries.

Table A.1: Travel and mobile internet consumption behavior across Europe.

	All EU			Close EU		
	Avg.	Std.	Z-score	Avg.	Std.	Z-score
Dom. tourism (%)	26.08	10.17	−0.46	25.14	13.96	−0.40
Outb. tourism (%)	16.43	14.96	0.81	14.89	9.96	1.06
Dom. tourism male (%)	26.39	9.77	−0.39	25.23	13.94	−0.36
Dom. tourism female (%)	25.50	10.30	−0.56	25.05	14	−0.45
Outb. tourism male (%)	16.50	14.98	0.81	15.23	10.26	1.06
Outb. tourism female (%)	16.36	14.96	0.80	14.56	9.70	1.05
Dom. tourism 15-24 (%)	28.48	12.82	−0.31	23.70	14.58	−0.60
Dom. tourism 25-44 (%)	28.14	11.76	−0.45	26.80	16.37	−0.41
Dom. tourism 44-64 (%)	25.28	10.13	−0.66	25.22	13.70	−0.49
Dom. tourism above 64 (%)	22.56	10.07	−0.26	23.70	11.70	−0.13
Outb. tourism 15-24 (%)	20.58	17.98	0.80	18.61	11.57	1.08
Outb. tourism 25-44 (%)	18.39	16.49	0.83	16.17	10.45	1.09
Outb. tourism 45-64 (%)	17.28	15.56	0.82	15.14	10.60	1.01
Outb. tourism above 64 (%)	11.21	11.91	0.71	11.11	8.44	0.98
Mob. Int. last 3 months (%)	76.33	10.80	0.03	78	14.75	0.14
Mob. Int. last 3 months 16-24 (%)	92.48	5.06	−0.50	93	6.89	−0.29
Mob. Int. last 3 months 25-54 (%)	81.11	12.11	0.17	82.25	16.92	0.19
Mob. Int. last 3 months 55-74 (%)	51.52	15.65	0.10	58.38	16.61	0.50
Mob. Int. last 3 months employed (%)	79.89	12.42	0.07	81.50	17.87	0.14
Mob. Int. last 3 months students (%)	93.70	3.97	−0.58	94	3.74	−0.53
Mob. Int. last 3 months unemployed (%)	72.96	12.18	0.08	75.62	12.92	0.28

'Avg.' and 'Std.' respectively capture the means and the standard deviation of countries designated location: *All EU* countries or *Close EU* countries being located within 2000km of our country's capital. Z-scores capture our country position relative to the variables distribution.

A.2 Choice of Estimation Sample

Table A.2 implements our DiD specification model of equation 8, for data from MOBILE using different sample trimming procedures.

First, we keep all travelers in the period regardless of how many times they travel or where they travel. We denote this sample as "*Not Balanced*". Second, we select users who traveled before and after the policy, irrespective of their travel destination. We denote this sample as "*Semi Balanced*". Finally, we select clients who traveled inside and outside the EEA before and after the policy. We denote this sample as "*Balanced*". We report different versions of equation (8), that includes users, week, and country fixed effects.

Table A.2: Impact of roaming like at home on mobile data consumption.

	Dependent variable:								
	Total (Mb)								
	Not Balanced			*Semi-Balanced*			*Balanced*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
After	−0.523**			−0.135			−0.067		
	(0.181)			(0.316)			(0.581)		
EUtravel	25.225***	37.099***		24.170***	37.848***		39.996***	43.975***	
	(0.250)	(0.781)		(0.366)	(0.933)		(1.909)	(1.822)	
After × EUtravel	65.311***	52.237***	52.198***	55.606***	54.415***	54.205***	54.229***	54.719***	54.705***
	(0.458)	(0.848)	(0.850)	(0.688)	(0.939)	(0.943)	(3.168)	(3.068)	(3.063)
Constant	5.587***			7.025***			11.546***		
	(0.149)			(0.244)			(0.673)		
Week FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
User FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Country FE	No	No	Yes	No	No	Yes	No	No	Yes
Observations	1,561,510	1,561,510	1,561,510	787,835	787,835	787,835	44,586	44,586	44,586
R^2	0.054	0.546	0.547	0.053	0.384	0.385	0.084	0.320	0.324
Adjusted R^2	0.054	0.384	0.384	0.053	0.304	0.305	0.084	0.268	0.271
Residual Std. Error	145.174	117.192	117.121	127.215	109.032	108.942	127.575	113.994	113.789

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001
Cluster robust standard errors in ()
Errors clustered by phone number

A.3 Regressions with Trends

We show that our results are robust to different trends specifications in our regression using the following models:

$$MobileData_{ijt} = \delta After_t \times RLAH_{ijt} + \gamma_{jt} + a_i + \kappa_j + \theta_t + v_{ijt} \tag{13}$$

$$MobileData_{ijt} = \delta After_t \times RLAH_{ijt} + \kappa_{jt} + a_i + \kappa_j + \theta_t + v_{ijt} \tag{14}$$

$$MobileData_{ijt} = \delta After_t \times RLAH_{ijt} + \gamma_{jt0} + \gamma_{jt1} + a_i + \kappa_j + \theta_t + v_{ijt} \tag{15}$$

$$MobileData_{ijt} = \delta After_t \times RLAH_{ijt} + \kappa_{jt0} + \kappa_{jt1} + a_i + \kappa_j + \theta_t + v_{ijt} \tag{16}$$

γjt and κ_{jt} are respectively treat-control specific and country specific trend coefficients that both multiply the time-trend variable, t. $\gamma jt0$, $\gamma jt1$, $\kappa jt0$, and $\kappa jt1$ allows us to decompose the trends between periods before and after the regulation. The error term v_{ijt} follows the usual assumptions. In our estimations, we cluster standard errors at the individual level to allow for arbitrary serial correlation.

Table A.3 displays the results. Column (1) is our baseline regression from (8). Columns (2) and (3) respectively capture trends by treat-control groups from equation (13) and countries from equation (14) over the all period. Columns (4) and (5) respectively decompose trends between before and after the regulation, by treat-control groups (equation (15)) and countries (equation (16)).

Using column (4), we compute the short-term and rather long-term effects of the regulation. The short-term impact captures the jump in mobile data consumption at the first period after implementing the regulation. The "long term" corresponds to around six months after RLAH rules, capturing the short-term effect and the developing trend in roaming mobile data consumption. Overall, we find that the regulation stimulated a short-term immediate increase of 39.98MB per user per traveled day, which rises to 69.5MB (39.98+29×1.021) by the end of 2017.

A.4 Robustness Checks Excluding January–August

In Table A.4, we report results from estimating equation (8) with different level of fixed effects and balancing specifications, excluding January-August for 2017. We include this specification to highlight that our results are robust to removing the summer months that usually correspond to vacations periods and may display unusually high travel behavior.

Table A.3: Impact of roaming like at home on mobile data consumption accounting for trends.

	Dependent variable:				
	Total (Mb)				
	(1)	(2)	(3)	(4)	(5)
After × EUtravel	54.205***	43.169***	41.718***	39.980***	39.980***
	(0.943)	(1.357)	(1.455)	(1.745)	(1.737)
Trend × EUtravel		0.351***			
		(0.036)			
$Trend_{aft}$× EUtravel				1.021***	
				(0.068)	
$Trend_{bef}$ × EUtravel				0.036	
				(0.050)	
Country trend	No	No	Yes	No	Yes
Country trend before/after	No	No	No	No	Yes
Week FE	Yes	Yes	Yes	Yes	Yes
User FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	787,835	787,835	787,835	787,835	787,835
R^2	0.385	0.385	0.385	0.385	0.385
Adjusted R^2	0.305	0.306	0.306	0.306	0.306
Residual Std. Error	108.942	108.939	108.922	108.933	108.919

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001
Cluster robust standard errors in ()
Errors clustered by phone numbers

Table A.4: Impact of roaming like at home on mobile data consumption. Period from September to December.

	Dependent variable:					
	Total (Mb)					
	All sample			Sept-Dec		
	(1)	(2)	(3)	(4)	(5)	(6)
After × EUtravel	52.198***	54.205***	54.705***	55.882***	58.566***	59.829***
	(0.850)	(0.943)	(3.063)	(1.660)	(1.848)	(4.887)
Balance	No	Semi	Full	No	Semi	Full
Week FE	Yes	Yes	Yes	Yes	Yes	Yes
User FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,561,510	787,835	44,586	650,413	309,717	18,552
R^2	0.547	0.385	0.324	0.605	0.502	0.413
Adjusted R^2	0.384	0.305	0.271	0.411	0.359	0.295
Residual Std. Error	117.121	108.942	113.789	130.842	121.203	123.115

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001
Cluster robust standard errors in ()
Errors clustered by phone numbers

A.5 Heterogeneity analysis

Table A.5: Impact of roaming like at home on mobile data consumption while traveling by decile

	Dependent variable:									
	Total (Mb) by decile									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
After × RLAH	30.831***	28.814***	43.768***	48.961***	55.624***	62.398***	69.100***	76.421***	79.427***	52.024***
	(3.599)	(2.648)	(3.399)	(2.424)	(2.714)	(2.791)	(3.411)	(3.253)	(4.054)	(5.200)
Avg. before RLAH	0.09	1.14	4.26	8.12	12.83	18.86	26.84	38.55	59.27	155.32
Week FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
User FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	64,836	65,876	70,398	83,268	85,899	82,915	77,028	73,785	67,961	63,969
R^2	0.416	0.413	0.369	0.344	0.337	0.322	0.302	0.327	0.322	0.305
Adjusted R^2	0.335	0.334	0.289	0.276	0.269	0.251	0.222	0.247	0.233	0.207
Residual Std. Error	73.193	69.791	75.369	80.395	81.526	94.720	105.116	112.334	129.198	218.472
Ave. before RLAH (Mb)	0.093	1.111	4.226	8.071	12.713	18.684	26.605	38.1689	58.656	153.858

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001
Cluster robust standard errors in (); Errors clustered by mobile phone number
+ p<0.1; * p<0.05; ** p<0.01; *** p<0.001
D1 (D10) captures users with the lowest (highest) mobile data consumption while traveling

Table A.6: Impact of roaming like at home on mobile data consumption. Decomposition by usage at home.

	Dependent variable:									
	Traffic by deciles									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
After x EUtravel	5.257***	15.249***	26.277***	33.887***	44.555***	53.929***	65.171***	84.509***	106.407***	140.713***
	(1.514)	(1.237)	(1.578)	(1.680)	(1.968)	(2.022)	(2.516)	(3.177)	(3.613)	(5.502)
Avg. before RLAH	6.65	15.99	20.54	24.77	28.24	31.22	37.11	42.77	50.29	73.06
Week FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
User FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	100,840	78,675	78,241	78,918	77,658	77,821	75,636	75,457	72,729	71,860
R^2	0.323	0.265	0.273	0.292	0.314	0.314	0.331	0.361	0.381	0.400
Adjusted R^2	0.256	0.169	0.177	0.200	0.222	0.222	0.239	0.273	0.292	0.312
Residual Std. Error	43.322	53.243	66.809	74.434	81.413	95.223	111.268	122.593	146.715	203.520

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001
Cluster robust standard errors in (); Errors clustered by mobile phone number
D1 (D10) captures users with the lowest (highest) mobile data consumption at home

Table A.7: Impact of roaming like at home on mobile data consumption. Decomposition by number of travels.

	Dependent variable:								
	Traffic								
	D1	D2-D3	D4	D5	D6	D7	D8	D9	D10
After x EUtravel	68.253***	67.864***	64.996***	59.632***	59.325***	57.237***	50.995***	48.676***	49.689***
	(3.257)	(2.674)	(2.747)	(2.443)	(3.210)	(2.243)	(2.384)	(1.733)	(2.154)
Avg. before RLAH	30.83	33.92	34.47	34.41	34.21	34.96	34.06	33.78	27.71
Week FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
User FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	28,654	47,361	47,236	42,465	37,242	60,386	65,564	134,900	324,027
R^2	0.618	0.547	0.466	0.465	0.436	0.421	0.379	0.364	0.331
Adjusted R^2	0.192	0.317	0.284	0.328	0.319	0.329	0.306	0.318	0.312
Residual Std. Error	108.357	104.657	108.579	101.492	98.924	105.849	106.425	103.612	113.989

Note: + p<0.1; * p<0.05; ** p<0.01; *** p<0.001

Cluster robust standard errors in (); Errors clustered by mobile phone number

D1 (D10) captures users with the lowest (highest) travel intensity

A.6 Substitution for Mobile Internet when Roaming

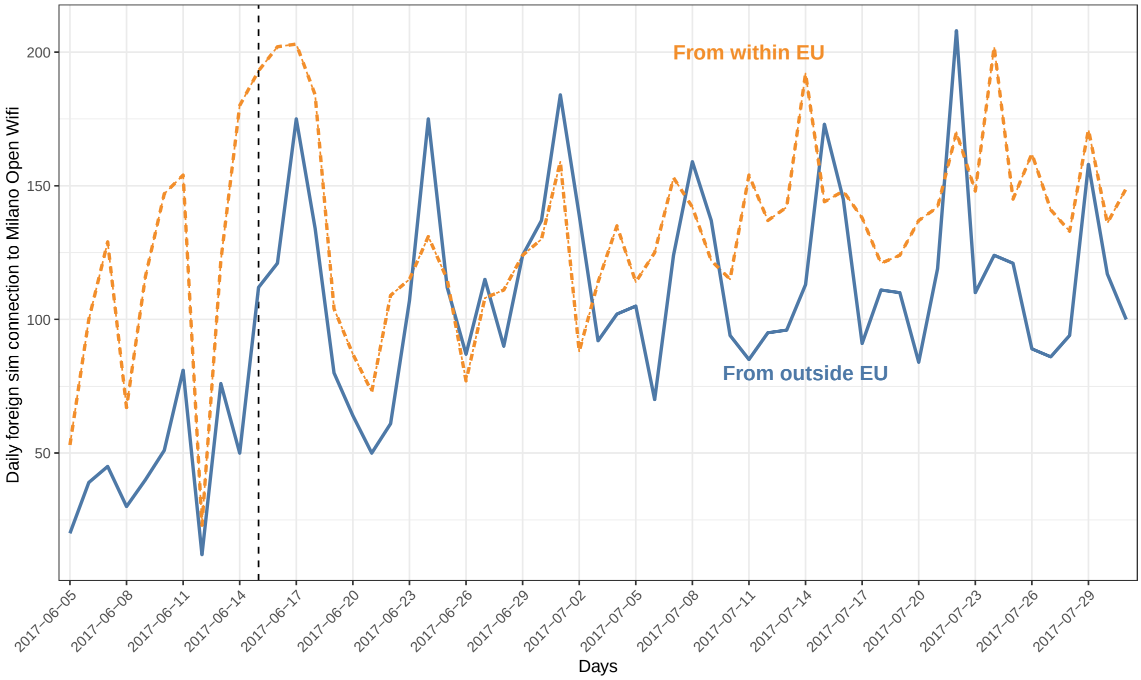

Figure A.1: Number of Milano Wifi Hotspot connection accross time and sim origin
Source: Open Data - Comune de Milano.

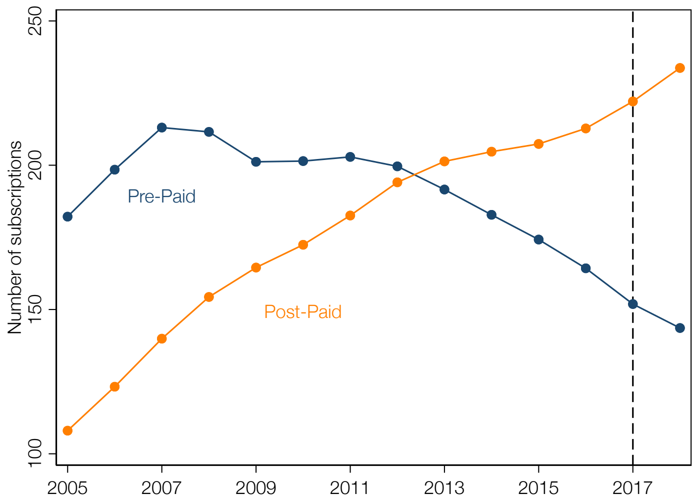

Figure A.2: Number of cellular telephone subscriptions, pre-paid and post-paid, EEA
Source: ITU World Telecommunication/ICT Indicators Database, 2019.

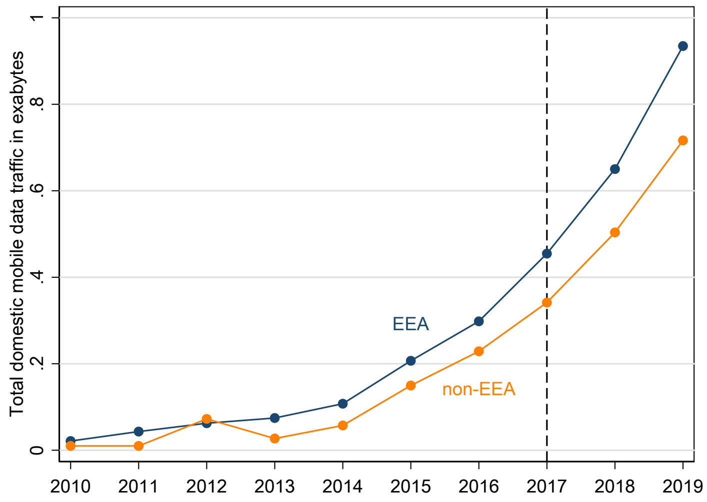

Figure A.3: Domestic mobile broadband traffic in exabytes, average of EEA and US/CA/BR.

Source: ITU World Telecommunication/ICT Indicators Database, 2019.

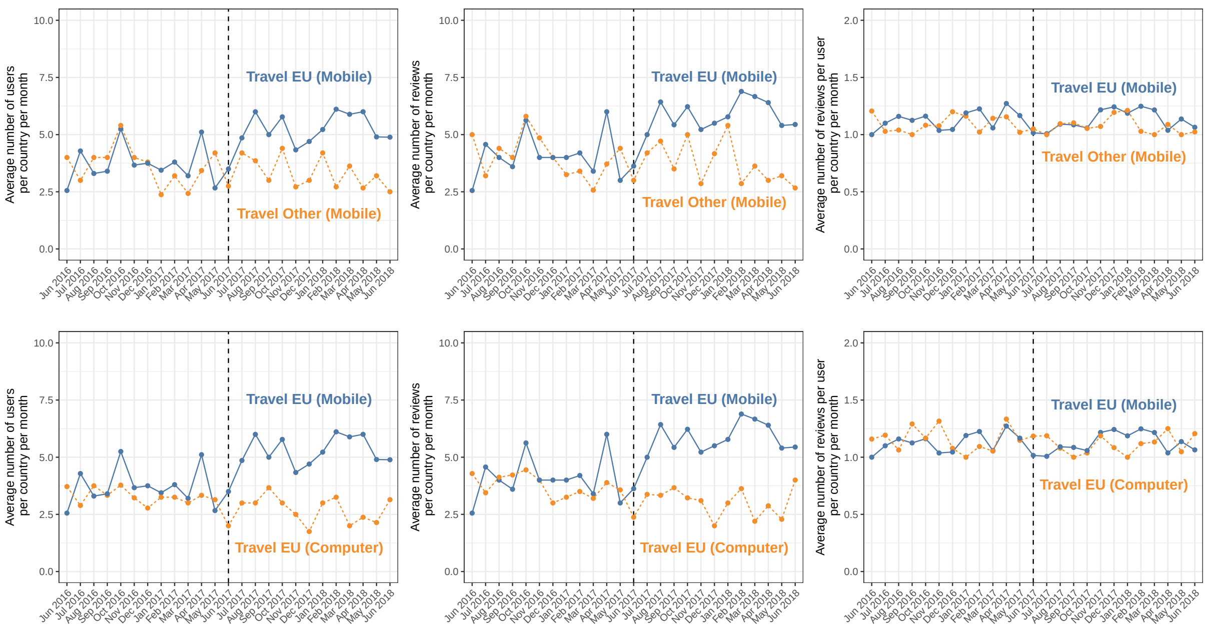

Figure A.4: Model free evidence of the impact of RLAH rules on user generated content on TripAdvisor

A.7 Consumer Surplus Computation with Positive Income and Income Elasticity of Demand

We perform a sensitivity analysis of varying income and income elasticity levels to alleviate potential concerns with the impact of this assumption on our consumer surplus estimates. To implement the sensitivity analyses, we recompute the compensating variation in the presence of $\sigma > 0$. Below we provide the math for these calculations.

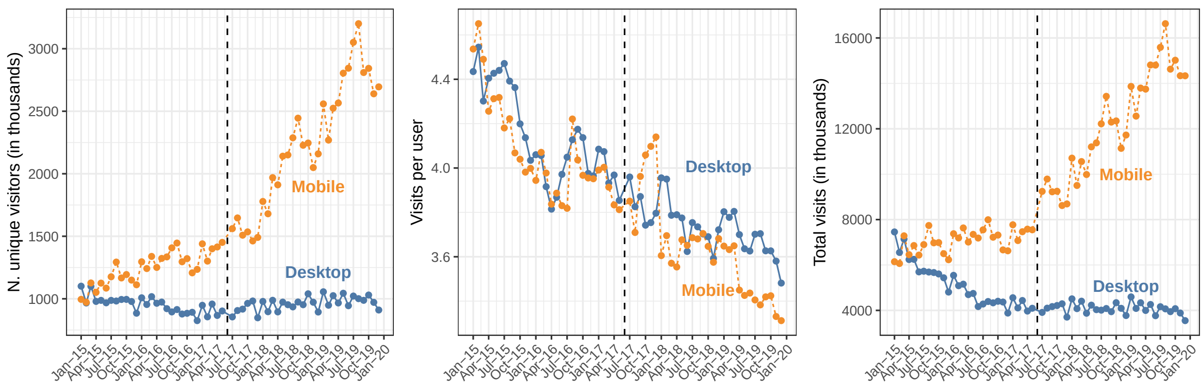

Figure A.5: Model free evidence of the impact of RLAH rules on website visits

$$CV = [\frac{1-\sigma}{1+\epsilon}y^{-\sigma}\big((p_{m0}+p_{c0})q_0-(p_{m1}+p_{c1})q_1\big)+y^{1-\sigma}]^{\frac{1}{1-\sigma}}-y \tag{17}$$

Subtituting $\epsilon = \frac{(q_1-q_0)}{(p_{m1}+p_c)-(p_{m0}+p_c)} \times \frac{(p_{m1}+p_c)+(p_{m0}+p_c)}{(q_1+q_0)}$, we have

$$CV = [\frac{(1-\sigma)(p_{m0}-p_{m1})(q_1+q_0)}{2y^{\sigma}}+y^{1-\sigma}]^{\frac{1}{1-\sigma}}-y \tag{18}$$

With $\sigma = 0$, $CV = \frac{(p_{m0}-p_{m1})(q_1+q_0)}{2} = 2.77$. With $\sigma > 0$ we can rewrite CV such that:

$$CV = [\frac{(1-\sigma)\times 2.77}{y^{\sigma}}+y^{1-\sigma}]^{\frac{1}{1-\sigma}}-y \tag{19}$$

We simulate different levels of income elasticity σ and average income y. We tried to parameterize our simulations with past results in the telecommuncations literature on income elasticity of demand (Baek, 2016; Sawadogo, 2021; Goel et al., 2006). Unfortunately, we did not find any study computing the income elasticity of demand for mobile data while roaming. Nevertheless, the literature suggests a positive but heterogeneous income elasticity of demand for Internet services and voice communication services. Considering this result, we simulate a wide range of positive income elasticity values (i.e. from 0 to 2). We also take into account that the decision to roam might be impacted by the daily travel budget of each traveler and we considered daily travel budgets in the range from 10 to 1000 euros. With these assumptions and travel budgets, we find that the average consumer surplus gains are higher in these alternative scenarios than what we initially reported in our paper.

		Daily travel budget				
		10	50	100	500	1000
Average elasticity	0	2.77	2.77	2.77	2.77	2.77
	0.25	2.86	2.79	2.78	2.77	2.77
	0.5	2.96	2.81	2.79	2.77	2.77
	0.75	3.07	2.83	2.80	2.78	2.77
	1					
	1.25	3.33	2.87	2.82	2.78	2.77
	1.5	3.47	2.89	2.83	2.78	2.78
	1.75	3.64	2.91	2.84	2.78	2.78
	2	3.83	2.93	2.85	2.79	2.78

Table A.8: Simulation of Consumer surplus gains per user per travelled day

A.8 Domestic Price for Similar EU Countries

Data available in documents from the European Commission[30] published in February 2016 displays a great range of minimum price per megabyte "at home" for exclusive data plans. In countries similar to those where MOBILE operated (which we left vague for confidentiality reasons) home price per megabyte for the same products ranged from 0.15c to 0.38c.

We focus on the 0.15c scenario for the most conservative view on consumer surplus gains. Table A.9 displays the minimum price per megabyte that we found for each country, for different data allowances.

Table A.9: Minimum local price per megabyte by country for different data allowance in 2016.

	Country	500MB	5GB	20GB
1	Austria	0.0142	0.0021	0.0010
2	Belgium	0.0222	0.0044	0.0091
3	Bulgaria	0.0142	0.0039	0.0015
4	Croatia	0.0786	0.0269	0.0087
5	Cyprus	0.0273	0.0080	0.0028
6	Czech Republic	0.4642	0.0953	0.0482
7	Denmark	0.1173	0.0215	0.0077
8	Estonia	0.0071	0.0013	0.0007
9	Finland	0.0174	0.0017	0.0007
10	France	0.0189	0.0033	0.0011
11	Germany	0.0273	0.0051	0.0034
12	Greece	0.0326	0.0036	0.0019
13	Hungary	5.1481	0.8184	0.3573
14	Iceland	2.8662	0.4429	0.2572
15	Ireland	0.0254	0.0040	0.0013
16	Italy	0.0114	0.0020	0.0015
17	Latvia	0.0097	0.0010	0.0005
18	Lithuania	0.0080	0.0021	0.0008
19	Luxembourg	0.0195	0.0032	0.0013
20	Malta	0.0138	0.0020	0.0014
21	Netherlands	0.0223	0.0048	0.0041
22	Norway	0.2980	0.0416	0.0198
23	Poland	0.0539	0.0054	0.0015
24	Portugal	0.0206	0.0038	0.0015
25	Romania	0.0097	0.0019	0.0011
26	Slovakia	0.0201	0.0036	0.0017
27	Slovenia	0.0155	0.0025	0.0006
28	Spain	0.0158	0.0049	0.0062
29	Sweden	0.1217	0.0219	0.0079
30	United Kingdom	0.0206	0.0029	0.0013
	Mean Euro Zone	0.018	0.0033	0.0021

[30] See https://digital-strategy.ec.europa.eu/en/library/mobile-broadband-prices-europe-2016

B Appendix: Online experiment

B.1 Descriptive statistics

Table B.1: Descriptive statistics for the online experiment dataset. The table exhibit data only for the 1182 users that use both a positive amount of megabyte before and after.

	Scenario	Variable	Avg. (mb)	Std. (mb)
1	Before RLAH	Search	2.237	98.603
2	Before RLAH	Social Media	2.103	110.723
3	Before RLAH	News	1.126	62.524
4	Before RLAH	Transportation	0.864	56.017
5	Before RLAH	Music and Video	1.497	97.769
6	Before RLAH	Communication	2.643	98.650
7	Before RLAH	Review Platforms	0.492	46.694
8	Before RLAH	Unused Megabytes	1.060	98.620
9	After RLAH	Search	19.863	938.866
10	After RLAH	Social Media	22.078	1,062.991
11	After RLAH	News	13.096	774.060
12	After RLAH	Transportation	8.789	602.137
13	After RLAH	Music and Video	22.462	1,407.138
14	After RLAH	Communication	29.020	1,354.112
15	After RLAH	Review Platforms	6.662	499.261
16	After RLAH	Unused Megabytes	9.049	903.758

Table B.2: Descriptive statistics for the online experiment dataset. The table exhibit data for all the 1789 users.

	Scenario	Variable	Avg. (mb)	Std. (mb)
1	Before RLAH	Search	1.515	86.433
2	Before RLAH	Social Media	1.450	96.059
3	Before RLAH	News	0.767	53.403
4	Before RLAH	Transportation	0.584	47.220
5	Before RLAH	Music and Video	1.022	82.970
6	Before RLAH	Communication	1.785	88.576
7	Before RLAH	Review Platforms	0.344	40.095
8	Before RLAH	Unused Megabytes	4.316	214.820
9	After RLAH	Search	19.892	913.020
10	After RLAH	Social Media	20.675	1,011.047
11	After RLAH	News	11.765	707.445
12	After RLAH	Transportation	8.403	565.610
13	After RLAH	Music and Video	19.374	1,237.899
14	After RLAH	Communication	26.751	1,259.409
15	After RLAH	Review Platforms	6.371	520.637
16	After RLAH	Unused Megabytes	14.351	1,301.745

Table B.3: Demographic statistics for the online experiment dataset. The table exhibit data for all the 1789 users.

Variable	Category	Avg.
gender	Female	0.440
gender	Male	0.554
gender	I don't want to answer	0.003
gender	Other	0.003
age	Under 18	0.002
age	18 - 24	0.231
age	35 - 44	0.240
age	25 - 34	0.387
age	45 - 54	0.095
age	55 - 64	0.038
age	65 - 74	0.003
age	I don't want to answer	0.003
degree	Less than high school degree	0.034
degree	Bachelor's degree	0.291
degree	High school graduate	0.235
degree	Master's degree	0.249
degree	Professional degree	0.027
degree	Some college but no degree	0.126
degree	Doctoral degree	0.022
degree	I don't want to answer	0.016
occupation	Unemployed	0.088
occupation	Student	0.221
occupation	Managers	0.074
occupation	Professionals	0.217
occupation	Clerical Support Worker	0.056
occupation	Other	0.112
occupation	I don't want to answer	0.055
occupation	Craft and Related Trade Workers	0.030
occupation	Service and Sales Workers	0.079
occupation	Armed Forces Occupations	0.009
occupation	Elementary Occupations	0.021
occupation	Agricultural, Forestry and Fishery Workers	0.009
occupation	Plant and Machine Operators	0.016
occupation	Retired	0.012
occupation	None	0.001

B.2 Results

Table B.4: Estimation results of daily data consumption per user for the 1233 users that use both a positive amount of megabyte before and after. Column (1) and (2) estimate the global effect of being after te regulation while column (3) estimates equation (10).

	Dependent variable:		
	Data consumption (Mb)		
	(1)	(2)	(3)
After	111.008***	111.008***	
	(3.306)	(10.407)	
After × Communication			26.378***
			(1.262)
After × Search			17.626***
			(0.861)
After × Social Media			19.974***
			(0.987)
After × News			11.969***
			(0.733)
After × Music and Video			20.965***
			(1.313)
After × Transportation			7.925***
			(0.561)
After × Review Platforms			6.170***
			(0.481)
Constant	10.963***		
	(2.338)		
Individual FE	No	Yes	Yes
Cont. provider FE	–	–	Yes
Observations	2,466	2,466	17,252
R^2	0.343	0.371	0.257
Adjusted R^2	0.342	0.365	0.199
Residual Std. Error	80.667	79.286	23.358
Note:	*p<0.1; **p<0.05; ***p<0.01		
	Cluster robust standard errors in ()		
	Errors clustered by individual		

We modify equation (10) to measure how the adoption of content typed changes with the regulation in the context of our online experiment.

$$Adoption_{ict} = \sum Content_{ict}(\gamma_c + \delta_c After_t) + a_i + v_{ict}, \tag{20}$$

In the new specification, $Adoption_{ict}$ is a dummy variable that is equal to 1 when user i spend positive amount in content service c at time t. We report the results in table B.5. We use these results to compute the percentage increases of the first column of table 4 related to the online survey.

Table B.5: Estimation results of online service adoption on all 1856 users in the online experiment database. It estimates equation (20) with Adoption of the service (0 or 1) as a dependent variable.

	Dependent variable:
	Adoption
After × Communication	0.238***
	(0.013)
After × Search	0.244***
	(0.014)
After × Social Media	0.249***
	(0.014)
After × News	0.226***
	(0.014)
After × Music and Video	0.286***
	(0.014)
After × Transportation	0.159***
	(0.013)
After × Review Platforms	0.163***
	(0.012)
Individual FE	Yes
Cont. provider FE	Yes
Observations	28,624
R^2	0.278
Adjusted R^2	0.23
Residual Std. Error	0.439
Note:	*p<0.1; **p<0.05; ***p<0.01
	Cluster robust standard errors in ()
	Errors clustered by individual

C Appendix: Online survey Extract

Disclaimer

Thank you for contributing to our research project. We need your help to determine how people use their smartphones. Please read the following information carefully before deciding whether to participate in this research survey. Purpose of the research: Your information will be used in an academic study.

What you will do in this research:

You will answer a web survey. The survey contains questions about your use of mobile in different scenarios. The survey also asks demographic questions. You may exit the survey at any time.

Time required:

This survey should only take you about 5 minutes.

Risks:

The risk and discomfort associated with participation in this study is no greater than that experienced in everyday life. This means that you will not be taking any additional risks by choosing to participate in this study.

Benefits:

You will be entitled to a payment. At the end of the survey you will receive a personalized code. Your payment will be processed after you have entered your code on the Clickworker platform*. Information about the time and the method of payment will be reiterated at the end of the survey. In addition to the task completion fee, the knowledge that we may generate from your participation could be of value to society.*

Anonymity:

Your responses will be anonymous and stored in encrypted form on a secure server. Only members of the research team participating in this study will have access to your answers and will use it to inform their research.

Contact:

If you have any questions, concerns, or suggestions related to this study, the researchers can be reached at: < deleted for anonymity >. The research project is lead by < deleted for anonymity > and < deleted for anonymity > from < deleted for anonymity > and < deleted for anonymity > from < deleted for anonymity > .

Consent:

By selecting to continue, you indicate that you are at least 18 years old, and you agree to complete this survey voluntarily. You accept that the data you provide will be used for the purpose of academic research. You also accept that we may publish aggregate summaries of your answers in academic documents such as academic papers, thesis, and memoranda.

Q1 How much mobile data (per month) is included in your smartphone contract / prepaid option?

Please refer to your data allowance in your *home country*.

Please give your answer in megabytes. 1 gigabyte = 1000 megabytes. If you have an *unlimited* allowance, please write "99999".

____

Q2 How much do you pay for your smartphone contract / prepaid option (per month)?

Please give your answer in EUR.

____

Scenario 1)

You are traveling abroad for vacation or work. You have your smartphone, but no other mobile devices (laptop, tablet, etc.).

You have access to the internet on your phone, and your data allowance is **140 megabytes** that you can use for free.

Q3 Are you going to use the internet on your phone? Remember - you have 140 megabytes for free.

◯ Yes

◯ No

Q4 (If selected Yes at Q3) How many megabytes do you use for the following purposes?

In case you do not want to use your entire 140 megabytes, please select "unused megabytes" for the remainder.
Example: You only want to occasionally use Whatsapp. Then you choose 2 MB for "Communication" and 138 MB for "Unused Megabytes".

_______ **Communication** (Whatsapp, iMessage...) 1MB: 250 messages or 2 pictures
_______ **Getting information** (Google Search, Maps, Blogs...) 1MB: 10 searches
_______ **Social media** (posting, reading) such as Instagram, Facebook... 10MB: 1 minute scrolling/posting
_______ **Reading the news** (news from home country, international news) 10MB: 5 articles
_______ **Music/video** (YouTube, Tiktok, Spotify...) 10MB: 2 songs or a 1 minute video
_______ **Transportation** (Uber, Bolt, public transport...) 1MB: 3 uses
_______ **Review platforms** (TripAdvisor, Yelp, Zomato...) 1MB: 2 reviews
_______ **Unused Megabytes**

<u>Scenario 2)</u>

You are traveling abroad for vacation or work. You have your smartphone, but no other mobile devices (laptop, tablet, etc.).

You have access to the internet on your phone, and your data allowance is **exactly the same as in your home country**.
That is, your data allowance is <Entry value fo Q1> MB.

Q5 Are you going to use the internet on your phone? Remember - you have <Entry value fo Q1>

○ Yes

○ No

Q6 (If selected Yes at Q5)
Your data allowance *while traveling abroad* is <Entry value fo Q1> MB.
How do you use your data allowance for the following purposes?
Please give your answer in percent of your data allowance.

In case you do not want to use your entire data allowance, please select "unused megabytes" for the remainder.

________ **Communication** (Whatsapp, iMessage...) 1MB: 250 messages or 2 pictures
________ **Getting information** (Google Search, Maps, Blogs...) 1MB: 10 searches
________ **Social media** (posting, reading) such as Instagram, Facebook... 10MB: 1 minute scrolling/posting
________ **Reading the news** (news from home country, international news) 10MB: 5 articles read
________ **Music/video** (YouTube, Tiktok, Spotify...) 10MB: 2 songs or a 1 minute video
________ **Transportation** (Uber, Bolt, public transport...) 1MB: 3 uses
________ **Review platforms** (TripAdvisor, Yelp, Zomato...) 1MB: 2 reviews
________ **Unused Megabytes**

Q7 Take a moment to think about the following question:

Assume you did not have a data plan. How much money would you pay to be able to use <Entry value fo Q1> MB of data while you are traveling abroad?

	0 40 80 120 160 200
EUR	

Q8 (If selected 200 in Q7) You selected 200 EUR. Which of the following statements describes you best?

- ◯ I would pay exactly 200 EUR
- ◯ I would pay more than 200 EUR

Q9 How many days did you spend outside of your home country in 2019? Where did you travel to?

The countries of the European Union (EU) are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.

	Within EU	Outside EU
Number of days spent outside your home country in 2019		

Q10 What do you do when traveling outside of your home country if the internet on your phone is expensive? (Check all that apply)

- ☐ I will not use the mobile internet on my phone.
- ☐ I will use Wifi/WLAN whenever I can.
- ☐ I will buy a local (prepaid) SIM card.
- ☐ I don't think it's too expensive to use the mobile internet on my phone.

Q11 What is your gender?

- ○ Male
- ○ Female
- ○ Other ____
- ○ I don't want to answer

Q12 What is your age?

- ○ Under 18
- ○ 18 - 24
- ○ 25 - 34
- ○ 35 - 44
- ○ 45 - 54
- ○ 55 - 64
- ○ 65 - 74
- ○ 75 - 84
- ○ 85 or older

○ I don't want to answer

Q13 In which country do you live?

(select Non-EU country if you do not live in one of the member countries of the European Union)

▼ Austria ... Sweden

Q14 What is the highest level of school you have completed or the highest degree you have received?

○ Less than high school degree

○ High school graduate (high school diploma or equivalent)

○ Some college but no degree

○ Bachelor's degree

○ Master's degree

○ Doctoral degree

○ Professional degree

○ I don't want to answer

Q15 Please indicate your occupation:

○ Armed Forces Occupations

○ Managers

○ Professionals (e.g. Teaching, Healthcare, Science & Engineering, Legal, Business Administration, ICT)

○ Clerical Support Worker (e.g. Keyboard Clerks, Secretaries, Customer Service Clerks)

○ Service and Sales Workers (e.g. Personal Services, Sales Workers, Personal Care, Protective Services)

○ Agricultural, Forestry and Fishery Workers

○ Plant and Machine Operators (e.g. Assemblers, Drivers and Mobile Plant Operators, Stationary Plant and Machine Operators)

○ Craft and Related Trade Workers (e.g. Metal, Machinery, Handicraft, Printing, Electrical and Electronics, Food Processing, Woodworking)

○ Elementary Occupations (e.g. Cleaners and Helpers, Mining, Construction, Manufacturing and Transport, Food Preparation)

○ Student

○ Retired

○ Unemployed

○ I don't want to answer

○ Other ____