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THE WELFARE EFFECTS OF MOBILE INTERNET ACCESS: EVIDENCE FROM ROAM-LIKE-AT-HOME*

Martin Quinn, Miguel Godinho de Matos and Christian Peukert

We evaluate the welfare effects of the Roam-like-at-home regulation, which has drastically reduced the price of accessing the mobile Internet for residents of the European Economic Area when travelling abroad in the European Economic Area. Our estimates using individual-level consumption data suggest that consumer surplus increased by around €2.44 per user and travel day. We show that around 40% of the consumer surplus gains originated from a reduction in deadweight loss, that is, new users accessing the mobile Internet. We also highlight that the regulation had a heterogeneous impact on consumers, varying with usage intensity and the reason for travel (business versus leisure).

Access to the Internet is linked to productivity, innovation, employment and economic growth (Czernich *et al.*, 2011; Cardona *et al.*, 2013; Hjort and Poulsen, 2019). At the micro-level, digitisation leads to more efficient entry and greater product variety, and hence substantial welfare gains (Brynjolfsson *et al.*, 2003; Aguiar and Waldfogel, 2018). However, the surplus gains are not distributed equally because of substantial heterogeneity in Internet access both within and across countries (Schleife, 2010; Viard and Economides, 2015; Silva *et al.*, 2018).

In the last 20 years, governments worldwide undertook a range of policy efforts to increase Internet penetration, most prominently by subsidising and regulating the telecommunication industry (Fabrizi and Wertlen, 2008; Nardotto *et al.*, 2015; Briglauer *et al.*, 2019). With Internet usage and applications increasingly going mobile (Einav *et al.*, 2014), one of the most important aspects of telecom regulation concerns roaming price caps (Spruytte *et al.*, 2017). Regulators set

* Corresponding author: Christian Peukert, Faculty of Business and Economics, University of Lausanne, Quartier Chamberonne, 1015 Lausanne, Switzerland. Email: christian.peukert@unil.ch

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The authors were granted an exemption to publish their data because access to the data is restricted. However, the authors provided a simulated or synthetic dataset that allowed the Journal to run their codes. The synthetic/simulated data and codes are available on the Journal repository. They were checked for their ability to generate all tables and figures in the paper, however, the synthetic/simulated data are not designed to reproduce the same results. The authors were granted an exemption to publish their data because access to the data is restricted. However, the authors provided the Journal with temporary access to the data, which allowed the Journal to run their codes. The codes are available on the Journal repository. The data and codes were checked for their ability to reproduce the results presented in the paper. The replication package for this paper is available at the following address: https://doi.org/10.5281/zenodo.10185000.

Specific queries about the data and the code in the replication package should be directed to miguel.godinhomatos@ucp.pt.

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rules for the price network operators can charge to allow clients of other operators access to their network (Zucchini *et al.*, 2013), and rules on how network operators can pass on such charges to end consumers. Surcharges for international roaming have historically led to high mobile Internet prices. In a 2014 Eurobarometer survey, 52% of respondents who travel to other countries in the European Union (EU) said that they never use the Internet on their phone when travelling.[1]

European regulators took a big step to lower prices for international roaming with the Roam-like-at-home (RLAH) regulation of June 2017. Network operators were effectively required to end surcharges to consumers travelling in the European Economic Area (EEA). Theory suggests that price regulation in telecommunication markets can have intricate welfare effects (Spruytte *et al.*, 2017), not only by transferring surplus from firms to consumers, but also by redistributing surplus across consumer types (e.g., Maillé and Tuffin, 2017; Chillemi *et al.*, 2020), and by increasing the surplus of content providers (e.g., Greenstein *et al.*, 2016). In this paper, we evaluate the consumer surplus effects of RLAH empirically using individual-level consumption data.

We have access to an anonymous dataset from a network operator in an EU country, where we observe the aggregate daily mobile data usage of all clients who used their mobile phones at least once while travelling abroad between September 2016 and December 2017. We use this dataset to compare mobile data usage when travelling within the EEA to mobile data usage when travelling outside the EEA using a difference-in-differences approach. We show that after the end of roaming charges, mobile data usage while travelling in the EEA increased by around 120% relative to travel outside the EEA. Furthermore, our analysis highlights significant heterogeneity. The quantity change after RLAH is larger for users with lower pre-regulation data consumption, and smaller for trips that do not include weekends and holidays (business trips). We complement our main results with an online experiment to provide a perspective on how consumers allocate mobile data across different types of content while travelling. We show that music and video content, transportation services and review platforms are the content categories for which usage grows the most as the price for mobile Internet decreases. At the same time, in absolute levels, communication services, search and social media account for more than half of the additional data use.

With quantity estimates at two different price points, one of which is shifted exogenously due to the regulation, we can characterise a demand function and compute the consumer surplus change. Our results imply that the RLAH generated an average consumer surplus gain of around €2.44 per user and travel day. We show that around 40% of the consumer surplus gains originated from a reduction in deadweight loss, that is, new users accessing the mobile Internet. Distinguishing between different types of users, our estimate of surplus for users on business trips is €1.99 per user and travel day. Overall, we estimate that the total consumer surplus gains for all travellers in the EU amount to around €2 billion in 2017.

Finally, we perform a simplified estimation of the average change in network operator surplus, which provides suggestive evidence that the benefits to consumers outweigh the losses of network operators, suggesting that RLAH was overall welfare improving. Our detailed micro-level evidence complements and expands the literature on the price and welfare effects of mobile Internet and RLAH (Canzian *et al.*, 2021; Munoz-Acevedo and Grzybowski, 2023). The paper closest to ours is Canzian *et al.* (2021), who used aggregated data to conclude that consumer surplus gains of RLAH out-weighted the profit loss of network operators and reported aggregate

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

consumer surplus estimates remarkably similar to ours. Beyond disaggregating and exploring the heterogeneous changes in consumer surplus, we shed light on how consumers may have used the additional mobile Internet data while roaming. This lets us hint at content provider surplus as the third dimension of welfare effects in evaluating RLAH, which no other study has addressed. Finally and more generally, our paper adds to the literature on telecommunication regulation (Chillemi *et al.*, 2020; Genakos and Valletti, 2011), including the distribution of rents between Internet service providers and content providers (Easley *et al.*, 2018), and contributes to the related literature on the welfare effects of digitisation and the Internet (Brynjolfsson *et al.*, 2003; Ghose and Han, 2011; Ghose *et al.*, 2013; Aguiar and Waldfogel, 2018; Brynjolfsson *et al.*, 2019; Xu *et al.*, 2019).

1. 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, global mobile broadband penetration increased from 4% in 2007 to 70% in 2018. More than 90% of the world's population was 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 privatised 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 the 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 fees) to consumers for using off-network telecommunication services in the same country and when crossing national borders (retail roaming fee). National roaming charges typically create varying price plans for on-network and off-network voice and text services (Zucchini *et al.*, 2013). However, international roaming charges go a step further by introducing distinct pricing schemes for both domestic and international data services. Historically, retail roaming fees have been above cost, despite the efforts of wholesale regulation (Infante and Vallejo, 2012).

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 in €c per megabyte (MB). The wholesale price cap for data services was reduced from €c100/MB in July 2009 to €c5/MB before implementing RLAH rules. Finally, on June 15, 2017, RLAH rules stipulated the end of retail roaming charges for EEA residents that travel to countries within the EEA (see highlighted area in Figure 1). Prices did not go down to zero for everyone. Wholesale prices were reduced to €c0.77/MB for 2017, while retail prices for in-plan roaming were capped to the minimum of half the wholesale price (hence €c0.385/MB for 2017) and the wholesale price for out-of-plan roaming within the EEA. In other words, a consumer with a mobile data plan with a domestic price exceeding €c0.385/MB will have access to her full data allowance when roaming in the EEA. However, if her domestic data plan is priced

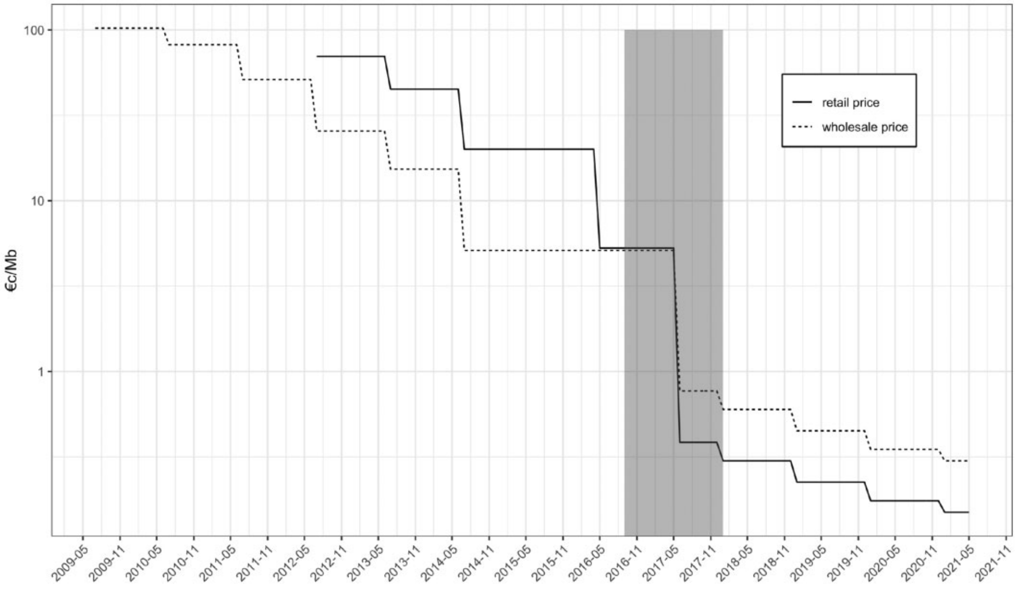

Fig. 1. *Retail and Wholesale Price Caps for Roaming in the EEA.*
Note: The vertical axis, denoted on a logarithmic scale, indicates price levels in €c per MB. The solid line shows retail price caps as specified by European regulation, whereas the dashed line indicates wholesale price caps. We focus on the highlighted period six months before and after the introduction of RLAH.

below €c0.385/MB, her data allowance will be reduced to comply with the retail price cap. Notably, wholesale and retail price caps have decreased consistently in 2018, 2019 and 2021.

In what follows, we evaluate the impact of RLAH on consumer behaviour, specifically in terms of quantity and content choices, and then we explore the consumer surplus implications.

2. Data and Estimation Strategy

2.1. *Data and Descriptives*

We have access to an anonymised individual-level panel dataset from MOBILE, a large network operator in a European country (MOBILE, 2017). The company is comparable to many other European network operators. They entered the mobile telecommunications business about 20 years before RLAH. The market share of MOBILE was over a third in 2017, and it competed with two other local operators.

We use Eurostat data (Eurostat, 2017) to compare the country characteristics of the market in which MOBILE is active relative to other European countries subject to the RLAH regulation. Notably, the country of MOBILE has higher domestic tourism and lower outbound tourism relative to other EU countries.[2]

[2] See the Online Appendix. To preserve the anonymity required by our non-disclosure agreement with MOBILE, we compute each variable's mean across all countries, including the country in which MOBILE operates. We then calculate the z-score for each variable associated with the focal country in the sample.

Table 1. *Average Daily Mobile Data Consumption.*

	Mean (SD)	
	Before RLAH	After RLAH
Home	83.9 (135.2)	100.2 (151.3)
Abroad within RLAH countries	31.2 (75.4)	86.5 (164.5)
Abroad outside RLAH countries	7.0 (24.9)	6.9 (27.2)

Note: The average daily consumption of mobile data is measured for three scenarios: domestic use, use in EEA countries where RLAH rules apply and use in non-EEA countries where RLAH rules do not apply.

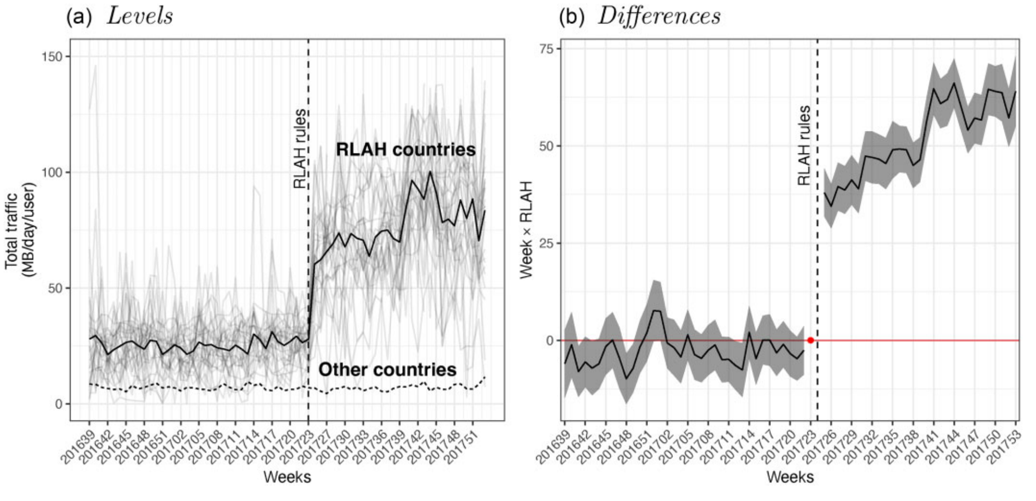

Fig. 2. *Average Daily Mobile Data Consumption while Travelling Abroad.*
Note: Panel (a) shows a user's average daily mobile data consumption in a destination country. The solid black line depicts the average across all destination countries affected by RLAH, whereas the dashed line depicts the average across all destinations unaffected by RLAH. The solid grey lines indicate the average consumption for each destination country affected by RLAH. Panel (b) depicts the average daily mobile data consumption difference between RLAH and other countries alongside a 95% confidence interval.

Our data include information from all clients who used their mobile phones for voice, text or data services at least once while travelling abroad between September 2016 and December 2017.[3] These clients represent 5% of all domestic clients, which matches the official Eurobarometer statistics (European Commission, 2017). For the clients in our sample, we observe the average daily MBs downloaded and uploaded per week. We also observe the country where the mobile Internet traffic originated from.

Table 1 shows that users in our dataset consume on average 83.9 MB of mobile data (sum of uploads and downloads) per day at home, which increases to 100.2 MB in the period after RLAH rules were introduced. When travelling inside the EEA, users go from an average of 31.2 MB before RLAH to 86.5 MB after RLAH. Daily mobile data consumption in countries outside the EEA averages 7.0 and 6.9 MB, respectively. Across the board, SDs are relatively large, suggesting substantial user heterogeneity.

Figure 2(a) depicts the dynamics in mobile data consumption during the period of analysis. We separate the data consumption abroad in EEA countries, where RLAH applies, from data

[3] In the Online Appendix, we show that our results are robust to different approaches of sample selection.

consumption in non-EEA countries, where RLAH does not apply. Travellers' mobile data consumption was stable before RLAH, and consumption trends were similar across both groups. We see a steep discontinuous increase in mobile data consumption for travel in countries affected by RLAH just after the introduction of RLAH. The plot also highlights substantial variation within RLAH countries.

2.2. *Difference-in-Differences Model*

We use a difference-in-differences approach to quantify how mobile Internet consumption changed due to RLAH. We compare individual i's demand for mobile data before and after RLAH when travelling in countries affected by RLAH (treatment group of countries in the EEA) and when travelling outside in countries unaffected by RLAH (control group of countries not in the EEA).

We use the regression specification

$$MobileData_{ijt} = \delta After_t \times RLAH_{jt} + \Psi_{jt} + \nu_{ijt},$$

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 and week t. Variable $RLAH_{jt}$ indicates whether an individual consumes mobile data while abroad in a country where RLAH rules apply. Since the regulation affects all individuals to the same extent, this variable only varies at the time and the country level following changes in the regulation. Here $After_t$ is a dummy variable equal to one throughout the period for which the RLAH policy is in effect; Ψ_{ijt} is a vector of user, week and country fixed effects, as well as country- and period-specific trends. Below we also discuss the results of models that include interactions of fixed effects. Because we include country-level regressors, we cluster SEs at the country level.

The identifying assumption of the difference-in-differences model requires that the treatment and control groups follow the same trend before RLAH. In Figure 2(b), we plot the coefficients of the weekly difference in mobile data consumption between RLAH countries and non-RLAH countries from a regression model that controls for user and country fixed effects. Consistent with parallel trends, there were no statistically significant differences in mobile data consumption between affected and unaffected countries before RLAH came into effect. After RLAH, however, there is a substantial and statistically significant difference.

3. Estimates of Changes in Data Consumption

3.1. *Baseline Results*

We present the baseline results for the econometric estimation of quantity changes in Table 2. In column (1), we report results from a model without fixed effects. In this specification, we can identify coefficients for *After* (because there are no week fixed effects) and *RLAH* (because there are no country fixed effects). The coefficient of *After* is close to zero and not statistically significant, suggesting that the control group was not affected by RLAH. The coefficient of interest, *After* × *RLAH*, remains almost unchanged when we add user, week and country fixed effects in columns (2) and (3). The point estimate in column (3) suggests that RLAH increased daily mobile Internet usage by 54.1 MB ($CI_{95\%}$[52.29, 55.96]). In relative terms, this is a 170% increase from the baseline of 31.2 MB when travelling in EEA countries before RLAH.

Table 2. *Changes in Data Consumption.*

	Dependent variable:			
	Total (MB)			
	(1)	(2)	(3)	(4)
After	−0.140			
	(0.393)			
RLAH	24.175***	37.890***		
	(2.218)	(2.618)		
After × RLAH	55.484***	54.339***	54.131***	39.887***
	(1.340)	(1.332)	(1.316)	(2.502)
Intercept	7.030***			
	(0.719)			
User FEs	No	Yes	Yes	Yes
Week FEs	No	Yes	Yes	Yes
Country FEs	No	No	Yes	Yes
Country trends	No	No	No	Yes
Contributing obs.	784,527	784,527	784,527	784,527
Total obs.	784,527	784,527	784,527	784,527

Note: *** $p < 0.001$. SEs in parentheses clustered at the destination country level.

As indicated in Figure 2(a), there are heterogeneous trends across RLAH countries with different slopes pre- and post-RLAH. To consider this econometrically, we include period- and country-specific time trends in column (4) of Table 2. It is important to note that *After* × *RLAH* has a slightly different interpretation in this model. Rather than the average effect over the entire observed post-period, *After* × *RLAH* in this specification captures the immediate increase right after RLAH went into effect. We find that RLAH stimulated an immediate increase of 39.9 MB ($CI_{95\%}$[34.93, 44.83]) per user and travelled day (an increase of 120% relative to the average in EEA countries before RLAH).[4]

3.2. *Models with Fixed-Effect Interactions*

In Table 3, we report the results of a range of additional model specifications designed to capture country- and/or time-specific variation within users. In columns (1)–(3), we consider user-country fixed effects, which capture unobserved heterogeneity in the case of repeated travel to the same country, and/or user-week fixed effects, which account for unobserved heterogeneity in cases where users travel to several countries in the same week. In columns (4)–(6), we additionally add period- and country-specific time trends.

The results show that there is substantial heterogeneity in the consumer response to RLAH, with point estimates that range from 13.4 to 49.4. Heterogeneity seems to come from differences in mobile data usage across country destinations and the intensity of travel. Given that our dataset is unbalanced among all dimensions of the panel, because we do not observe all users in all weeks travelling to all countries, the fixed-effect interactions essentially act like selecting users that travel often. This is illustrated in the number of contributing observations (i.e., cases where we observe at least two observations for each of the fixed-effect interactions) reported for each column in Table 3. The most stringent models in columns (3) and (6) only use variation from

[4] Using the model in column (4), we can estimate a 'long-run' effect by calculating $\hat{\delta}_{LR} = After \times RLAH + \sum_j (After \times C_j \times t_t)$ at the end of our observation period, $t = T$. The 'long run' in our sample corresponds to around six months after RLAH. Overall, the results suggest that the effect is an increase of 69.46 MB (= 39.88+29×1.02) by the end of 2017.

Table 3. *Results with Fixed-Effect Interactions.*

	Dependent variable:					
	Total (MB)					
	(1)	(2)	(3)	(4)	(5)	(6)
After × RLAH	49.395*** (2.039)	39.546*** (3.919)	20.046*** (3.891)	36.086*** (2876)	37.992*** (7.258)	13.384 (23.952)
Country × user FEs	Yes	No	Yes	Yes	No	Yes
Week × user FEs	No	Yes	Yes	No	Yes	Yes
User FEs	Yes	Yes	Yes	Yes	Yes	Yes
Week FEs	Yes	Yes	Yes	Yes	Yes	Yes
Country FEs	Yes	Yes	Yes	Yes	Yes	Yes
Country trends	No	No	No	Yes	Yes	Yes
Contributing obs.	677,593	111,772	93,019	677,593	111,772	93,019
Total obs.	784,527	784,527	784,527	784,527	784,527	784,527

Note: *** $p < 0.001$. SEs in parentheses clustered at the destination country level.

users that repeatedly travel to the same country and/or users that travel to several countries in the same week. These users account only for 11.9% (= 93,019/784,527) of the observations used in the baseline results of Table 2. For the presentation of *baseline* results, we prefer to average over multidimensional heterogeneity across users. Hence, column (4) of Table 2 is our preferred specification to carry over to a calculation of the consumer surplus effect for the *average* user.

We do, however, take the results in Table 3 as motivation for a thorough heterogeneity analysis in the next section. Compared to adding fixed-effect interactions that effectively select some users and exclude others in the estimation of the RLAH effect, in the next section, we compare the RLAH effect *across* different groups of users.

3.3. *Heterogeneity Analysis*

To provide additional insight into how RLAH affected the demand for mobile Internet, we estimate quantity effects for different user types and travel types, and study how demand varies with destination country characteristics. Finally, we report results concerning heterogeneity by content type that we derive from an online experiment.

3.3.1. *Heterogeneity by user type*

First, we group users into deciles according to their pre-RLAH mobile Internet consumption intensity when travelling abroad within the EEA. We run regressions separately per decile using the same specification as in column (4) of Table 2, where we control for user, week and country fixed effects and country- and period-specific trends.

We report the resulting effect sizes from this estimation in Figure 3 and Online Appendix Table A.1. Here D1 captures users with the lowest pre-RLAH consumption intensity and D10 captures users with the highest pre-RLAH consumption intensity.

The results suggest that the regulation had heterogeneous effects across users. We find that the relative increase in data usage from the regulation was higher for the lower deciles than for upper deciles of pre-RLAH roaming intensity. In the first decile, 99% of post-RLAH consumption is new, while for the tenth decile, only 13% of the mobile data consumption after June 15, 2017 would not have happened in the absence of RLAH.

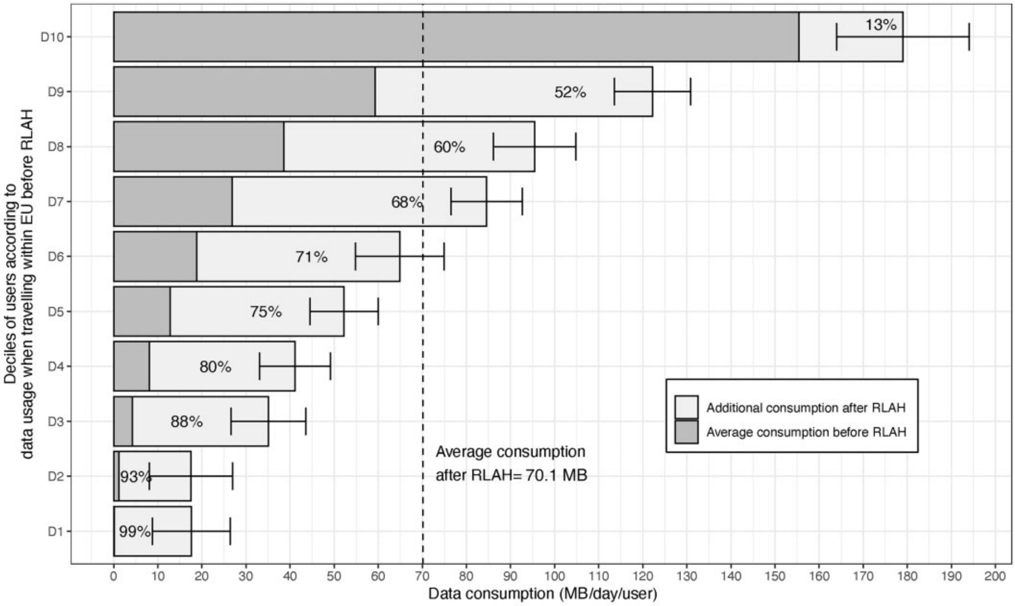

Fig. 3. *Quantity Changes by Deciles of Usage Intensity Abroad.*
Note: The reported effect sizes come from estimates of $After_t \times RLAH_{jt}$ estimated separately on sub-samples of deciles of average daily data consumption while roaming in the EEA before RLAH. We compute corresponding 95% confidence intervals for the additional effects. The corresponding regression results are reported in Online Appendix Table A.1.

Table 4. *Impact of Roaming Like at Home on Mobile Data Consumption Heterogeneity.*

	Dependent variable:			
	Total (MB)			
	(1)	(2)	(3)	(4)
After × RLAH	39.887***	40.031***	36.787***	38.312***
	(2.502)	(2.493)	(3.931)	(4.165)
After × RLAH × Business		−12.423***		
		(1.999)		
After × RLAH × Arrivals			3.653	
			(4.808)	
After × RLAH × Broadband				2.747
				(4.345)
Week FEs	Yes	Yes	Yes	Yes
User FEs	Yes	Yes	Yes	Yes
Country FEs	Yes	Yes	Yes	Yes
Country trends	Yes	Yes	Yes	Yes
Observations	784,527	784,527	784,527	784,527

Note: *** $p < 0.001$. SEs in parentheses clustered at the destination country level.

3.3.2. *Heterogeneity by travel type and country characteristics*

Next, we aim to distinguish the effect of RLAH for different types of travel. Results are reported in Table 4. In column (1) we repeat the results from our preferred baseline specification in column (4) of Table 2 for reference. In column (2), we test whether the effect of RLAH is different for different trip structures. The variable *Business* indicates trips that do not include weekends and holidays, which account for 27% of the observations in our dataset.[5] The results indicate that during trips that do not include weekends and holidays, the effect of RLAH is about 30% smaller. In absolute terms, the quantity change is 12.4 MB smaller.

We also explore correlations with characteristics of the destination country. We first measure tourist appeal using data on the number of arrivals from the 2017 World Development Index Database.[6] The variable *Arrivals* indicates countries with a higher number of arrivals than the 2017 EU average of 32.7 million. The point estimate in column (3) suggests that the effect of RLAH might be more pronounced in countries with a higher aggregate travel intensity. However, the estimate is not statistically significant. We then investigate differences with respect to the destination country's telecommunication infrastructure, using data on the average coverage of broadband networks (LTE) per operator and country.[7] The variable *Broadband* indicates countries with a higher than the average broadband coverage in the EU (91.8%). The point estimate in column (4) suggests that the effect of RLAH may be more pronounced in countries with better mobile broadband coverage, but the additional effect is not statistically significant. The results with respect to country characteristics are robust to alternative specifications, where we impose a linear relationship or decompose the variation in country characteristics into dummies indicating deciles.

3.3.3. *Heterogeneity by content type*

In the observational dataset we cannot observe the type of content that users are consuming. To provide suggestive evidence of how consumers in general distributed the additional data they consumed after RLAH, we run an online experiment with more than 1,000 European consumers through the crowd-sourcing platform Clickworker (Survey, 2020).[8]

We asked participants about their monthly data allowance and presented them with two choice scenarios. In each scenario, we tell participants to imagine travelling abroad without access to Wifi or a desktop computer. We placed our first scenario in the context before RLAH and gave participants a data allowance of 140 MB.[9] Participants were asked to allocate their data allowance across seven content types and a residual category: communication, search, social media, news, music/video, review platforms and transportation. For each category, we gave 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 placed our second scenario after RLAH and told participants that there

[5] Because our dataset is anonymised, we cannot directly differentiate between private and corporate clients of MOBILE.

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

[7] See http://www.czechcompete.cz/files/uploads/News/7502/BroadbandCoverageinEurope2017_Final_Reportpdf.pdf.

[8] After cleaning, the final sample we use for analysis includes 1,238 users. 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 sub-sample of consumers in Eurobarometer that state that they have travelled at least once in the EU in the previous 12 months. Compared to this sample, our participants are more likely to be male (56% versus 50%) and less likely to have tertiary education (54% versus 87%). Still, our participants have a similar age profile (86% versus 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%).

[9] We use 140 MB based on a pre-study where we asked participants ($N = 400$) about their data allowance. This number appears reasonable when compared to actual usage data. In the dataset from MOBILE, the average trip length for travel within the EEA before RLAH is 2.2 days (SD of 1.7), and the average data consumption is 31.2 MB per day, suggesting that most users stayed within their allowance.

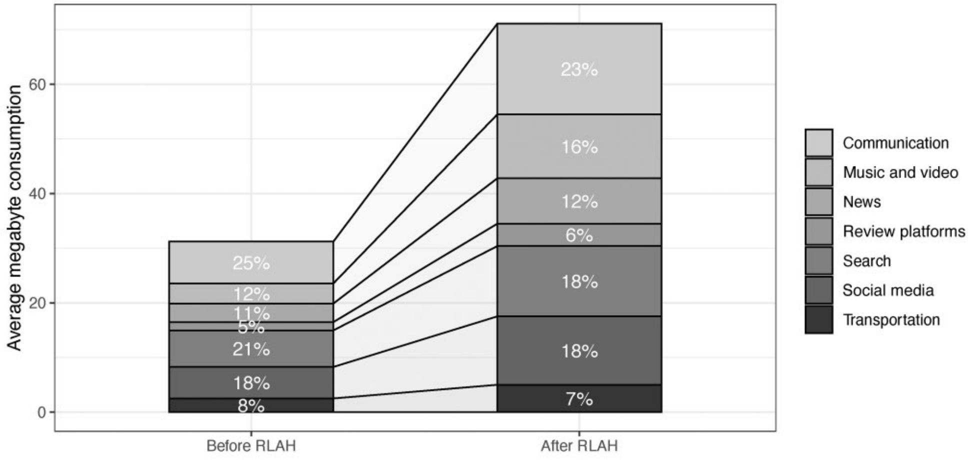

Fig. 4. *Average Daily Consumption by Content Types.*
Note: Percentages reflect estimates of γ_c and $\gamma_c + \delta_c$ as defined in (1). We find a significant decrease in the share of mobile data consumption from communication ($p < 0.1$), transportation content ($p < 0.01$) and search ($p < 0.01$). However, the share of review platforms increases significantly ($p < 0.01$), as does the share of music and video ($p < 0.01$). Average mobile data consumption on the y axis is estimated by multiplying the category shares with the total quantity estimates from our preferred specification in column (4) of Table 2.

was no longer a surcharge on top of the domestic price for using the mobile Internet while travelling. We also asked them to allocate their allowance across content. In both scenarios, participants could allocate unused MBs to a residual category.[10]

We determine consumption of each content type according to

$$ShareMobileData_{ict} = \sum Content_{ict}(\gamma_c + \delta_c After_t) + \nu_{ict}, \tag{1}$$

where $ShareMobileData_{ict}$ captures respondent i's share of data consumption going to content category c in scenario t. The γ_c parameters capture the average share of content category c in the scenario before RLAH, while the δ_c coefficients reflect the difference between scenarios. Here $After_t$ is a dummy variable equal to 1 in the scenario that captures the RLAH rules. We cluster SEs at the user level.

Figure 4 plots average total consumption and shares by content type for both roaming scenarios. More precisely, we use (1) to estimate the average weight of each content type in the total data consumption before and after the regulation. We report the weights in Figure 4 and use them to decompose the additional daily data consumption we estimated using the observational data from MOBILE.

We find no statistically significant change in the share of mobile data consumption going to news and social media. However, the share of mobile data that goes to communication, transportation content and search reduced, and the shares of music and video, as well as review platforms, increased. Both changes are statistically significant.

[10] The context users were presented with was: 'You are travelling abroad for vacation or work.' Hence, our experiment does not suggest travelling to a specific country and does not point to a specific activity. In that case, a user's MB allocation translates to an overall average effect of an increase in MB allowance. However, it cannot distinguish between work/leisure activities or country-specific treatment effects.

In total consumption levels, we find that communication is the content category with the highest increase. We can only speculate about the mechanism, but it seems reasonable that users expect to share more data-heavy content, such as photos and videos, through messaging applications while travelling. The smallest increase is in the usage of review platforms, perhaps because there are decreasing returns in this type of information when travelling.

3.4. *Robustness*

We provide a range of robustness checks to counter potential sources of estimation bias and alternative explanations.

First, our analyses focus on clients of MOBILE who travelled at least once before and at least once after RLAH. This choice allows us to compute pre-policy usage statistics for all clients in the sample. At the same time, it removes clients from the sample who only travelled before or those who only travelled after RLAH. We relax this restriction in the Online Appendix and show that our results do not depend on our particular sampling strategy.

Second, demand for mobile Internet while travelling may be seasonal, but we do not have data for the summer of 2016 as the pre-policy period. To check the impact of 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. We provide the results of this analysis in Online Appendix Table C.2. The estimates are consistent, but between 7% and 9% larger than our baseline results.

Third, consumers may have primarily used other means to access the Internet to circumvent high roaming charges when travelling before RLAH. We cannot rule out this possibility entirely, but we find some evidence suggesting that such substitution is likely marginal. An important substitution scenario is a switch from public Wifi networks to accessing mobile data networks through roaming. To test this hypothesis, we obtained data from the number of connections to the public hotspots in Milano (Wifi Milano, 2017), one of Europe's most popular tourist destinations. To access Milano's Wifi hotspots, users must register with their mobile phone number, verified via a text message. We observe the country of origin based on the phone number, which allows us to separate EEA visitors from non-EEA visitors. Suppose that EU tourists substituted between Wifi usage and mobile data after the RLAH rules. In that case, Milano's hotspots should have fewer users from EEA countries relative to non-EEA countries after RLAH. However, Online Appendix Figure C.1 shows that there is no decrease in usage by EU users. Furthermore, consumers may substitute cellular roaming on their smartphones with Internet access via Wifi networks on their laptop devices. Data about content demand from a variety of German-speaking websites obtained through IVW (The German Audit Bureau of Circulation, IVW (2017)) allows us to distinguish between Internet traffic originating from mobile devices (smartphones and tablets) and computer devices (laptops and desktop computers). This dataset includes monthly visits and page impressions of more than 1,100 websites, including a large set of news outlets, magazines, but also other platforms. For example, we can observe visits to *Bild*, Germany's most popular newspaper, as well as local news outlets such as *Allgäuer Zeitung*, but also visits to Doodle.com. In total the dataset covers about four billion visits and 30 billion pageviews per month, representing a substantial share of the German-speaking Internet. Online Appendix Figure C.4 shows no change in desktop usage when RLAH comes into effect, suggesting the absence of important substitution patterns between mobile and desktop Internet usage. Finally, one might worry that consumers used cheap local prepaid SIM cards to access the mobile Internet while travelling before RLAH. Data from the International Telecommunication Union (ITU, 2020) show a consistent downward trend in the number of prepaid subscriptions in the EEA countries since 2011 and no accentuated drop after RLAH (see Online Appendix Figure C.2). Additionally, Online Appendix Figure C.3 shows that the average domestic mobile broadband traffic in 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 would expect to see a slower growth of domestic traffic in EEA than in non-EEA countries.

4. Welfare Effects

4.1. *Simple Model of Consumer Surplus*

We follow Hausman (1981), Hausman and Leonard (2002) and Brynjolfsson *et al.* (2003) to derive a simple model of consumer surplus change. Consumers benefit 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 price 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 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

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

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

We assume that demand follows a log-linear form:

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

with A a shift parameter, y denoting 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 the mobile Internet when roaming within a certain travel budget. Our demand specification captures that consumers purchase a data allowance from the network operator and use it for content. That is, consumers are sensitive to the total price per MB of data, that is, $p_m + p_c$.

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

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

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 that $\sigma = 0$, which allows us to arrive at a

Marshallian expression of consumer surplus change:[11]

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

We also assume that prices of online content do not change over time, $p_{c0} = p_{c1} = p_c$. This assumption appears reasonable because a large part of online content, such as search, is free and it is unlikely that content providers start to price discriminate against travellers only after RLAH. We can then write

$$CV = \frac{p_{m0}q_0 - p_{m1}q_1}{1+\epsilon} + p_c\frac{q_0 - q_1}{1+\epsilon}, \tag{2}$$

and further approximate ϵ as the midpoint arc elasticity of demand (Allen and Lerner, 1934), such that

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

While the approximation of ϵ as the arc elasticity can lead to overestimating the consumer surplus gains, the bias is small in the presence of large price differences, as is the case with RLAH. Now we can simplify (2) to

$$CV = (p_{m0} - p_{m1}) \times \frac{q_0 + q_1}{2}, \tag{3}$$

and estimate the consumer surplus change of RLAH by empirically calibrating the parameters p_{m0}, p_{m1}, q_0 and q_1.

Unfortunately, our observational dataset from MOBILE does not include price information. However, we can approximate average values of p_{m0} and p_{m1}. As a first step, we use the fact that European regulation defines a binding constraint on the retail price (as described in Section 1). Before RLAH, the maximum price per MB that operators could charge was a surcharge of €c5 on the domestic price. After RLAH, the surcharge was limited to €c0.385. In practice, if the domestic price 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 the domestic price is higher than the regulated roaming price, consumers will be able to use the entire domestic data allowance while roaming. Hence, the price per MB p_{mt} paid by users in period t can be defined as the maximum between the domestic price p_h and the regulated price. Hence, $p_{m0} = \max(0.05 + p_h, p_h) = 0.05 + p_h$ and $p_{m1} = \max(0.00385, p_h)$.

With data published by the European Commission, we determined that the average domestic price is in the range from €c0.15 to €c0.38 per MB.[12] We choose the lower bound to arrive at conservative estimates of consumer surplus changes.

We now turn to quantity estimates. Our estimate of q_0 is the average mobile data consumption while travelling in the EEA before RLAH. We can then use our baseline estimate of the quantity

[11] We relax this assumption in the Online Appendix. 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).

[12] See https://digital-strategy.ec.europa.eu/en/library/mobile-broadband-prices-europe-2016. For confidentiality reasons, we cannot reveal the country of the European network operator that shared individual-level data with us. Therefore, we use an average across similar countries.

change $\hat{\delta}$ and express (3) as

$$CV = (0.0515 - 0.00385) \times \frac{2\hat{q}_0 + \hat{\delta}}{2}. \quad (4)$$

4.2. *Changes in Consumer Surplus*

4.2.1. *Consumer surplus per user and travel day*

We compute a range of estimates for the consumer surplus by using the results of column (4) in Table 2 and (4). We find that the average consumer surplus gain per user and travel day is about €2.44 ($CI_{95\%}[2.31, 2.55]$).[13] We can further decompose the effect and find that €1.49, representing around 60% of the total consumer surplus gain, comes from the revaluation of past consumption. In contrast, €0.95 (40%) stems from new consumption.[14]

When calculating the consumer surplus effects, we can also consider user heterogeneity. Our results suggest that a large share of consumer surplus from new data consumption stems from consumers with low data consumption in the EEA before RLAH.

We can further compute surplus changes for business trips using the causal estimates and SEs from column (2) of Table 4. We find that the regulation generated a consumer surplus of about €1.99 ($CI_{95\%}[1.79, 2.19]$) per user and travel day for business trips.[15]

4.2.2. *How much did European consumers gain?*

To put the consumer surplus estimates into context, we can calculate aggregate numbers. We first compute the total consumer surplus increase for all users in our sample. Clients of MOBILE in our database travelled around 2.5 million days in 2017 within the EEA after RLAH. Using our estimate of the average consumer surplus increase per travelled day, we compute that the total consumer surplus gain from the regulation of our sample is around €7 million in 2017.

Using aggregate tourism statistics, we can also compute the overall consumer surplus gains for the country in which MOBILE operates. According to the national statistics office of that country, residents spent around 50 million days travelling in the EU between June and December 2017, which adds up to a total consumer surplus gain for the country in which MOBILE operates of around €120 million in 2017.

Finally, we can approximate the total consumer surplus change in the entire EU. Eurostat data show that EU residents spent 846.32 million nights travelling in the EU between June and December 2017 according to Eurostat.[16] Assuming that our estimates are representative across the EU, the total consumer surplus gain of RLAH would be around €2 billion in 2017.

While the assumption that MOBILE users represent the entire EU is strong, several observations suggest that our estimates of consumer surplus effects might be lower bound. First, we show in the Online Appendix that individuals from the country in which MOBILE operates

[13] We use the causal estimates and SEs from column (4) in Table 2. Column (1) of Table 2 gives us $\hat{q}_0 = 31.2$ and $\hat{q}_1 = 31.2 + 39.9 = 71.1$. Overall, we have $\hat{q}_0 + \hat{q}_1 = 102.3$, which leads to an estimate of the compensating variation of $CV = (0.0515 - 0.00385) \times 102.3/2 = 2.44$.

[14] We show in the appendix that our estimate of the consumer surplus gain is higher when considering positive average income (y) and income elasticity (σ) in both cases.

[15] We have $\hat{q}_0 = 28$ and $\hat{q}_1 = 28 + 40 - 12.4 = 55.6$. Overall, we have $\hat{q}_0 + \hat{q}_1 = 83.6$, which leads to an estimate of the compensating variation of $CV_{business} = (0.0515 - 0.00385) \times 83.6/2 = 1.99$. We compute the confidence intervals using the causal estimates and SEs from column (2) of Table 4.

[16] See https://ec.europa.eu/eurostat/databrowser/view/TOUR_OCC_NIM__custom_61795.

tend to travel abroad to a lesser extent compared to the average of other EU countries. Second, related research shows that the country where MOBILE operates has a lower consumer surplus change from data consumption than the average (Canzian *et al.*, 2021). Third, our consumer surplus estimate for 2017 would be 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 run several simulations to relax the assumption of a zero income elasticity and show that the average consumer surplus gains are higher in scenarios with positive income elasticities (see the Online Appendix).

4.3. *Suggestive Evidence of Changes in Network Operator Surplus*

To complement the consumer surplus estimations, we also approximate the change in surplus for network operators after RLAH. Network operators receive two types of revenue from roaming. They levy roaming charges on their clients during travel (outgoing roaming) and wholesale costs to other network operators because of visitors travelling to the operator's country (incoming roaming), both of which are changed with the RLAH regulation.

We focus on travellers to/from countries affected by RLAH because we assume that these were the only groups of individuals who had an impact on the network operator's surplus. Evidence shows that there are limited effects of RLAH on domestic consumption (Munoz-Acevedo and Grzybowski, 2023). In our approximation, we assume that wholesale prices are the same for all network operators in all countries affected by RLAH. We set w_t as the wholesale price cap before/after RLAH, the retail price using the same assumptions introduced in Section 1, and the immediate effect of around 40 MB extra mobile data consumption induced by the regulation. We also assume that RLAH changes mobile data usage, but not the likelihood of travel.

With these parameters, we calculate the changes in marginal revenue from national roamers and roaming visitors. The profit change for a network operator, due to RLAH, depends on the mobile data home price (details can be found in the Online Appendix):

$$\Delta\Pi = \begin{cases} N_1^{out} \times [31p_h + €c27] + N_1^{in}[€c101 + 40 \times c_{ope}] & \text{if } p_h \leq 0.385, \\ N_1^{out} \times [€c55 - 40p_h] + N_1^{in}[€c101 + 40 \times c_{ope}] & \text{if } p_h > 0.385. \end{cases} \quad (5)$$

We can use (5) to map the 2017 post-regulation gains for any European network operator depending on their network operating cost (c_{ope}), their domestic price per MB p_h, and the numbers of roaming visitors N_1^{in} and national roamers N_1^{out} after the regulation.

Using data on the distribution of domestic prices and operating costs across European countries (see European Commission, 2016), we find that operators' marginal profits decreased from incoming roaming more than from outgoing roaming. 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), we estimate that the daily marginal revenue loss due to RLAH amounted to €c32 per outgoing roamer and €c117 per incoming roamer due to RLAH. Operators in countries with many incoming visitors lost more due to RLAH. Additionally, network operators with higher operating costs were also penalised more by RLAH. These heterogeneous impacts are likely to be substantial given the heterogeneity in roaming operating costs across countries in Europe (European Commission, 2016). In total, however, the suggestive evidence presented here suggests that consumer surplus increased more than network operator surplus decreased, implying that RLAH had overall positive welfare effects.

5. Conclusion

The EU's RLAH regulation substantially lowered the price of roaming for travel in the EEA. Using individual-level data from a network operator, we show that the regulation increased demand for mobile Internet and allowed more travellers to access the mobile Internet, which led to substantial consumer surplus gains. However, we document that the impact on consumer surplus was heterogeneous across consumer types. Consumers who were already intensive mobile Internet users when travelling abroad benefited the most from RLAH. At the same time, we show that the RLAH regulation has reduced the digital divide between EU travellers, allowing more users to access the Internet. Furthermore, our results suggest that the regulation had smaller consumer surplus effects for trips that exclude weekends and holidays. This result suggests that tourists, rather than business users, benefited the most from the reduction in roaming charges.

Data from an online experiment additionally 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 network operators' revenues directly to other market participants, which may reduce Internet Service Providers' incentives to invest in bandwidth quality in the future (Pil Choi and Kim, 2010). Our study also carries implications for trade policy. In Europe, a few large firms dominate the supply of online content. For example, 90% of Europeans with access to the Internet use Google as a search engine,[17] making it likely that travellers' online search activities will benefit Google directly. If RLAH increases search behaviour, Google captures a part of the enlarged pie. Hence, it is likely that the RLAH regulation transferred surplus from European network operators toward multinational content providers. Therefore, while the regulation increased consumer surplus for European consumers, it likely reinforced the dominant position of non-EU content providers.

Our paper is not free from limitations. First, we cannot rule out entirely that EEA 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 cannot observe the content choices of clients of MOBILE and have to approximate change in content demand with a separate online experiment.

Our results may stimulate more research on the indirect effects of mobile data access. For example, the economic geography of cities may have been impacted by enhanced access to the mobile Internet. With lower consumer search costs, firms may change marketing, quality investments and location choice (Donati, 2021). More broadly, if better access to information changed users' optimal choices, firms may also undertake different strategic decisions to adapt, which provides exciting avenues for future research.

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

Erasmus University, Netherlands & Catholic University of Portugal, Portugal
Catholic University of Portugal, Portugal
University of Lausanne, Switzerland

Additional Supporting Information may be found in the online version of this article:

Online Appendix
Replication Package

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