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Abstract

We empirically assess the impact of the EU roaming regulation on mobile operators' average revenues per user (ARPU) and retail prices. Using a differences-in-difference approach, hedonic price regressions and detailed operator and plan-level data we find that the regulation decreased mobile operator's revenues per user, while it had no impact on tariffs during the latest phase of the regulation.

JEL-Codes: L130, L50, L960.

Keywords: roaming, mobile telecommunications, regulation.

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1 Introduction

Roaming regulation implemented in years 2007-2017 is considered a success story in the European Union (EU) and a decisive step towards the consolidation of the EU digital single market.[1] First, in 2007, the European Commission introduced regulations, which capped the maximal roaming fee that mobile users had to pay for voice services, as well as the wholesale tariffs for outgoing calls. In the following years, further regulations capped roaming charges for SMS and data, both at the retail and wholesale levels. Finally, in June 2017, the Commission implemented the "Roam Like at Home" (RLAH) regulation, which equalized roaming fees for voice, SMS and data with prices that mobile users pay for these services in their home countries. Since this last regulation was implemented, users of mobile services in the EU do not need to worry about being surprised by high mobile bills after trips abroad within the European Economic Area (EEA).[2],[3]

Back in the middle 2000s, following complaints about excessive prices for roaming services and lack of transparency in the market, the European Commission started monitoring prices and evaluating different policy options for a regulation of roaming within the EU.[4] The European Commission's investigation revealed that on average, international roaming prices were four times higher than those of national mobile calls. Such price differences were however not explained by differences in the costs of service provision. According to the European Commission's findings, on average retail charges for a roamed call were five times higher than the actual cost of providing the wholesale service (50% higher than the average inter-operator tariffs).[5] In this context, the EU roaming regulations were conceived with the objective of achieving substantial reductions in international roaming charges in the EU and intensifying competition in the European mobile telecommunications markets.

While the regulations have greatly benefited millions of travelling consumers in the EU, they

[1]The EU roaming regulation concerns international roaming services. International roaming allows mobile subscribers to make and receive calls, send and receive SMS or use data services when travelling occasionally outside the geographic coverage area of their home network. The use of these services abroad is done based on the network of a mobile operator in the visited country.

[2]In order to prevent abuses or anomalous use of roaming services - such as permanent roaming at domestic prices -, the RLAH regulation contains two provisions: a fair use policy and a sustainability derogation. The first provision aims to ensure that roaming is used only when periodically travelling in the EEA. The second intends to avoid domestic price increases in the case where an operator cannot provide roaming services without the application of a surcharge, given its price-cost model at the domestic level. This is subject to the approval by the national regulatory authority.

[3]The European Economic Area covers EU Member States and also includes Norway, Iceland and Liechtenstein.

[4]See: Falch (2012).

[5]See: Commission Staff Working Paper SEC(2006) 925.

do not come without important risks and challenges. In the words of BEREC, *"[...] there are substantial trade-offs between the policy objectives of promoting greater use of roaming services, protecting competition, protecting investments and, importantly, protecting European consumers"*.[6] First, there exist diverse travel and consumption patterns across Member States, coupled with significant variations on the level of tariffs and costs of different mobile operators across Member States.[7],[8] Thus, imposing the exact same price caps across Member States and ultimately equalizing retail roaming charges with domestic prices could in practice introduce distortions in national competition and challenge the sustainability of certain mobile operators. Second, there was an increase in consumers' use of roaming services encouraged by the regulation, which increased the wholesale bill of the operators and put pressure on the network capacity.[9] This increase in demand and investment needs arrives in a context where wholesale tariffs are also capped and decrease over time. Such dynamics can significantly affect the competition conditions at the national level, impose constraints on investment incentives and lead to potential strategic reactions by mobile operators. In particular, mobile operators could attempt to recoup lost revenues and profits by adjusting upwards domestic prices. In such case, consumers who do not travel abroad would be worse off as a result of roaming regulation with higher domestic bills and no compensation through lower roaming fees.[10] This unintended distributional effect was one of the main concerns expressed by BEREC during the consultation period preceding the adoption of RLAH regulation.[11] Note that this distributional effect can be rationalized as a waterbed effect similar to the one discussed

[6]See: BEREC, International Roaming Analysis of the impacts of "Roam Like at Home" (RLAH), BoR (14) 209, December 2014, page 2.

[7]For instance, according to the Flash Eurobarometer 2018 "The end of roaming charges one year later", 46% of respondents had travelled to another EU country within the last 12 months, while 53% had not travelled to another EU country during this period. Travelling habits vary considerably across countries: in Luxembourg (85%), Austria (78%) and Slovenia (75%) respondents had travelled to another EU country at least once in the last 12 months, compared to 26% of respondents in Greece, 28% in Portugal and 30% in Spain.

[8]Costs differences are explained mainly by differences in spectrum costs, labor and property costs, coverage obligations, geographies, drivers of demand for network capacity, etc.

[9]The rapid and massive increase in demand for mobile consumption while travelling in the EU/EEA is documented in different reports, including the European Commission's Report on the implementation of Regulation (EU) 531/2012 of the European Parliament and of the Council of 13 June 2012 on roaming on public mobile communications networks within the Union, as amended by Regulation (EU) 2015/2120 and Regulation (EU) 2017/920, COM(2018) 822 final.

[10]According to estimates reported by BEREC in 2014, an average EU citizen spent 5.7 days abroad in another Member State. The percentage of EU citizens who never travel abroad was estimated at 36%, with large variation across countries. Source: BEREC, International Roaming Analysis of the impacts of "Roam Like at Home" (RLAH), BoR (14) 209, December 2014.

[11]See: BEREC, International Roaming Analysis of the impacts of "Roam Like at Home" (RLAH), BoR (14) 209, December 2014.

in the literature studying regulation of mobile termination rates.[12]

Even though roaming regulation was a successful political move and had a great economic impact on both consumers and mobile operators, so far there are scant rigorous empirical studies on its impact on prices of mobile services, and consequences for revenues and profits of mobile operators. This paper is an attempt to provide such evidence based on detailed operator-level data on average revenue per user (ARPU) and plan tariffs of a large number of European and non-European operators in OECD countries. The non-EU operators were not affected by roaming regulation and are included in this analysis as a control group.[13]

There are reasons why such analysis has not been conducted so far. First, reliable information on ARPU is not easily available. We combine such data for years 2004-2018 for a large number of operators using different sources. Second, the pricing of mobile services is complex including a range of different services sold as bundles, which also change frequently. Likewise, international price information is not easily available and requires substantial data collection effort. We use a large database of tariff plans from a number of operators for years 2014-2017. Moreover, there are also substantial differences across EU countries with respect to consumption patterns of mobile services and traveling patterns, which make it difficult to assess how benefits of roaming regulation are distributed across countries and between segments of population within the country.[14] Due to lack of detailed information on the demand side, we are not able to assess welfare effects of roaming regulation and how it is distributed across Member States, which is an interesting avenue

[12]See Genakos and Valletti (2011) and Genakos and Valletti (2015).

[13]The impact of roaming regulation on the telecommunications market has been analyzed mainly in studies conducted by BEREC, the European Commission or on their behalf. For instance, a report from July 2011 by the European Commission explains how BEREC collected data to study the consequences of European regulations. See: "Commission Staff Working Paper, Impact Assessment of Policy Options in Relation to the Commission's Review of the Functioning of Regulation (EC) N544/2009 of the European Parliament and of the Council of 18 June 2009 on Roaming on Public Mobile Telephone Networks within the Community". After the implementation of RLAH regime, the European Commission has published three documents reviewing the roaming market: (1) On 12 December 2018 an interim Report to the European Parliament and the Council on the implementation of the RLAH rules over the first 18 months, (2) on 28 June 2019 a Staff Working Paper Document on the findings of the review of the rules of fair use policy and the sustainability derogation and (3) on 29 November 2019 a Report to the European Parliament and the Council on the review of the roaming market. All these reports mainly rely on a descriptive analysis.

[14]For instance, BEREC's analysis based on the Eurobarometer Household Survey shows that in 2014, 75% of households in Italy have prepaid subscriptions in contrast to Denmark where 83% of households have postpaid subscriptions. Moreover, Eurostat and Eurobarometer data shows that the average number of days spent abroad for citizens of different Member States ranges from less than 1 day per year in Greece to 27 days per year in Luxembourg, and there is a general trend of greater travel from Northern to Southern Member States than vice versa. Source: BEREC, International Roaming Analysis of the impacts of "Roam Like at Home" (RLAH), BoR (14) 209, December 2014.

for further research.

Our analysis is carried out in the following steps. First, we put together a database including information on ARPU for 111 European and non-European mobile operators in 33 OECD countries on a quarterly basis for years 2004-2018. The data covers the period of roaming regulations implemented step-wise in years 2007-2017. We estimate a number of specifications using a difference-in-difference approach, in which we assess whether roaming regulations impacted ARPU of mobile operators in the EU. We compare the quarters before and during roaming regulation and as a control group use information on a number of mobile operators from non-European OECD countries, which were not affected by the regulation. In one model specification we assess the impact of roaming regulation from the start in 2007 and find that it led to lower ARPU of mobile operators in the EU. When exploring the effect of different phases of the regulation, we see that the decrease in ARPU is gradual, but is uncertain for the latest phase of the regulation. The results are robust when different control variables are included and for ARPU measured with and without considering purchasing power parities (PPP).

Next, we estimate hedonic price regressions using a large number of tariff plans on a quarterly basis between January 2014 and December 2017 for 12 mobile operators from selected OECD countries including EU Member States. The pricing information is much shorter than our ARPU data set because such data is not readily available on a cross country basis. Thus, the earlier some roaming regulation was already in place in the whole period and we can only assess the impact on prices of the latest roaming regulation (RLAH regime) which took place in June 2017. In the first stage, the regressions include a number of covariates to control for differences in quality of mobile services offered in different countries. In particular, we create a set of dummy variables, which account for different data and minutes allowance included in tariff plans, as well as length of contract. We estimate the regressions for all tariff plans, including prepaid and postpaid segments. In the second stage, using quality-adjusted price indices from the first stage, we estimate a number of difference-in-differences models with non-EU countries being our control group. Our results suggest that the latest phase of the regulation had no impact on mobile operators' tariffs. Thus, the potential upward adjustment of domestic prices by mobile operators - feared by the authorities - does not seem to have taken place after the entry into force of the RLAH regime.

Our paper makes an important policy contribution since, to the best of our knowledge, it is the first academic paper which relies on detailed operator-level data to assess empirically the impact of one of the key regulations implemented at the European Union level. We show that the regulation had a significant impact on revenues of mobile operators in the EU in comparison to mobile operators based in OECD countries outside the EU. We also show that roaming regulation does not seem to have affected retail mobile prices in the EU.

Our paper contributes to the following streams of literature. First, it contributes to the literature studying the impact of regulation on outcomes in telecommunications markets. Among studies on the impact of regulation on prices of telecommunications services, Genakos and Valletti (2011) analyze how the regulatory intervention to cut fixed-to-mobile (F2M) termination rates impacts mobile retail prices. Using panel data of prices and profit margins for mobile operators in more than 20 countries in a period of over six years, they find that a reduction in F2M termination rates leads to an increase in retail prices, which they call the 'waterbed' effect.[15] In a more recent paper by the same authors, Genakos and Valletti (2015) estimate the impact of regulation of F2M termination rates on mobile phone bills using a large panel covering 27 countries. They find that the "waterbed" phenomenon becomes insignificant on average over the 10-year period, 2002-2011. They argue that this is due to the changing nature of the industry, whereby mobile-to-mobile traffic surpassed fixed-to-mobile traffic.[16] Recently, Canzian et al. (2021) evaluate the impact of the Roam-Like-at-Home regulation (latest phase of the EU roaming regulation) on EEA roaming traffic. Using detailed data from BEREC for the period 2016-2019, they find that RLAH substantially raised international roaming volumes and wholesale revenues, with large and heterogeneous effects on retail and wholesale traffic volumes and revenues. Based on the empirical results and a theoretical framework, they conclude that gains in consumer surplus from RLAH are large and far outweigh profit losses. Moreover, as an extension to their main analysis and using data from Teligen, they study whether the RLAH involved a waterbed effect. Consistent with our results, they find that

[15] They obtained information on retail prices from a consultancy firm Teligen, which collects telecommunications pricing data. The prices are expressed in terms of three representative usage baskets (heavy, medium and low) based on a number of characteristics (number of calls and messages, average call length, time and type of call, etc.) which are then held fixed across countries and over time. The "waterbed" effect suggests that pressing down prices in one part of firms' operations causes another set of prices to rise.

[16] More than a decade ago there was a burgeoning theoretical literature on the impact of mobile termination rates on prices, which started with the seminal works of Armstrong (1998) and Laffont et al. (1998). For surveys, see Armstrong (2002) and Laffont and Tirole (2001).

RLAH does not seem to have induced operators to raise their domestic prices.

Second, we contribute to the literature using hedonic price regressions in application to the telecommunications industry. The hedonic price model is based on the idea that any product can be viewed as a bundle of attributes. Firms and consumers trade with each other to determine the price attached to each attribute (see Griliches (1961) and Rosen (1974) for a formal presentation of this model in perfectly competitive framework). Hedonic price regressions were commonly used to study price changes in different industries. There is also a number of empirical studies for telecommunications markets including Karamti and Grzybowski (2010) and Nicolle et al. (2018) for mobile prices in France; Greenstein and McDevitt (2011) for broadband industry in the U.S.; Wallsten and Riso (2014) for broadband services in OECD countries; Calzada and Martinez-Santos (2014) for broadband prices in 15 EU countries.

The reminder of this paper is organized as follows. Section 2 discusses the main changes in mobile telecommunications industry in the EU. Section 3 presents the data used in the estimation. Section 4 introduces the econometric framework. Section 5 presents the estimation results. Finally, Section 6 concludes.

2 Regulation of the Mobile Industry in the EU

This section describes the EU roaming regulation and the main events that took place in the mobile telecommunications industry in Europe in years 2004-2018 covered by our data.

The main regulatory measures implemented in recent years at the EU level relate to international roaming services. International roaming is a service that allows mobile phone users, by means of using a visited network, to automatically make and receive voice calls, send and receive SMS, or access data services when travelling occasionally outside the geographical coverage area of their home network. The roaming market is divided into wholesale and retail markets. Wholesale market corresponds to transactions between operators based on agreements, which are signed between them.[17],[18] Retail market corresponds to the roaming services provided by telecom operators to

[17]Such agreements are generally bilateral and consist of two parts: "inbound roaming" and "outbound roaming". Inbound roaming is the situation where foreign customers use an operator's network in the home territory, while outbound roaming refers to customers of the operator in the home territory who go abroad and use the network of another operator.

[18]The first roaming agreement was signed in 1992 between Vodafone UK and Telecom Finland. See: GSMA, Brief

mobile users.

Before June 2017, mobile users in Europe had to pay additional fees to use mobile services when travelling abroad. Since 15 June 2017, additional fees were abolished for European mobile users travelling within the countries of the European Economic Area. This is known as "Roam Like At Home" (RLAH).

While the entry into force of RLAH regime is the most recent and symbolic regulatory event relating to international roaming in the EU, the origins of the regulation date back to the years 2000. Following complaints about excessive rates and lack of transparency for international roaming, in 2005 the European Commission started monitoring international roaming prices. In a study published in 2006, the European Commission revealed that, on average, international roaming prices were four times higher than those of national mobile calls. Moreover, on average, retail charges for a roamed call were five times higher than the actual cost of providing the wholesale service (50% higher than the average inter-operator tariffs).[19] Consequently, in 2006 the European Commission launched a consultation to collect feedback on broad roaming principles and frame concepts for the roaming regulation.[20] In 2007, the first roaming regulation was implemented by the Commission.[21]

Roaming regulation in the EU was carried out in stages. After the first stage in 2007, setting wholesale and retail price limits for calls made and received while abroad ("Eurotariff"), further regulations entered into force in 2009, 2012, 2015 and 2017. Table 9 in the Appendix provides a list of different roaming regulations. These regulations reviewed and set rules for further reductions in wholesale and retail price caps for calls, but they also introduced price caps for SMS and mobile internet. Other provisions of these regulations include automatic protections against data roaming bill shocks and structural measures aiming to foster competition on the roaming market and drive roaming prices further down. In particular, in 2013 the European Commission adopted a legislative package for building a "Connected Continent" and ultimately for creating a "Telecoms Single Market".[22] This package translated later in 2015 into the adoption of the end of roaming charges

History of GSM and the GSMA, available online at: https://www.gsma.com/aboutus/history.

[19] See: Commission Staff Working Paper SEC(2006) 925

[20] See: https://ec.europa.eu/digital-single-market/en/roaming-charges-what-has-european-commission-done-so-far

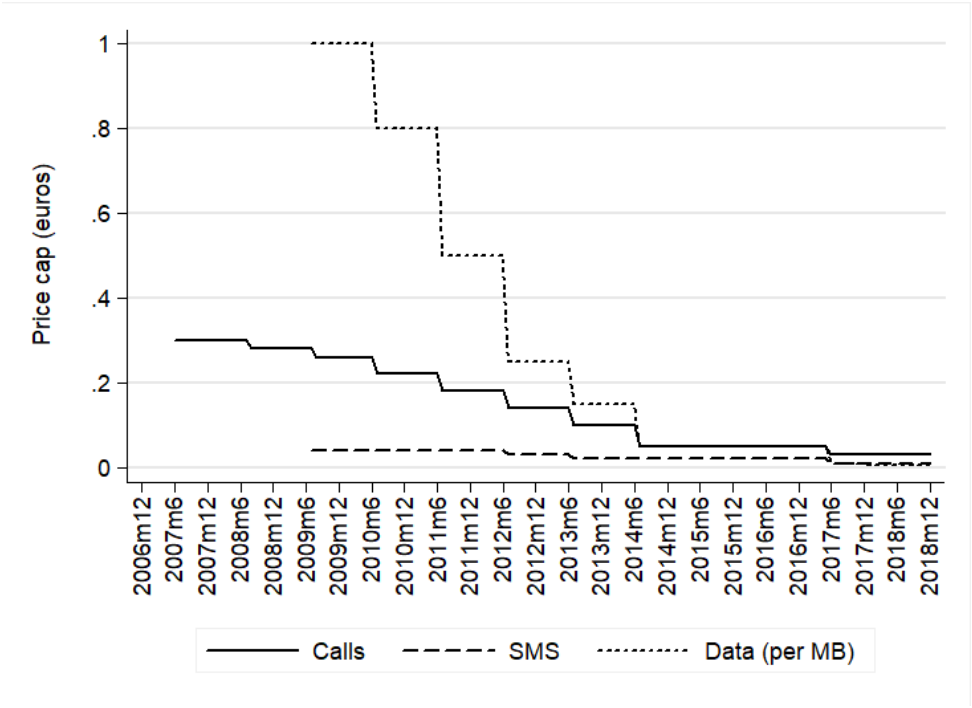
[21] Regulation (EC) No 717/2007 of the European Parliament and of the Council of 27 June 2007 on roaming on public mobile telephone networks within the Community and amending Directive 2002/21/EC

[22] See: https://ec.europa.eu/digital-single-market/en/node/67489/roaming

(to be applied in 2017) and the adoption of fair use policy on roaming at domestic price in 2016.[23],[24]

Figures 1 and 2 illustrate the evolution of Eurotariffs set by the regulation since June 2007 to December 2018 for both wholesale and retail markets. At the retail level, after ten years of regulation the price for an outgoing call went down from 0.49 Euros per minute to zero. The price for one SMS fell from 0.11 Euros in 2009 to zero after June 2017 and 1MB of data went down from a maximum of 0.70 euros in 2012 to zero after the RLAH regime entered into force.

Figure 1: Roaming regulation: Evolution of wholesale price caps



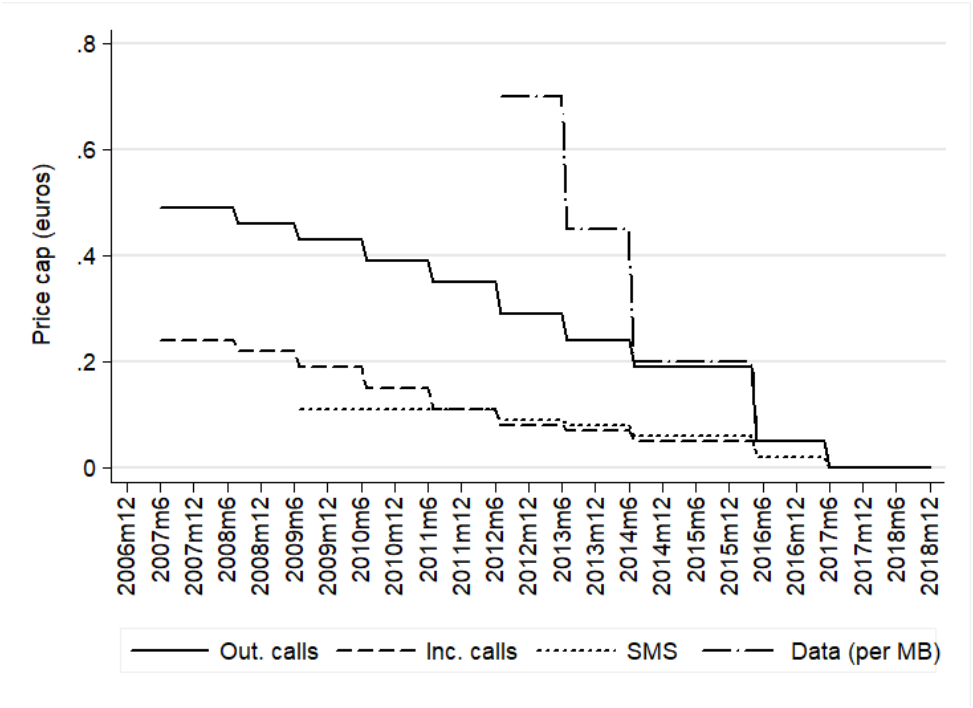
Source: Own elaboration based on EU roaming regulations (see Table 9)

Beyond roaming regulation, telecommunications markets worldwide have been subject to regulatory intervention since the early 2000s. In particular, regulators have worried about termination

[23]For a chronological summary about the European Commission's actions concerning roaming charges, visit: https://ec.europa.eu/digital-single-market/en/roaming-charges-what-has-european-commission-done-so-far

[24]The fair use policy consists on limits to the use of roaming services that subscribers can consume. Those limits aim to prevent abusive or anomalous use of roaming services, which are intended only for occasional use. Note also that in 2010 the BEREC (Body of European Regulators for Electronic Communications) was created with the aim of assuming the role of "super regulator" with the mission to coordinate and advise National Regulatory Authorities (NRAs). This body has also a right of veto over so-called important decisions taken by the NRAs.

Figure 2: Roaming regulation: Evolution of retail price caps



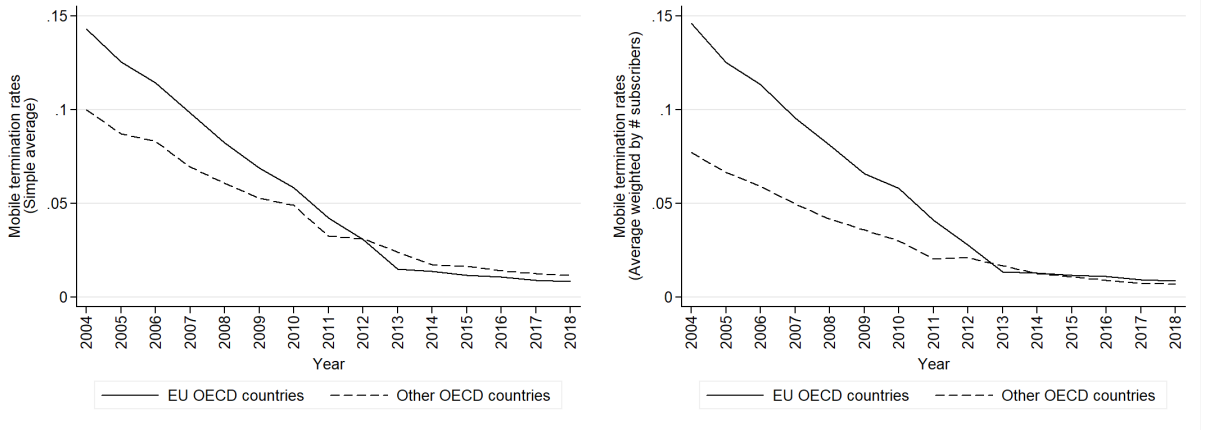
Source: Own elaboration based on EU roaming regulations (see Table 9)

rates for calls made to mobile networks. These termination rates correspond to the wholesale services telecommunication networks sell to each other to terminate calls that originate and end in different networks. Over the years, regulators have repeatedly intervene to set caps with the aim to cut these charges, which appeared to be too high to foster competition and benefit final consumers. Unlike the EU roaming regulation, which imposed the same wholesale and retail price caps to all operators within countries in the EEA, mobile termination rates (MTR) regulation has been applied at different moments in time, and with different degrees of 'toughness' across and within countries.[25] In most OECD countries, the price caps for termination rates are set on the basis of long-run incremental costs (LRIC) following bottom-up approach. This approach takes into account network design (technologies and coverage), traffic (volume, busy-hour characteristics) and

[25]See Genakos and Valletti (2015) for a chronology of the mobile termination rate regulation on 27 OECD countries and an example of differences in caps within France.

cost (CAPEX, OPEX, asset lifetime).[26] Figure 3 illustrates the average decline over time of mobile termination rates for EU and other OECD countries.[27]

Figure 3: Evolution of Mobile Termination Rates in EU and other OECD countries (Euros)



(a) Simple average

(b) Weighted average

Source: Own elaboration based on reports from the European Commission, BEREC, OECD and mobile subscriber data from OVUM

Following different waves of consolidation in the telecommunications sector, another important front of policy intervention has been merger control. In the EU, these mergers have been subject to review by the national competition authorities or by the European Commission. Table 13 in the Appendix presents a list of mergers between mobile network operators in our sample of 33 OECD countries between 2004 and 2018. In practice, mergers alter competition in the market and may affect revenues and prices of mobile network operators in different ways.

Entry into the mobile telecommunications market has been another major event changing the competitive landscape in different countries around the world. Table 12 in the Appendix provides the date and identity of operators that entered the mobile market in countries in our sample during

[26]Based on the European Commission's Recommendation from 2009, MTRs should be set on a 'pure LRIC' basis, i.e., reflecting the long run incremental cost exclusive of any fixed and common costs. See "Commission Recommendation on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU - Implications for Industry, Competition and Consumers (07/05/2009)".

[27]EU countries which belong to the OECD include: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom. Other OECD countries include: Australia, Canada, Chile, Israel, Japan, Mexico, New Zealand, Switzerland, Turkey, USA.

the period 2004 to 2018. Note that entry is not free in this market. Barriers to entry are high as the necessary infrastructure to support the services requires large investments and the allocation of spectrum is also a prerequisite.

Finally, an important development during our period of study is the granting of licenses and the subsequent deployment of 4G networks. In practice, spectrum policy is an important lever in the hands of policy makers to affect the structure of mobile markets and innovation. From the perspective of mobile network operators, while the deployment of the 4G networks creates new commercial opportunities and modifies the competitive environment, it also entails important investments putting extra pressure on their budgets. Tables 10 and 11 in the Appendix present the date of 4G service commercial roll-out for each operator in our database during the period 2004 to 2018.

3 The Data

For our analysis of revenues we matched several data sources over the period from the first quarter of 2004 to the third quarter of 2018. First, we used data from OVUM to get information on ARPU and number of subscriptions at the operator level. Second, we used data from GSMA to complement missing information on ARPU in OVUM's database. Third, we used the World Bank to gather information about population, purchasing power parities (PPP), exchange rates, Gross Domestic Product (GDP) and surface for each OECD country covered by OVUM. Fourth, from our own research on the internet we collected information about the dates of entries and mergers of mobile network operators (MNO) in each country, as well as the dates of 4G commercial service launches for each MNO in our database (see respectively Tables 12, 13, 10 and 11 in the Appendix).[28] Fifth, using reports from the European Commission, the BEREC and the OECD we gathered information about mobile termination rates (MTRs) at the country level.[29] Table 1 presents the number of

[28] In total, there were 21 mergers in countries included in our database and during our period of study. The total number of entries is 13. Regarding 4G, all operators in our sample deployed 4G services at some point in time, except one. The average number of quarters with 4G service availability is 22.6 (in reference to a total period of 59 quarters covered by our data).

[29] The reports from the European Commission and the BEREC provide information about MTRs at the operator and country levels only concerning countries included in the European Economic Area (EEA) and Switzerland (although not always available throughout the period 2004-2018). Regarding OECD countries outside the EEA, which we use as control group in our analysis, we used two OECD reports providing information about MTRs from

countries and operators in our database and Table 2 presents summary statistics of ARPU and country level variables. Our level of observation is a country-operator-quarter.

Table 1: Analysis of ARPU - Number of countries and operators considered

	Total	Regulated	Non-regulated
Number of countries	33	23	10
Number of operators	111	76	35

Table 2: Analysis of ARPU - Summary statistics at the operator and country levels

	Obs.	Mean	Std. Dev.	Min	Max
ARPU (Euros)	6,285	22.9	11.6	2.4	68.1
ARPU (Euros PPP)	6,285	23.6	10.4	4.3	110.0
Population (in millions)	1,947	36.2	58.7	1.3	328.2
Population density	1,947	120	109	2.6	411
GDP per capita (Euros)	1,947	27,315	15,388	4,867	79,128
GDP per capita (Euros PPP)	1,947	26,480	8,876	9,194	53,413
MTR (Euros)	1,947	0,05	0,05	0,00	0,30
MTR (Euros PPP)	1,947	0,07	0,07	0,00	0,35

For our analysis of prices we matched information from three different sources over the period comprised between the first quarter of 2014 and the fourth quarter of 2017. First, we used Tarifica to get information about tariffs and plan characteristics. This information is available for several mobile plans for one mobile operator per country. In total, we count 12 OECD countries in our database (thus a total of 12 mobile operators), 6 concerned by the regulation, 6 unconcerned. Table 17 in the Appendix presents the list of countries and operators covered in the database. Second, we used OVUM to gather information about the Herfindahl-Hirschman Index (HHI) of the mobile telecommunications market in each country. Third, we used the World Bank to collect information about population, purchasing power parities (PPP), exchange rates, GDP, surface, number of fixed broadband subscriptions and proportion of urban population for each OECD

2004 to 2012 and for 2014 and 2017. These reports only provide information at the country level. In order to keep our sample unchanged, we treated missing values in the following way. First, we used linear interpolation. Second, when missing values corresponded to the first years of the period we assumed that MTRs were the same as the first MTR we observe. Third, when a missing value concerned the year 2018, we assumed that the MTR was the same as in 2017. Note that information about MTRs at the operator level for OECD countries outside the EEA is not readily available from public sources. For this reason, we use information about MTRs at the country level when including this variable in some of our regressions. Also, note that Canada (from 2004 to 2014) and the US (since 2017) present MTRs equal to zero. Thus, before taking the logarithm of MTRs, which we include in our regressions, we applied a linear transformation by adding 1 to MTRs in levels.

country covered by Tarifica data. Our level of observation is a country-operator-plan-quarter. Table 3 presents summary statistics of tariffs and characteristics of plans in our database.[30] Table 4 presents summary statistics at the country level.

Table 3: Analysis of Tariffs - Summary Statistics - Plan Level

Variable	Obs.	Mean	Std. Dev.	Min	Max
Tariff (USD PPP)	11,496	60.7	81.0	0.5	790
Tariff (USD)	11,496	52.2	78.6	0.3	790
Prepaid plan	11,496	0.3	0.5	0	1
Voice included	11,496	0.6	0.5	0	1
Data validity (prepaid)	3,394	51.6	82.2	1	365
Credit value included (prepaid)	3,394	0.2	0.4	0	1
Contract length (postpaid)	8,102	10.1	9.7	1	24
Minutes allowance	8,305	154.3	312.1	0	1600
SMS allowance	7,079	54.9	186.7	0	1500
Data allowance (in GB)	11,467	7.8	15.3	0	100

Table 4: Analysis of Tariffs - Summary Statistics - Country Level

Variable	Obs.	Mean	Std. Dev.	Min	Max
HHI	192	0.3	0.1	0.3	0.5
Fixed Broadband (subs. per 100 people)	192	29.3	9.2	10.5	43.8
GDP per capita (USD PPP)	192	38,492	10,823	17,253	59,532
GDP per capita (USD)	192	35,162	15,603	8,450	62,328
Population Density	192	99.9	89.7	3.1	272.9
Urban (% of total population)	192	79.3	7.3	60.1	87.5

4 Empirical Analysis

4.1 Difference-in-Differences Regression

We use a difference-in-differences (DID) estimation to assess how roaming regulation impacted ARPU of mobile network operators. In the estimation, we use data for selected $i = 1, ..., N$ mobile network operators from OECD countries. We divided them into treatment and control group, where treatment group, denoted by $G_i = 1$, includes selected EU operators falling under

[30]Note that 3,191 plans in our database present infinite minute allowances, 4,417 present infinite SMS allowances and 29 contain data allowances significantly greater than 100 GB, which we assume to correspond to infinite data allowance. The are 3,394 and 8,102 prepaid and postpaid plans, respectively.

the roaming regulation and control group, denoted by $G_i = 0$, consists of selected non-European operators we observe in the data periods before roaming regulation, $R_t = 0$, and during roaming regulation, $R_t = 1$. The estimated model can be specified as follows:

$$ln(y_{it}) = \alpha + \delta(G_i * R_t) + \eta_t + \lambda_i + \phi X_{it} + \varepsilon_{it} \tag{1}$$

where y_{it} is the dependent variable, ARPU, for mobile operator i in quarter t. The estimated parameters include a constant term denoted by α. The parameter of interest providing the effect of the regulation is denoted by δ. The operator and time fixed effects are denoted respectively as λ_i and η_t. ϕ denotes a vector of parameters corresponding to different control variables. Depending on the specification, control variables include: (i) GDP per capita, (ii) population density, (iii) dummy variables identifying mergers and acquisitions in the mobile market in each country, (iv) a dummy variable identifying the entry of a new mobile operator in a given country and (v) a dummy variable identifying 4G commercial roll-out period for each operator in our sample. The error term ε_{it} is assumed to be normally distributed. The DID estimator is unbiased when the model is correctly specified and the error term is uncorrelated with the other explanatory variables. In particular, there should be no correlation with $G_i \cdot R_t$, which is called common trends assumption. When common trends assumption is violated, i.e., y_{it} follows a different trend for the EU operators than for non-EU operators outside the regulation period, the DID estimator will be biased (for a discussion see Meyer (1995)).

The difference-in-difference estimator is defined as the difference in average outcome in the treatment group before and after treatment minus the difference in average outcome in the control group before and after treatment as follows:

$$\hat{\delta}_{DD} = \bar{y}_1^T - \bar{y}_0^T - (\bar{y}_1^C - \bar{y}_0^C) \tag{2}$$

4.2 Hedonic Price Regression

To assess the impact of the latest phase of the roaming regulation (RLAH) on mobile retail tariffs, we use an hedonic price regression approach.

In the first step, we estimate the impact of tariff characteristics and the interaction between country and quarterly dummy variables on the cost of tariffs, based on the following hedonic price regression:

$$y_{ict} = \alpha + \beta X_{ict} + \delta_{ck}\mathbf{I}(k = t) + u_{ict} \tag{3}$$

where y_{ict} denotes the list price of plan i in country c, which was available in quarter-year t. The estimated coefficients δ_{ck} of the country-time dummy variables $\mathbf{I}(k = t)$ represent the quality-adjusted price indices for each country in our sample. These coefficients are used as dependent variable in the second stage of the analysis.

The vector of tariff characteristics X_{ict} includes: (i) a dummy variable identifying plans including voice, (ii) a dummy variable identifying prepaid plans, (iii) an interaction variable identifying plans including voice that are prepaid, (iv) dummy variables for prepaid data validity (in number of days: less than 15, 15 to 29, 30 to 59, 60 to 180 and equal or greater than 180), (v) dummy variables for postpaid plans contract length (in number of months: 1, 6, 12, 18, 24), (vi) a dummy variable for credit value greater than zero of prepaid plans, (vii) dummy variables for minutes allowances (in number of minutes: greater than zero to 50, 51 to 100, 101 to 150, 151 to 200, 201 to 300, 301 to 400, 401 to 500, 501 to 1600, greater than 1600), (viii) dummy variables for message allowances (in number of SMS: 1 to 50, 51 to 100, 101 to 200, 201, to 250, 251 to 500, 501 to 750, 751 to 1000, 1001 to 1500, greater than 1500), and (ix) dummy variables for data allowance (in GB: 0.01 to 0.249, 0.25 to 0.49, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 to 12, 13 to 15, 15 to 19, 20 to 24, 25 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 99 and equal or greater than 100). The normally distributed error term is denoted by u_{ict}, and the vector of coefficients $\gamma = (\alpha, \beta, \delta)$ is estimated using ordinary least squares (OLS).

In the second step, we regress the quality-adjusted price index for each country δ_{ct} on a set of competition, regulation and socio-demographic variables. We use a difference-in-differences approach, as follows:

$$\delta_{ct} = \gamma + \theta Z_{ct} + \beta G_c + \lambda(G_c * RLAH_t) + \eta_t + \varepsilon_{ct} \tag{4}$$

where Z_{ct} denotes a set country-level control variables, including: (i) the Herfindahl-Hirschman Index for the mobile market (HHI), (ii) the number of fixed broadband subscriptions per 100

people, (iii) GDP per capita and (iv) population density. The share of urban population is also included in the analysis instead of population density in an alternative specification. G_c is an indicator variable denoting the group of regulated countries in our sample, η_t is a vector of quarter-year fixed effects and $RLAH_t$ is an indicator variable of the last phase of the regulation. The parameter of interest providing the effect of the last phase of the regulation on tariffs is denoted by λ. Finally, ε_t is normally distributed error term.

5 Estimation Results

5.1 Analysis of Revenues

Results from our baseline model (1) are reported in Table 5. Columns (1) to (3) present the results from our main specifications when the dependent variable is the logarithm of mobile network operators' ARPU in Euros. As a robustness check, columns (4) to (6) present the results for specifications where the dependent variable is the logarithm of mobile network operators' ARPU in Euros PPP.

In columns (1) and (4) no control variables are included in the estimation except for time and operator fixed effects. Columns (2) and (5) take into account the effect of mergers and acquisitions on operators' ARPU. Columns (3) and (6) report the results including as additional control variables the logarithm of GDP per capita, the logarithm of population density, a dummy variable for the commercial roll-out of 4G services and a dummy variable for the entry of a new mobile operator in a given country. In all 6 specifications we find a negative and statistically significant effect of the regulation on operators' ARPU. This effect is comprised between -9.3% and -20% depending on the specification.[31] GDP per capita, as can be expected, has a positive and significant impact on operators' ARPU. The effect of entry of a new mobile operator in a country on operators' ARPU is negative as expected, but it is only significant in the specification considering ARPU in Euros PPP as dependent variable. Population density and 4G commercial rollout do not appear to have any statistically significant impact on operators ARPU on average.

To explore potential differentiated effects throughout the more than ten years of regulation, we

[31] We translate the effects into percentage terms by applying the formula: $exp(\delta) - 1$.

Table 5: OLS estimates of the impact of the EU roaming regulation on operators' Average Revenues per User - Entire regulation period

Dep. Variable	Log(ARPU euros)			Log(ARPU euros PPP)		
	(1)	(2)	(3)	(4)	(5)	(6)
Did regu since 2007q4	-0.224***	-0.183***	-0.135***	-0.134**	-0.113*	-0.0981**
	(0.0523)	(0.0572)	(0.0477)	(0.0555)	(0.0648)	(0.0482)
Log (GDP per capita)			0.479***			0.413*
			(0.111)			(0.211)
Log(Population Density)			0.0985			0.0868
			(0.357)			(0.373)
Entry			-0.0771			-0.121*
			(0.0619)			(0.0700)
4G Commercial Rollout			-0.00581			-0.0146
			(0.0245)			(0.0231)
Constant	3.262***	3.262***	-1.838	3.427***	3.426***	-1.044
	(0.0263)	(0.0255)	(1.947)	(0.0272)	(0.0268)	(2.835)
Mergers		Yes	Yes		Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Operator Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,285	6,285	6,285	6,285	6,285	6,285
R-squared	0.551	0.589	0.619	0.637	0.653	0.667
Number of operators	111	111	111	111	111	111

Notes: Robust standard errors are in parenthesis. Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

distinguish the effect of different phases of the regulation in alternative specifications. Based on the entry into force dates of the different regulations adopted since 2007 and on the scheduled decreases of wholesale and retail tariffs, we define the following 5 phases: (1) from the fourth quarter of 2007 to the third quarter of 2009, (2) from the fourth quarter of 2009 to the second quarter of 2012, (3) from the third quarter of 2012 to the second quarter of 2014, (4) from the third quarter of 2014 to the second quarter of 2017 and (5) from the third quarter of 2017 onwards.[32] DID coefficients are reported with respect to the period prior to the first phase of the regulation (i.e., from the first quarter of 2004 to the third quarter of 2007).

Table 6 reports our DID results from specification equation (1), considering the different phases of the regulation. Different specifications are reported in the same order as in the previous table. Regarding operator's ARPU in Euros (columns (1) to (3) in Table 6), although the coefficients have a negative sign, the regulation does not appear to have any statistically significant effect during its first phase (fourth quarter of 2007 to third quarter of 2009). On the contrary, for the subsequent four periods we find a negative and statistically significant effect of the regulation. This effect appears to be gradual, except for the last period (third quarter of 2017 onwards) for which coefficients are negative and statistically significant, but smaller in absolute terms with respect to the coefficients corresponding to the previous period.

Results regarding operator's ARPU in Euros PPP are qualitatively similar. In column (4), where no control variables other that time and operators fixed effects are considered, we find a negative and statistically significant effect of the first four periods of the regulation on operators' ARPU, and no statistically significant effect during the last period. This effect appears to be gradual. In column (5), where we also take into account the effect of mergers and acquisitions on operators' ARPU, the regulation seems to have significantly decreased regulated operators' ARPU only during its second and third periods. In column (6), which reports the results including as additional control variables the logarithm of GDP per capita in Euros PPP, the logarithm of population density, a dummy variable for the commercial roll-out of 4G services of each operator and a dummy variable for the entry of a new mobile operator in a given country, we find a negative and significant effect of the second, third and fourth periods of the regulation on operators' ARPU,

[32] See Figures 1 and 2 and Table 9 in the Appendix.

and no significant effect during the first and last periods.

Our results suggest that roaming regulations decreased mobile operators' ARPU over the period between the fourth quarter of 2007 and the third quarter of 2018, in particular during the second, third and fourth periods of the regulation. The average effect of the regulation on EU mobile operators' ARPU in Euros is -12.6% and on ARPU in Euros PPP is -9.3%, when considering the specification including all control variables in the regression. The absence of effect during the first phase of the regulation can be explained by the fact that it only concerned voice services. The most stringent measures of the regulation related to data services began in 2009 and 2012, for wholesale and retail price caps respectively, while price caps on voice and SMS services continued to decrease gradually. The absence or lower magnitude of the effect during the last phase of the regulation may imply a different story. In line with a waterbed effect mechanism, mobile operators might have adapted their behavior during this period. In particular, mobile operators might have increased domestic mobile retail tariffs. This possibility makes it relevant to look at the impact of the RLAH regulation on mobile operators' tariffs, which we do in Section 5.2. Another possibility is a change in consumer behavior since the RLAH regulation. Different reports published by the European Commission after the implementation of the RLAH regime reveal a rapid and massive increase in roaming consumption in the EU/EEA after 15 June 2017.[33] In this context, subscribers might purchase extra data or upgrade to plans with more allowances, thus increasing revenues per user of mobile operators in the EU with respect to the period preceding RLAH.

The key identifying assumption of the DID estimation method is that had the regulation not been implemented, ARPU of regulated and non-regulated operators would have, conditional on the control variables included in the regression, followed the same evolution. Figure 6 in the Appendix represents the evolution of average residuals from the estimation of equation (1) in the group of regulated and non-regulated countries over time, for ARPU in Euros and ARPU in Euros PPP.[34] It shows that both groups follow parallel trends prior to the regulation. During the first phase of the regulation, both groups seem to continue the same trend, but at some point the trends differ

[33] See for example the Report From the Commission to the European Parliament and the Council on the review of the roaming market of 29 November 2019, p. 6.

[34] Average residuals by group are reported based on the estimation including as control variables: GDP per capita, population density, dummy variables identifying mergers and acquisitions in the mobile market in each country, a dummy variable identifying the entry of a new mobile operator in a given country and a dummy variable identifying 4G commercial roll-out period for each operator in our sample.

Table 6: OLS estimates of the impact of the EU roaming regulation on operators' Average Revenues per User - Five regulation periods

Dep. Variable	Log(ARPU euros)			Log(ARPU euros PPP)		
	(1)	(2)	(3)	(4)	(5)	(6)
Did regu 2007q4-2009q3	-0.0320	-0.0251	-0.0435	-0.0736**	-0.0609	-0.0554
	(0.0364)	(0.0395)	(0.0356)	(0.0333)	(0.0367)	(0.0354)
Did regu 2009q4-2012q2	-0.223***	-0.189***	-0.155***	-0.125***	-0.0986*	-0.0907*
	(0.0483)	(0.0530)	(0.0510)	(0.0456)	(0.0541)	(0.0470)
Did regu 2012q3-2014q2	-0.309***	-0.265***	-0.225***	-0.187***	-0.153**	-0.146**
	(0.0625)	(0.0718)	(0.0670)	(0.0637)	(0.0769)	(0.0633)
Did regu 2014q3-2017q2	-0.311***	-0.270***	-0.238***	-0.167**	-0.155	-0.156**
	(0.0691)	(0.0797)	(0.0763)	(0.0772)	(0.0957)	(0.0777)
Did regu since 2017q3	-0.207***	-0.182**	-0.166**	-0.0909	-0.0942	-0.100
	(0.0764)	(0.0849)	(0.0816)	(0.0879)	(0.109)	(0.0873)
Log (GDP pc PPP)			0.391***			0.377*
			(0.116)			(0.210)
Log(Population Density)			-0.169			-0.0540
			(0.337)			(0.361)
Entry			-0.0757			-0.125*
			(0.0620)			(0.0706)
4G Commercial Rollout			-0.00207			-0.0132
			(0.0236)			(0.0228)
Constant	3.263***	3.262***	0.146	3.427***	3.426***	-0.0991
	(0.0263)	(0.0255)	(1.912)	(0.0272)	(0.0268)	(2.796)
Mergers		Yes	Yes		Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Operator Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,285	6,285	6,285	6,285	6,285	6,285
R-squared	0.576	0.607	0.628	0.641	0.655	0.669
Number of operators	111	111	111	111	111	111

Notes: Robust standard errors are in parenthesis. Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

and even inverse.

We further verify whether the parallel trends assumption is satisfied by running a placebo test, as suggested by Autor (2003). The test consists in introducing placebo treatments in the estimation equation at all periods except one. The following equation is estimated:

$$ln(y_{it}) = \alpha + \sum_{j \neq 2006q4-2007q3} \delta_j (G_i \cdot I(t = j)) + \eta_t + \lambda_i + \phi X_{it} + \varepsilon_{it} \quad (5)$$

where as before y_{it} represents ARPU for mobile operator i in quarter t. G_i represents the group of regulated countries, η_t are time-specific dummies, λ_i are operator specific fixed effects, X_{it} is a vector including the same set of control variables as in equation (1), and ε_{it} is the error term. The sum includes time dummies for all periods, except the year just before the entry into force of the first phase of the regulation (from 2006q4 to 2007q3). In equation (5), all coefficients δ_j with j preceding the last period before the regulation (from 2006q4 to 2007q3) are placebo tests for whether the regulation had an effect on ARPU between the two groups of countries prior to the regulation, which by definition should not be the case.

The estimated coefficients δ_j are plotted in Figure 7 in the Appendix for both ARPU in Euros and ARPU in Euros PPP. They suggest that there is no difference between the two groups before the regulation. None of the coefficients for periods preceding the entry into force of the regulation are significant (at 5% significance level), which confirms the parallel trends assumption. We note that after its first phase, the regulation decreased mobile operators' ARPU gradually, except for the last phase. This is consistent with a step-wise decrease in the wholesale and retail caps set by the regulation (see Figures 1 and 2 in section 2).

As a robustness test, Table 15 in the Appendix presents the OLS results of the same specifications from Table 5, including as additional control variable mobile termination rates (MTR) at the country level.[35] In practice, MTRs constituted an important front of regulatory intervention in the telecommunications market, in particular during the decade of the 2000s and the beginning

[35]MTRs at the operator level are available for mobile operators belonging to EU countries from reports published by the European Commission and the BEREC. Nonetheless, to our knowledge, this information is not publicly available at the operator level for other OECD countries outside the EU. We have thus considered average MTRs at the country level as reported by the European Commission, the BEREC and the OECD.

of the 2010s, which could explain part of the decrease in ARPU which we observe.[36] In general, there is a decreasing trend of MTRs in most of the OECD countries in our analysis, but with a different magnitude, which could explain differences in ARPU's evolution in the group of regulated and non-regulated countries.

When including MTRs in our regressions, in four out of six specifications, the coefficient representing the effect of the EU roaming regulation is negative and statistically significant (columns 1 to 4 in Table 15). In the remaining two specifications, which consider ARPU in Euros PPP as dependent variable, the coefficient is negative but non-statistically significant (columns 5 and 6 in Table 15). Note that how to consider the effect of MTR regulation on revenues during the period 2004-2018 is not a straightforward endeavour. First, systematic information about MTRs at the operator level is not readily available for operators in OECD countries outside the EU. This data availability limitation constraints us to use information at the country level. Second, the share of MNO's revenues from data services has increased sharply during the period. This suggests that the impact of MTR regulation on revenues, if ever existent, should be decreasing over time as it only concerns voice services (see Figure 8 in the Appendix). After reminding the need for caution when analyzing the effect of MTR regulation on revenues during the 2004-2018 period, we consider that these results are in line with the negative and statistically significant effect of the EU roaming regulation in our main specifications.

Beyond MTR regulation, there might be very different regulatory trends across OECD countries in our analysis regarding other intervention fronts (e.g, cost of capital, universal services, access regulation, etc.) affecting the costs of providing mobile services. Such differentiated trends could also explain differences in the evolution of mobile operators' ARPU in EEA countries relative to those in OECD countries outside the EEA. As an additional robustness test, Table 16 in the Appendix presents the OLS results of the same specifications from Table 5, including as additional control variable an index of product market regulation (PMR) specific to the telecommunications sector.[37] The OECD PMR indicators are, to the best of our knowledge, the only regulatory

[36]For instance, at the European level, the average MTR decreased by 86% between January 2004 and January 2014 (from around 14 to 2 euro-cents). Calculations based on: BEREC, BoR (19) 91, Termination rates at the European level, January 2019.

[37]Sector specific PMR indicators measure countries' regulatory stance and track reform progress over time. In particular, they measure the regulatory barriers to firm entry and competition at the level of individual sectors. We use the index for "E-communications" within the "Network Sector PMR indicators – Time series" produced by

indicators specific to the telecommunications sector providing sufficient historic data to carry-out our difference-in-differences analysis. However, they do not include information about three countries in our sample: USA, Latvia and Lithuania. We are thus forced to exclude them from the test. In all 6 specifications from Table 16, we find a negative and statistically significant effect of the regulation on operators' ARPU, similar in magnitude to the coefficients on Table 5. We believe these results are not driven by the exclusion of USA, Latvia and Lithuania from the sample. Very similar results hold when estimating the specifications on Table 5 without the PMR index and using the restricted sample.[38]

Finally, we also test for differences in the effect of the regulation for incumbent relative to non-incumbent operators and for big operators relative to small ones. The results suggest that there is no specific effect in neither case. Moreover, we checked whether mobile operators in countries with higher tourism flows were more or less impacted by the regulation. The results suggest that operators in countries with a higher number of departures per capita within the group of regulated countries have a higher ARPU during the regulation period. This result is consistent with a particular decrease in roaming wholesale expenditure in countries with a high proportion of departures per capita in the EU. On the contrary, operators in countries with a higher number of net arrivals per capita within the group of regulated countries have a particularly lower ARPU during the regulation period. This result could be explained by roaming wholesale revenues that decrease relatively more in those countries due to the regulation.[39]

5.2 Analysis of Tariffs

Table 7 reports the OLS results from our hedonic price model (3), using as dependent variables tariffs in US dollars (column 1) and tariffs in US dollars PPP (column 2). The coefficient of the dummy variable for the presence of voice minutes in the tariff plan is positive and statistically significant, which implies that plans including voice are more expensive. The coefficient of the

the OECD. See: https://www.oecd.org/economy/reform/indicators-of-product-market-regulation/. Other indicators of regulatory activity or intensity exist (e.g., "ICT Regulatory Tracker" by the ITU). However, to the best of our knowledge, no other indicator covers a sufficiently long period as the one needed for our difference-in-differences analysis.

[38]These results are not reported here due tu space constraints, but are available upon request.

[39]The table results corresponding to this last set of tests are not reported here due to space constraints, but are available upon request.

dummy variable for prepaid plans is negative but not significant for tariffs in USD and statistically significant at the 10% level for tariffs in USD PPP. Nonetheless, the coefficient of the interaction term identifying prepaid plans with voice included is negative and significant, which indicates that prepaid plans including voice are cheaper that postpaid plans including voice. Almost all coefficients for dummy variables for prepaid plans, which identify different number of days of data validity are positive but non statistically significant. Only the coefficient for data validity greater than 180 days is positive and significant for both tariffs in USD and USD PPP, which indicates that prepaid plans with validity of more than 180 days are more expensive. Prepaid plans which include credit are also more expensive than those without credit.

Regarding postpaid plans, contract length does not seem to influence in a monotonic way the price of tariff plans. The coefficients of dummy variables identifying different minute allowances are almost all non-statistically significant, except for allowance between 500 and 1600 minutes, which is positive and statistically significant. Also, tariff plans with infinite minute allowances do not appear to be more expensive. The majority of coefficients for different SMS allowances are non-statistically significant. Not surprisingly, this suggests that the inclusion of more or less SMS allowances does not affect the price of tariff plans. Finally, as expected, prices increase gradually with the inclusion of greater data allowances. In particular, coefficients identifying data allowances above 1GB are all positive and statistically significant. Thus, data allowance is the main factor which impacts the price of tariff plans.

Figure 4 illustrates the evolution of country-quarter interaction dummies from our hedonic regression in Table 7, which represent the quality-adjusted price indices for each country in our sample. We use them as dependent variables in the second stage of our analysis.[40]

[40]The quality-adjusted price indices shown in this figure correspond to the regression based on tariff plans in USD. They are very similar to those obtained from the regression based on tariff plans in USD PPP.

Table 7: OLS estimates of Hedonic Price Regression for All Tariffs

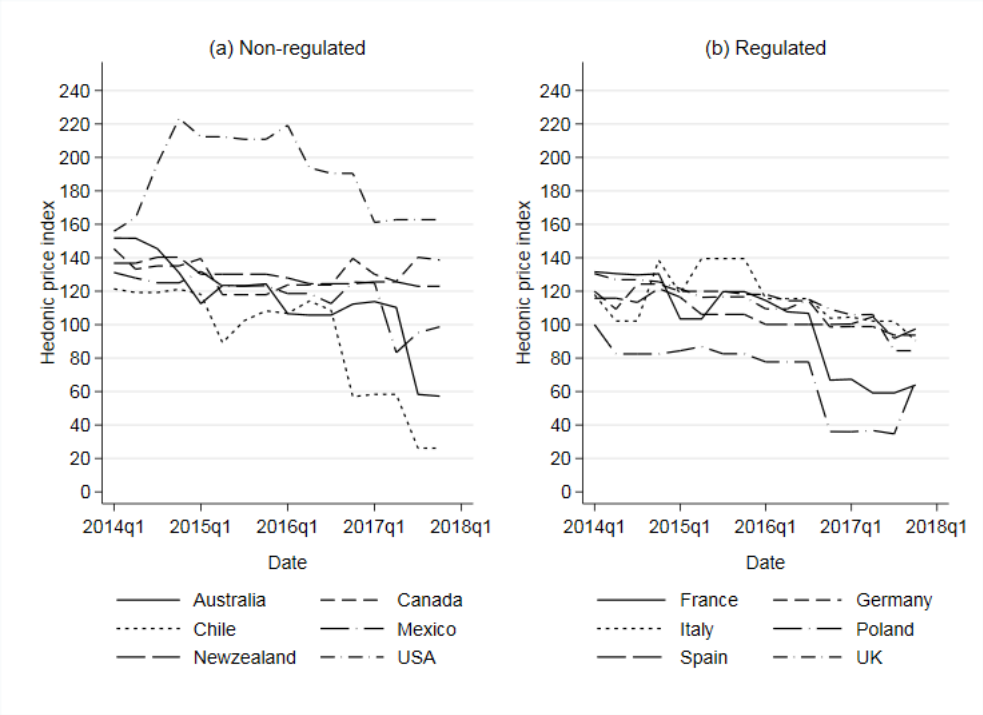
	(1)		(2)	
Dep. Variable	Tariff USD		Tariff USD PPP	
Voice	27.69***	(7.521)	29.55***	(8.358)
Voice * Prepaid	-17.16***	(6.093)	-16.09**	(6.652)
Prepaid	-8.705	(7.516)	-17.09*	(8.957)
Prepaid data validity (days)				
PrepaidV [15,30)	6.355	(7.949)	8.670	(8.730)
PrepaidV [30,60)	6.546	(4.647)	12.61**	(5.601)
PrepaidV [60,180)	7.574	(10.63)	15.01	(11.03)
PrepaidV (>180]	52.44***	(11.95)	61.14***	(13.39)
Postpaid contract length (months)				
PostL 6	-10.12*	(5.418)	-18.47**	(6.986)
PostL 12	-1.650	(2.537)	-0.116	(2.995)
PostL 18	0.982	(2.364)	5.620**	(2.571)
PostL 24	2.584	(3.100)	1.552	(3.287)
Credit included	24.05***	(7.871)	25.85***	(8.484)
Minutes allowance				
Minutes (0,50]	-7.599*	(4.260)	-5.232	(4.898)
Minutes (50,100]	-3.297	(5.350)	-4.021	(5.410)
Minutes (100,150]	-5.786	(4.414)	-5.458	(4.925)
Minutes (150,200]	-2.118	(4.131)	-3.278	(4.816)
Minutes (200,300]	-0.969	(5.118)	0.239	(5.775)
Minutes (300,400]	-0.896	(6.199)	-2.301	(7.617)
Minutes (400,500]	4.641	(4.419)	6.900	(5.476)
Minutes (500,1600]	16.77***	(4.674)	26.44***	(6.505)
Minutes (>1600)	5.199	(5.005)	6.949	(5.301)
SMS allowance				
SMS (0,50]	-8.206	(6.252)	-4.719	(9.155)
SMS (50,100]	-9.897	(6.780)	-16.12*	(8.652)
SMS (100,200]	1.575	(8.543)	-1.317	(11.35)
SMS (200,250]	-6.585	(6.507)	-4.584	(8.761)
SMS (250,500]	-7.429	(8.253)	-7.109	(11.65)
SMS (500,750]	-14.64**	(6.379)	-16.49**	(7.498)
SMS (750,1000]	-5.238	(5.787)	0.110	(6.691)
SMS (1000,1500]	-1.035	(4.752)	11.46	(9.793)
SMS (>1500]	-8.646	(5.626)	-7.150	(7.353)
Data allowance (GB)				
Data [0.01,0.25)	8.534**	(3.705)	11.65**	(5.334)
Data [0.25,0.5)	5.121	(3.420)	7.427*	(3.891)
Data [0.5,1)	5.183	(4.296)	-0.175	(4.581)
Data [1,2)	8.667**	(3.260)	9.340**	(3.754)
Data [2,3)	14.63***	(4.085)	18.20***	(4.382)

	(1)		(2)	
Dep. Variable	Tariff USD		Tariff USD PPP	
Data [3,4)	22.13***	(3.956)	28.09***	(6.252)
Data [4,5)	17.00**	(6.421)	22.85***	(7.276)
Data [5,6)	33.59***	(4.886)	39.72***	(6.027)
Data [6,7)	28.99***	(6.441)	39.49***	(7.772)
Data [7,8)	41.57***	(5.887)	46.69***	(5.480)
Data [8,9)	33.42***	(6.185)	45.02***	(8.814)
Data [9,10)	47.43***	(9.133)	62.52***	(6.058)
Data [10,11)	46.52***	(4.078)	57.18***	(5.903)
Data [11,13)	38.71***	(7.830)	52.80***	(11.63)
Data [13,15)	39.54***	(10.73)	58.97***	(15.89)
Data [15,20)	46.00***	(6.555)	54.58***	(7.196)
Data [20,25)	56.80***	(5.599)	64.58***	(6.743)
Data [25,30)	56.94***	(8.565)	67.98***	(9.219)
Data [30,40)	86.78***	(14.76)	96.96***	(15.22)
Data [40,50)	111.1***	(24.37)	120.2***	(24.17)
Data [50,60)	157.9***	(33.82)	171.0***	(32.87)
Data [60,100)	282.1***	(52.26)	291.9***	(51.61)
Data (>100]	262.8**	(103.1)	268.7**	(104.0)
Constant	-13.61	(10.82)	-3.695	(12.46)
Country-quarter dummies	Yes		Yes	
Observations	11,496		11,496	
R-squared	0.647		0.633	

Notes: Clustered standard errors at the country-year level are in parenthesis. Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

The results from the second stage of our price analysis, which correspond to estimating equation (4), are reported in Table 8 for tariff plans in USD and USD PPP, respectively. In columns (1) and (4) no control variables are included in the estimation except for quarter and country fixed effects. Columns (2) and (5) present the results of regressions which take into account HHI, fixed broadband penetration (fixed broadband subscriptions per 100 people), GDP per capita and population density as control variables. Columns (3) and (6) report the results of the regressions including the same control variables, except for population density which is replaced by the proportion of urban population in the country. We find that the coefficients corresponding to our measure of concentration (HHI) are positive and statistically significant. The coefficients for fixed broadband penetration are non-statistically significant. The coefficients of GDP per capita and population density are positive and statistically significant. The proportion of urban population presents posi-

Figure 4: Quarterly Coefficients for All Tariffs - Quality-Adjusted Price Index by Country



tive coefficients, but it is only statistically significant when considering tariffs in USD PPP. Finally, the interaction term on RLAH, which identifies the effect of the last phase of the regulation on quality-adjusted prices, is positive but non-statistically significant in all the specifications. This result suggests that quality-adjusted prices in selected EU countries did not change after the latest phase of the roaming regulation.

This final result suggests that the potential negative distributional effects of RLAH feared by policy makers have not materialized. Moreover, it seems in line with the idea that the fair use policy and sustainability derogation rules introduced with the RLAH regime have adequately worked as safeguards to avoid distortions on domestic markets. The fair use policy aims at ensuring that roaming at domestic prices is not used permanently, only when periodically travelling in the EEA. For this purpose, mobile operators can set limits to the use of roaming services.[41] A sustainability

[41] A mobile operator may ask its customers for a proof of residence in, or stable link with, the EEA country where it provides services and issues the SIM card to be used at domestic prices when travelling abroad. An operator may also check that the SIM card is used more in its home Member State than abroad. If such a fair use policy is applied and, during a time window of at least four months, the customer has roaming consumption prevailing over domestic consumption, the operator has to alert the customer to verify whether there is any abusive or anomalous

derogation consists of an exceptional permission granted to the operator by its national regulatory authority (NRA) to apply surcharges for roaming services.[42]

Table 8: OLS estimates of the impact of the RLAH phase of EU roaming regulation on tariffs

	Tariff USD			Tariff USD PPP		
	(1)	(2)	(3)	(4)	(5)	(6)
Did RLAH	5.856	3.107	4.564	5.576	0.348	1.292
	(5.334)	(4.794)	(5.830)	(5.209)	(5.390)	(5.514)
HHI		281.9***	239.1***		284***	235.2***
		(62.652)	(62.184)		(59.718)	(68.591)
Fixed Broadband (subs. per 100 people)		0.616	0.955		-0.757	-1.205
		(1.809)	(1.732)		(1.714)	(1.779)
GDP per capita		1.656***	1.46***		3.045***	3.267***
		(0.381)	(0.318)		(1.021)	(0.862)
Population Density		2.326***			2.312***	
		(0.612)			(0.582)	
Urban (% of total population)			1.472			8.830*
			(4.117)			(4.734)
Constant	84.09***	-312***	-105.3	81.94***	-341.7***	-572.1**
	(5.491)	(90.925)	(241.703)	(6.936)	(83.533)	(278.093)
Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	192	192	192	192	192	192
R-squared	0.837	0.850	0.848	0.793	0.808	0.807

Notes: Bootstrap standard errors in parenthesis (100 repetitions). Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

use of roaming services at domestic prices. After a period of 14 days or more, from the date of the alert, the operator may apply small roaming surcharges linked to the wholesale price caps if the customer continues to consume mobile services abroad. Operators may also apply a volume safeguard on roaming data consumed at domestic prices. Beyond that volume, the operator may apply a small roaming surcharge not exceeding the wholesale roaming price cap on data. The main objective is to allow for the continuous development of the best data offers, in particular unlimited data allowances plans. See: Commission Staff Working Paper SWD(2019) 288 final, page 3.

[42]This provision is exceptional and only applies in specific circumstances. The main objective is to avoid domestic price increases. For this purpose, the operator must demonstrate that the provision of roaming services without the application of a surcharge would not be sustainable with its current domestic charging model. In that case, the National Regulation Authority may authorize the operator to apply a small roaming surcharge for one year. In order to prolong such an authorization, the operator must renew its application yearly. See: Commission Staff Working Paper SWD(2019) 288 final, pages 3 and 4.

6 Conclusion

Using detailed operator and tariff plan-level data, we assess the impact of EU roaming regulation on the average revenue per user and on the quality adjusted prices set by mobile network operators. The EU roaming regulation has been an important effort for pursuing the consolidation of a digital single market in the EU, whose impact and potential unintended consequences have been debated since its beginning.

Our results suggest that ARPU of EU mobile network operators has decreased on average by 12.6% since 2007 due to the regulation. When considering power purchasing parities, the decline of ARPU is quantified at 9.3% on average. Although a possible waterbed effect could have prompted mobile network operators to increase their domestic retail tariff plans after the RLAH regime entered into force, we find no evidence of such response.

Our results entail important policy implications. First, they suggest that in its quest for substantially reducing international roaming charges in the EU and promoting greater use of roaming services, the European Commission has succeeded to avoid unintended increases in domestic tariffs. This means that, at least up to some extent, the potential negative distributional effects of RLAH pointed out by BEREC in 2014 do not seem to have materialized. Moreover, this suggests that the fair use policy and sustainability derogation rules have adequately worked as safeguards to avoid distortions on domestic markets, as foreseen by the regulation and argued in several reports.[43] Second, our results suggest that mobile network operators have absorbed the effects of the regulation and have seen their revenues per user decrease over the course of the regulation period. An important consideration is that the observed decrease in ARPU could have translated into a decrease in mobile operators' profits, which we cannot verify due to limited data on profits.[44] The risks of such potential effect include lowering the quality of mobile operators' offers and reducing incentives to invest. Regarding the former, qualitative studies suggest that overall, the availability of operators' tariff plans and their domestic tariff structures have been largely unchanged after the regulation.[45] As regards to the latter, to our knowledge no formal studies exist and there is no

[43] See: Commission Staff Working Paper SWD(2019) 288 final.

[44] The reason why we do not address this question directly is that information about mobile operators' profits is scarcer and less complete than information about revenues.

[45] See: Commission Staff Working Paper SWD(2019) 288 final.

sufficient evidence allowing to conclude on this.

Thus, to balance the short-run benefits of the EU roaming regulation with its long-run consequences, the extent to which the regulation has affected mobile operators' incentives to provide high quality offers and to invest in their networks is an important question that is worth the attention of policy makers. Likewise, due to significant differences across Member States in travel and consumption patterns, as well as in mobile operators' cost structures, it is imperative to assess whether the regulation has introduced any distortions across the EU countries. Finally, the assessment of welfare effects of roaming regulation and how it is distributed across Member States is an interesting avenue of further research, which we do not address here due to lack of detailed information about demand for roaming services.

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Appendix

Table 9: EU Roaming Regulations

Title and reference	Date of document	Date of effect
Regulation (EC) No 717/2007 of the European Parliament and of the Council of 27 June 2007 on roaming on public mobile telephone networks within the Community and amending Directive 2002/21/EC	27/06/2007	30/06/2007
Regulation (EC) No 544/2009 of the European Parliament and of the Council of 18 June 2009 amending Regulation (EC) No 717/2007 on roaming on public mobile telephone networks within the Community and Directive 2002/21/EC on a common regulatory framework for electronic communications networks and services	18/06/2009	02/07/2009
Regulation (EU) No 531/2012 of the European Parliament and of the Council of 13 June 2012 on roaming on public mobile communications networks within the Union Text with EEA relevance	13/06/2012	01/07/2012
Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services and Regulation (EU) No 531/2012 on roaming on public mobile communications networks within the Union (Text with EEA relevance)	25/11/2015	29/11/2015
Commission Implementing Regulation (EU) 2016/2286 of 15 December 2016 laying down detailed rules on the application of fair use policy and on the methodology for assessing the sustainability of the abolition of retail roaming surcharges and on the application to be submitted by a roaming provider for the purposes of that assessment (Text with EEA relevance)	15/12/2016	17/12/2016
Regulation (EU) 2017/920 of the European Parliament and of the Council of 17 May 2017 amending Regulation (EU) No 531/2012 as regards rules for wholesale roaming markets	17/05/2017	12/06/2017

Table 10: Analysis of ARPU: List of treated countries and mobile network operators with respective 4G commercial launch dates

Country	Operator	4G commercial launch date	4G Quarter of effect
Austria	A1 Telekom Austria	November 2010	2010Q4
	Hutchison 3G Austria	November 2014	2014Q4
	Orange Austria	November 2014 (acq. by 3)	2014Q4
	T-Mobile Austria	July 2011	2011Q3
Belgium	Orange Belgium	March 2014	2014Q2
	Proximus Belgium	November 2012	2012Q4
	Telenet	October 2013	2013Q4
Czech Republic	O2 Czech Republic	June 2012	2012Q4
	T-Mobile Czech Republic	October 2013	2013Q4
	Vodafone Czech Republic	December 2013	2014Q1
Denmark	HI3G Denmark	September 2012	2012Q4
	TDC Mobil	October 2011	2011Q4
	Telenor Denmark	March 2013	2013Q2
	Telia Denmark	December 2010	2011Q1
Estonia	EMT Estonia	December 2010	2011Q1
	Elisa Estonia	February 2013	2013Q1
	Tele2 Estonia	November 2012	2012Q4
Finland	DNA Finland	December 2011	2012Q1
	Elisa Finland	December 2010	2011Q1
	Telia Company Finland	November 2010	2010Q4
France	Bouygues Telecom	October 2013	2013Q4
	Numericable-SFR	November 2012	2012Q4
	Orange France	April 2013	2013Q2
Germany	E-Plus	March 2014	2014Q2
	O2 Germany	July 2011	2011Q3
	T-Mobile Germany	April 2011	2011Q2
	Vodafone D2	December 2010	2011Q1
Greece	Cosmote	November 2012	2012Q4
	Vodafone Greece	June 2013	2013Q3
	WIND Hellas	March 2015	2015Q2
Hungary	T-Mobile Hungary	January 2012	2012Q1
	Telenor Hungary	July 2012	2012Q3
	Vodafone Hungary	November 2014	2014Q4
Ireland	O2 Ireland	June 2015	2015Q3
	Three Ireland (Hutchison)	September 2013	2013Q4
	Vodafone Ireland	October 2013	2013Q4
	eir Mobile	September 2013	2013Q4
Italy	Iliad Italy	May 2018	2018Q2
	Telecom Italia	November 2012	2012Q4

Country	Operator	4G commercial launch date	4G Quarter of effect
	Vodafone Italia	November 2012	2012Q4
	Wind	January 2014	2014Q1
	Wind Tre	January 2014	2014Q1
Latvia	Bite Latvia	May 2015	2015Q2
	LMT	May 2011	2011Q2
	Tele2 Latvia	December 2013	2014Q1
	Telekom Baltija	Non available	
Lithuania	Bite Lithuania	April 2015	2015Q2
	Omnitel	April 2011	2011Q2
	Tele2 Lithuania	March 2013	2013Q2
Netherlands	KPN Mobile	May 2012	2012Q2
	T-Mobile Netherlands	May 2012	2012Q2
	Vodafone Libertel	May 2012	2012Q2
Norway	Telenor Mobil	October 2012	2012Q4
	Telia Norway	December 2009	2010Q1
Poland	Orange (Poland)	September 2013	2013Q4
	P4	Novemeber 2013	2013Q4
	Plus (Cyfrowy Polsat SA)	September 2012	2012Q4
	T-Mobile Poland	June 2014	2014Q3
Portugal	MEO Portugal	March 2012	2012Q2
	NOS	March 2012	2012Q2
	Vodafone Portugal	March 2012	2012Q2
Slovakia	Orange Slovak Republic	July 2014	2014Q3
	T-Mobile Slovak Republic	November 2013	2013Q4
Slovenia	A1 Slovenia	July 2012	2012Q3
	Mobitel Slovenia	March 2013	2013Q2
Spain	Orange Spain	July 2013	2013Q3
	Telefonica Moviles	February 2013	2013Q1
	Vodafone Espana	May 2013	2013Q2
Sweden	HI3G	April 2012	2012Q2
	Tele2 Sweden	November 2010	2010Q4
	Telenor Sweden	November 2010	2010Q4
	TeliaSonera Sweden	December 2009	2010Q1
UK	O2 (UK)	August 2013	2013Q3
	Orange UK	October 2012	2012Q4
	T-Mobile UK	October 2012	2012Q4
	Vodafone UK	August 2013	2013Q3

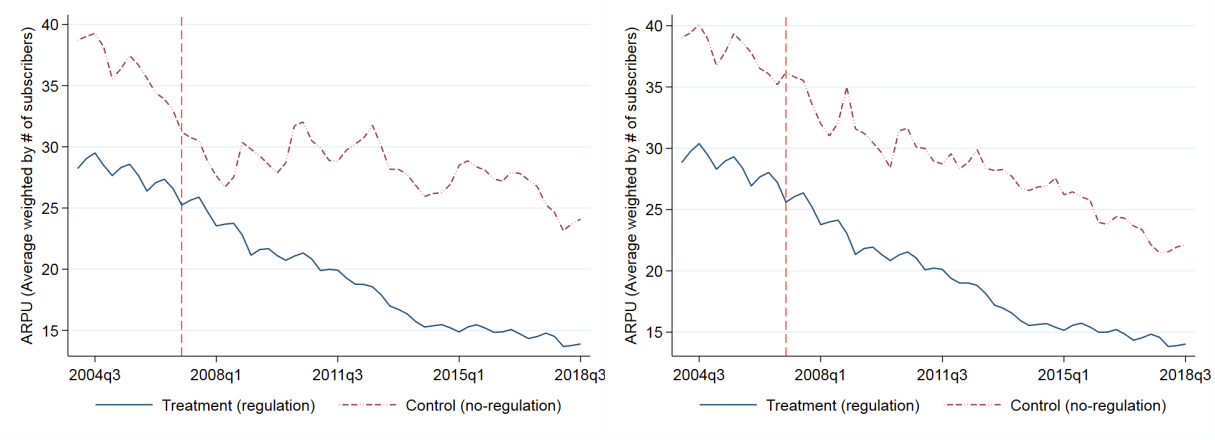
Table 11: Analysis of ARPU: List of control countries and mobile network operators with respective 4G commercial launch dates

Country	Operator	4G commercial launch date	Quarter of effect
Australia	Optus	September 2012	2012Q4
	Telstra	September 2011	2011Q4
	VHA	June 2013	2013Q3
Canada	Bell Wireless Affiliates	September 2011	2011Q4
	MTS Mobility	September 2012	2012Q4
	Rogers Wireless Communications	July 2011	2011Q3
	SaskTel Mobility	January 2013	2013Q1
	Telus Mobility	February 2012	2012Q1
Chile	Claro Chile	June 2013	2013Q3
	Entel Chile	March 2014	2014Q2
	Movistar Chile	November 2013	2013Q4
Israel	Cellcom Israel	August 2014	2014Q3
	Hot Mobile	January 2015	2015Q1
	Partner Communications	July 2014	2014Q3
	Pelephone	August 2014	2014Q3
Japan	KDDI	September 2012	2012Q4
	NTT DoCoMo	December 2010	2011Q1
	Softbank Mobile	February 2012	2012Q1
Mexico	AT&T Mexico	October 2014	2014Q4
	Movistar Mexico	October 2012	2012Q4
	Nextel Mexico	April 2015	2015Q2
	Telcel Mexico	December 2012	2013Q1
New Zealand	Spark New Zealand	November 2013	2013Q4
	Vodafone New Zealand	February 2013	2013Q1
Switzerland	Salt	May 2013	2013Q2
	Sunrise	June 2013	2013Q3
	Swisscom Mobile	November 2012	2012Q4
Turkey	Turk Telekom	April 2016	2016Q2
	Turkcell	April 2016	2016Q2
	Vodafone Turkey	April 2016	2016Q2
USA	AT&T Mobility USA	September 2011	2011Q4
	Sprint Nextel USA	July 2012	2012Q3
	T-Mobile US	Septembre 2010	2010Q4
	US Cellular	March 2012	2012Q2
	Verizon Wireless	December 2010	2011Q1

Table 12: Mobile network operator entries since 2004 - OECD countries in our sample

Country	**Operator**	**Date**	**Quarter of effect**
Chile	Nextel (WOM)	May 2006	2006Q2
France	Free	January 2012	2012Q1
Ireland	Three Ireland	July 2005	2005Q3
Israel	Golan Telecom	May 2012	2012Q2
Italy	Iliad	May 2018	2018Q2
Latvia	SIA Bite Latvia	January 2005	2005Q1
New Zealand	2degrees	August 2009	2009Q3
Norway	Network Norway (Ice)	September 2007	2007Q4
Poland	Play	February 2007	2007Q1
Slovakia	O2	February 2007	2007Q1
Slovenia	Telematch (Tusmobil)	October 2007	2007Q4
Spain	Yoigo	December 2006	2007Q1
Ukraine	Lifecell	January 2005	2005Q1

Figure 5: Evolution of ARPU by group (average weighted by number of subscribers)



(a) ARPU in Euros

(b) ARPU in Euros PPP

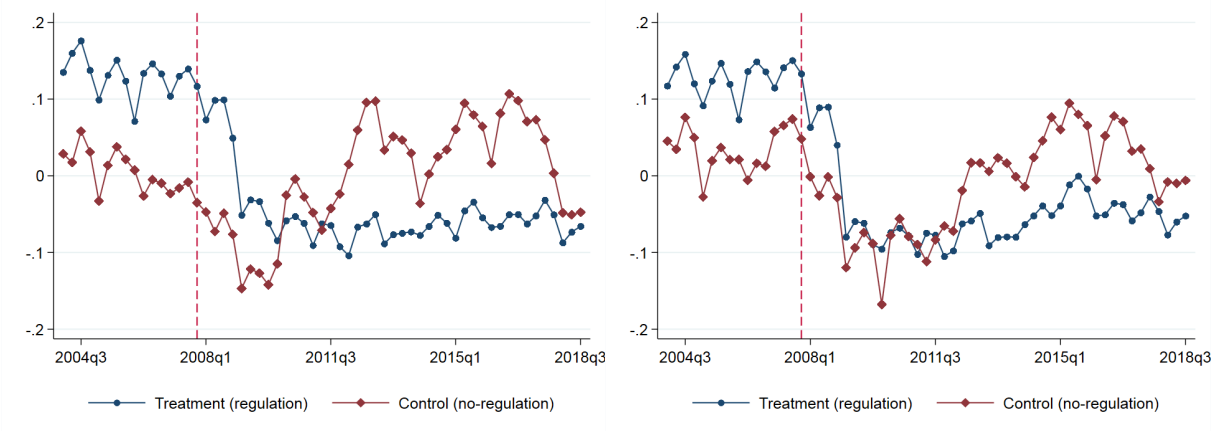
Table 13: Mobile network operator mergers since 2004 - OECD countries in our sample

Country	**Operator**	**Date**	**Quarter of effect**
Australia	Hutchison Australia's operations (3) were merged with Vodafone Australia to form VHA.	June 2009	2009Q3
Austria	Mobile and Tele.ring merger.	April 2006	2006Q2
Austria	Hutchison Whampoa acquired Orange Austria.	February 2013	2013Q1
Chile	Telefonica acquired Bellsouth and merged it with its mobile subsidiary Telefonica Movil. They formed what is called today as Movistar Chile.	February 2005	2005Q1
Germany	Takeover of E-Plus by Telefonica Germany.	October 2014	2014Q4
Ireland	O2 was merged into Hutchison Whampoa's subsidiary Three Ireland.	March 2015	2015Q2
Italy	Merger between Wind Telecomunicazioni and 3 Italy to create a sole new company Wind Tre.	November 2016	2016Q4
Mexico	Nextel and Lusacell dissapear to form AT&T Mexico, after the succesive acquisitions of Lusacell (January 2015) and Nextel (April 2015).	April 2016	2016Q2
Netherlands	KPN Mobile and Telfort merge after KPN's acquisition of Telfort.	August 2005	2005Q3
Netherlands	Deutsche Telekom (T-Mobile) acquires Orange Netherlands.	September 2007	2007Q4
Netherlands	T-Mobile Netherlands acquires Tele2 Netherlands.	January 2019	2019Q1
Norway	Tele2 was acquired by TeliaSonera, Network Norway was divested to Ice.	November 2015	2015Q4
UK	Orange UK merged with Deutsche Telekom's T-Mobile UK to form a joint venture (EE).	April 2010	2010Q2
USA	Western Wireless merged with Alltel Corporation.	August 2005	2005Q3
USA	AT&T acquisition of Dobson Cellular with market transition in December 2007.	February 2008	2008Q1
USA	T-Mobile acquired SunCom, which brand was phased out in September 2008.	September 2008	2008Q4
USA	Verizon Wireless acquired RCC (Rural Cellular Corporation).	January 2009	2009Q1
USA	The remaining activity of Alltel was acquired by AT&T.	January 2013	2013Q1
USA	T-Mobile acquires Metro PCS.	May 2013	2013Q2
USA	AT&T acquired Leap Wireless.	July 2013	2013Q3
USA	Verizon Wireless acquired Cincinnati Bell.	October 2014	2014Q4

Table 14: Summary statistics by group at the country level - focus on 2007q3 (quarter before the regulation)

	Group	Mean	Std. Dev.	Min	Max
Population (in millions)	Control	69.9	92.7	4.2	301.0
	Treatment	20.3	24.1	1.3	80.9
Population density	Control	105.1	127.4	2.7	336.6
	Treatment	123.5	100.6	12.2	395.9
GDP per capita (Euros)	Control	23537.41	13499.8	6902.3	46429.2
	Treatment	26336.56	14267.6	8222.1	62218.7
GDP per capita (Euros PPP)	Control	25631.1	10704.0	11539.8	40997.5
	Treatment	26407.6	8372.1	13835.5	46066.2
ARPU in euros	Control	28.1	11.4	9.8	41.9
	Treatment	26.2	9.2	7.2	42.1
ARPU in euros PPP	Control	32.3	9.5	16.9	42.9
	Treatment	27.9	5.7	12.7	36.2
Number of operators per country	Control	3.5	1.0	2.0	5.0
	Treatment	3.3	0.8	2.0	5.0

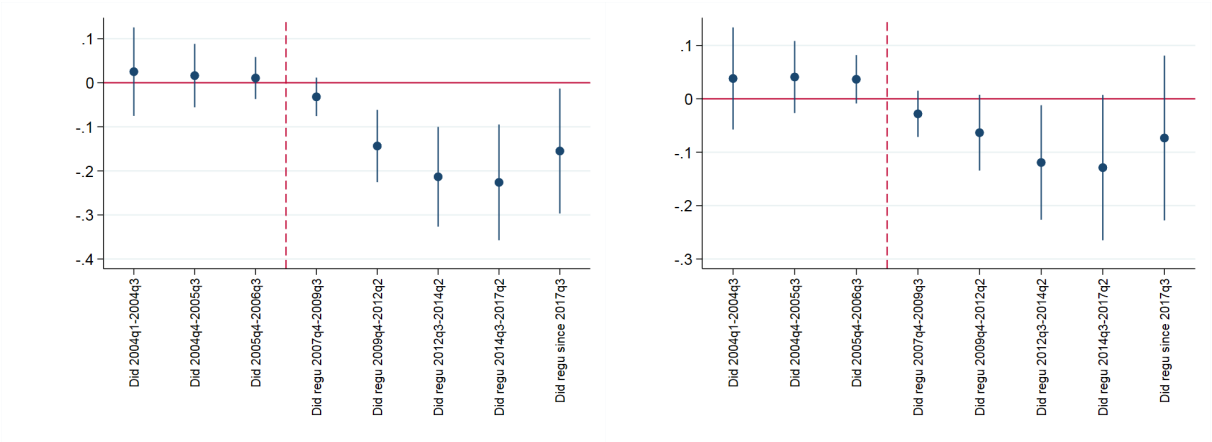
Figure 6: Parallel trends assumption - Evolution of average residuals from full regression by group



(a) ARPU in Euros

(b) ARPU in Euros PPP

Figure 7: Parallel trends assumption - Placebo test - Time relative to the regulation



(a) ARPU in Euros

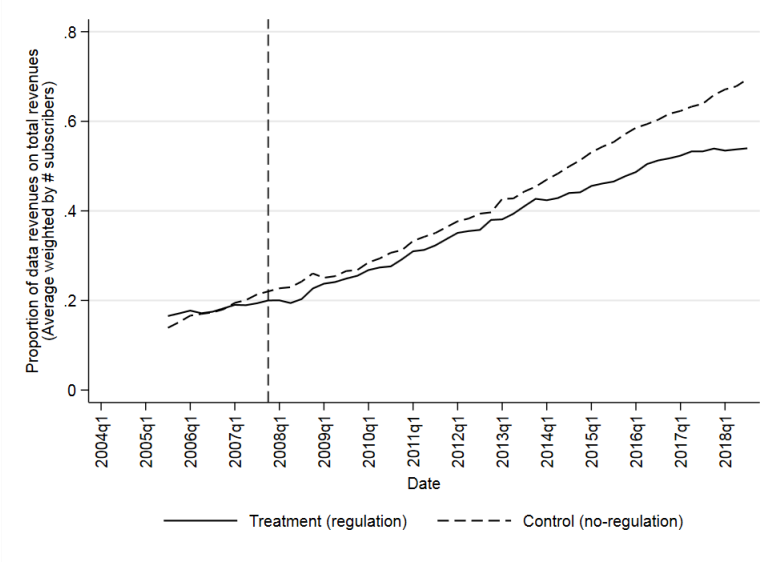
(b) ARPU in Euros PPP

Table 15: OLS estimates of the impact of the EU roaming regulation on operators' Average Revenues per User including the effect of Mobile Termination Rates

Dep. Variable	Log(ARPU euros)			Log(ARPU euros PPP)		
	(1)	(2)	(3)	(4)	(5)	(6)
Did regu since 2007q4	-0.156***	-0.130**	-0.0956**	-0.0980*	-0.0812	-0.0599
	(0.0516)	(0.0502)	(0.0392)	(0.0526)	(0.0595)	(0.0400)
Log(MTR+1)	2.257***	2.341***	2.185***	1.138***	1.188***	1.849***
	(0.563)	(0.671)	(0.643)	(0.352)	(0.409)	(0.483)
Log(GDP pc PPP)			0.449***			0.656***
			(0.107)			(0.197)
Log(Population Density)			-0.00801			-0.0955
			(0.331)			(0.318)
Entry			-0.0769			-0.113
			(0.0617)			(0.0713)
4G commercial Rollout			-0.0110			-0.0240
			(0.0238)			(0.0228)
Constant	2.990***	2.979***	-1.363	3.262***	3.253***	-2.965
	(0.0744)	(0.0896)	(1.848)	(0.0594)	(0.0690)	(2.528)
Mergers		Yes	Yes		Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Operator Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,285	6,285	6,285	6,285	6,285	6,285
R-squared	0.575	0.610	0.637	0.649	0.663	0.688
Number of idop	111	111	111	111	111	111

Notes: Robust standard errors are in parenthesis. Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Figure 8: Evolution of average data revenue share of MNOs in the OECD by group of regulated and non-regulated countries



Note: Own calculations based on OVUM data. The number of countries and operators considered changes over time depending on the availability of information about total revenues, data revenues and number of subscribers per operator. Considering these caveats, the figure shows the general trend observed for all operators in the database. The vertical dashed line represents the start date of the EU roaming regulation.

Figure 9: Evolution of Quality-Adjusted Price Index by Group

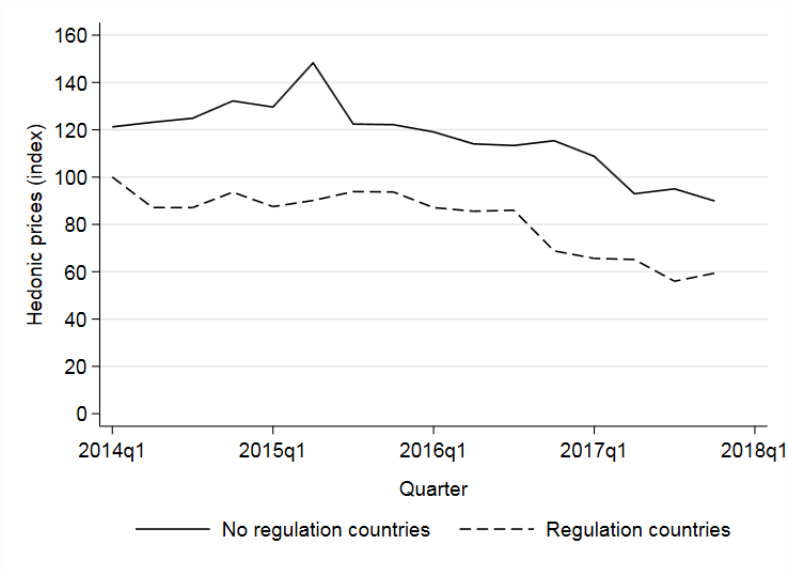


Table 16: OLS estimates of the impact of the EU roaming regulation on operators' Average Revenues per User including the effect of regulatory intensity

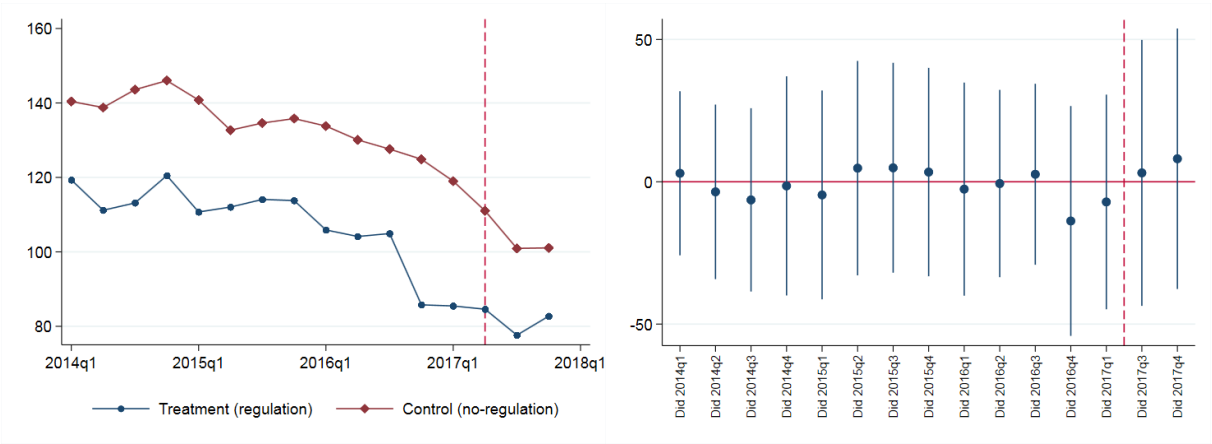
Dep. Variable	Log(ARPU euros)			Log(ARPU euros PPP)		
	(1)	(2)	(3)	(4)	(5)	(6)
Did regu since 2007q4	-0.231***	-0.191***	-0.132***	-0.135**	-0.118*	-0.0938*
	(0.0551)	(0.0569)	(0.0498)	(0.0559)	(0.0596)	(0.0490)
Regulatory Intensity Index	-0.00159	-0.0284	0.0259	0.0323	0.0177	0.0358
	(0.0487)	(0.0517)	(0.0523)	(0.0516)	(0.0605)	(0.0472)
Log (GDP per capita)			0.479***			0.427*
			(0.115)			(0.222)
Log(Population Density)			0.223			0.158
			(0.407)			(0.406)
Entry			-0.0604			-0.103
			(0.0645)			(0.0745)
4G Commercial Rollout			-0.00185			-0.0137
			(0.0221)			(0.0204)
Constant	3.287***	3.323***	-2.411	3.375***	3.395***	-1.559
	(0.0673)	(0.0730)	(2.177)	(0.0665)	(0.0778)	(2.789)
Mergers		Yes	Yes		Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Operator Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,595	5,595	5,595	5,595	5,595	5,595
R-squared	0.598	0.630	0.655	0.666	0.681	0.693
Number of operators	99	99	99	99	99	99

Notes: Robust standard errors are in parenthesis. Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 17: Analysis of tariffs - list of treatment and control countries and mobile operators

Treated	Control
France Orange	Australia Telstra
Germany T-Mobile	Canada Rogers Wireless
Italy TIM	Chile Movistar
Poland Orange	Mexico Telcel
Spain Movistar	New Zealand Vodafone
UK EE	USA Verizon Wireless

Figure 10: Parallel trends assumption - Time relative to the latest phase of the regulation



(a) Average residuals by group

(b) Placebo test