Evaluating the Impact of Price Caps - Evidence from the European Roam-Like-at-Home Regulation*

Giulia Canzian[a], Gianluca Mazzarella[b], Louis Ronchail[b], Frank Verboven[c], and Stefano Verzillo[b]

[a]European Commission, Joint Research Centre (JRC), Ispra, Italy and CESifo - Munich (Germany) - Corresponding author, giulia.canzian@ec.europa.eu

[b]University of Milan, Department of Economics, Management and Quantitative Methods (Italy)

[c]European Commission, Joint Research Centre (JRC)

[d]KU Leuven, Department of Economics (Belgium) and CEPR - London

Disclaimer:

The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any other person on behalf of the Commission is responsible for the use that might be made of this publication.

Declarations of interests: none

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

*We are particularly grateful for comments and suggestions to Matthieu Delescluse, Erika Busechian, Minas Karatzoglou, Enrico Rettore, Carlo Fiorio and Shoshana Vasserman. Early versions of this paper were presented at various conference and seminars, including JRC (2019), COMPIE (2021), EiC Beijing (2021) and IRVAPP (2021). Data collection and initial research started in the context of the Administrative Agreement SMART 2018/0010 between the JRC and DG CNECT. The research was conducted independently, and does not imply a policy position of the European Commission or BEREC. Neither the European Commission nor any person on behalf of the Commission is responsible for the use that may be made of this publication. An early version of the empirical results based on the framework developed in this paper has appeared in Annex IV of the Impact Assessment for the prolongation of the roaming regulation (SWD(2021)28).

Evaluating the Impact of Price Caps - Evidence from the European Roam-Like-at-Home Regulation

Abstract

The roam-like-at-home regulation (RLAH) eliminated all mobile roaming surcharges to European consumers travelling within Europe. We measure the causal impact of the regulation on European roaming traffic, using the Rest of the World as a control group. We find large and heterogeneous effects on retail and wholesale traffic volumes and revenues. To evaluate the welfare effects of the regulation, we develop a framework that includes consumer surplus, retail and wholesale profits. The gains in consumer surplus are large, and mainly stem from data services. The consumer gains are proportionately larger in small, open economies and in countries with previously high roaming prices. Finally, total welfare increases considerably, because the consumer surplus gains outweigh profit losses. As such, the removal of market power more than compensates for a distortion from a possible overconsumption at zero surcharges.

1 Introduction

Over the past decades governments across the world have liberalized traditional network monopolies through privatization, vertical separation and the promotion of new entry. At the same time, price regulations have remained important to control market power in bottleneck situations where competition proved difficult. The mobile telecommunications industry provides an interesting case; see Cave, Genakos, and Valletti (2019) for an overview of the regulatory developments in the EU. On the one hand, competition has been actively promoted, especially since the introduction of the second-generation (2G) systems. On the other hand, price regulation has been introduced in markets where competition did not function well, in particular the regulation of mobile termination rates[1] and the regulation of international roaming charges, i.e. the surcharges to customers when using their mobile phones abroad.

In this paper we study the impact of the EU's Roam-Like-At-Home (RLAH) regulation, implemented in the second quarter of 2017.[2] This regulation has essentially banned all international roaming

[1]These are the rates mobile operators charge to each other and fixed operators for terminating calls from subscribers of other networks

[2]The regulation is known as Regulation (EU) 2015/21201.

surcharges to consumers in the European Economic Area (EEA) when travelling within the EEA[3]. As a result, these travelling consumers need to pay only the domestic tariffs for voice, SMS and data services. At the same time, the regulation further tightened the caps on wholesale prices that domestic operators pay to foreign operators for enabling international roaming services to their customers. Note that the regulation of (wholesale) roaming prices has also been important in the US. Despite the centralized licensing policy, US operators have gaps in geographic coverage, so they also rely on roaming services to serve their customers when travelling across the country; see Xiao and Yuan (2018) for an analysis on the role of complementarities between geographically distinct areas.

The welfare effects of the roaming price regulations are *ex ante* ambiguous. One main motivation in favour of the price regulations had been the existence of very high prices during the unregulated period before 2007. The key bottleneck problem can be explained as follows. Foreign operators faced limited competitive constraints when charging wholesale prices to domestic operators for enabling access to their networks.[4] Under certain conditions, foreign operators may charge monopoly wholesale prices. Domestic operators may, in turn, pass these charges onto their customers with an extra markup, giving rise to a double marginalization problem. Moreover, an important and related political motivation for the regulation has been the European Union's long concern with achieving the common market objective. As such, it was one prominent initiative in the development of an EU "Digital Single Market". The very high roaming prices to consumers were considered to create an obstacle to trade and free movement of persons, so a reform was put high on the political agenda. In sum, proponents of the RLAH regulation would invoke both efficiency reasons stemming from market power reduction and the political objective of the common market.

Opponents of the regulation, in contrast, cautioned that the regulation would entail new distortions because of overconsumption as a retail roaming surcharge of zero is below the extra cost of providing

[3]At that time, the EEA included all 28 Member States of the EU (including the UK) plus Iceland, Liechtenstein, Norway, Switzerland and Turkey.

[4]In the context of international roaming, the wholesale prices charged by foreign operators to domestic operators are called interoperator tariffs, or IOTs. As discussed further below, Armstrong (2001) and Wright (2002) analyze the related bottleneck issue of mobile termination charges for domestic calls, while Lupi and Manenti (2009) analyze the roaming bottleneck issue.

international roaming services. In addition, opponents argued that the regulation would mainly constitute a transfer from producers to consumers and threaten the operators' long-run profitability. These profitability effects could be heterogenous across the EEA, depending on the countries' net traffic flows (relating to tourism and business activities). They could also differ between mobile network operators (MNOs), who own their own network infrastructure, and mobile virtual network operators (MVNOs), who need to purchase network access from the MNOs.[5] Finally, opponents of the regulation pointed out that the regulation would also redistribute surplus among different consumer groups (from non-travellers to frequent travellers). This is because of a possible waterbed effect, i.e. the risk that operators would raise their domestic prices to compensate for their roaming revenue losses.

Note that the common market objective behind the RLAH regulation is an interesting illustration of the European Union's broader political goal to achieve free movement of people, goods, services and capital. Head and Mayer (2021) analyze recent progress, concluding that there is no "United States of Europe" but also that: "on multiple fronts, EU economic integration now matches or even beats the equivalent measure for the 50 American states". Another regulation in a similar vein has been the EU's cross-border payments regulation (Regulation 924/2009). This regulation aimed to reduce the cost of all intra-EU payments. More specifically, it aimed at ensuring that there is no difference for consumers and businesses when carrying out Euro transactions in their own countries or with other countries in the Euro area. Just like the RLAH regulation, the cross-border payments regulation also had consequences on firms because of existing interchange fees between banks of different countries. Another example is EU Directive 2011/24, encouraging the patients' rights to cross-border health care, and their entitlement for reimbursement. This regulation is currently still subject to many restrictions, but this may change in future directives.

To evaluate the impact of the RLAH regulation on total welfare, we develop an economic framework that includes consumer surplus, retail profits and wholesale profits. To implement the framework, we take advantage of a unique operator-level dataset collected by the European Commission. This consists

[5]MVNOs are fully dependent on the foreign MNOs' wholesale roaming charges, as they cannot make reciprocal agreements.

of quarterly data per mobile operator for international voice and data roaming traffic before and after the RLAH regulation. We measure the causal impact of the regulation on roaming traffic in the EEA, using roaming traffic in the Rest of the World (RoW) as a control group. More specifically, we estimate the impact of the regulation on the operators' outbound retail volumes and their inbound wholesale volumes and revenues. We then use these estimates to quantify the impact of the regulation on consumer surplus, retail and wholesale profits, and ultimately total welfare.

We obtain the following main findings from our empirical analysis. First, the regulation substantially raised international roaming volumes within the EEA, even more strongly for data than for voice services. Second, wholesale revenues also increased, but by proportionately less than wholesale volumes in the case of data services. Third, the estimated impact shows substantial heterogeneity between operators. For example, operators from countries in the Central-East and South of the EEA experienced higher traffic increases than operators from the West and especially from the North. MVNOs experienced higher traffic increases than MNOs, as they constrained roaming traffic more strongly before the regulation.

Based on these estimates we then quantify the impact of the regulation on consumer surplus. Because the regulation led to a rather substantial increase in roaming volumes in most European countries, a parametric demand model may give misleading results. To deal with this inherent uncertainty, we use a bounds methodology following recent insights of Kang and Vasserman (2022). More specifically, we consider the family of demand functions that is convex but still satisfies Marshall's second law of demand (according to which the price elasticity of demand is increasing in price). A linear demand function then provides an upper bound for the consumer surplus increase, while a constant elasticity demand function generates a lower bound. Based on this approach, we estimate that the RLAH regulation raised annual total consumer surplus in the EEA by between 1.4 and 2 billion Euro. About 1 billion Euro of this increase is due to existing demand and the remaining part stems from newly generated demand. Most of the consumer surplus gains (80%) stem from data services. The gains to consumers vary considerably across countries. Large countries evidently tend to benefit more. But their gains are less than proportional to population, because international roaming is relatively more important in small, open economies. Countries with previously high roaming retail prices also tend to benefit more.

Finally, we quantify the impact of the regulation on total EEA retail profits, wholesale profits and total welfare. The total annual consumer surplus gains come at the expense of 1.3 billion Euro retail profit losses, as operators can no longer charge their customers for roaming services but still incur wholesale costs. Wholesale profits increase by about 300 million Euro, mainly because of increased wholesale revenues, but also partly because of lower costs of providing roaming services after the regulation. The impact of the regulation thus amounts to annual total welfare gain of between 0.2 and 1 billion Euro. Note that these estimates refer only to the gains that were specifically due to the RLAH regulation in 2017. As we discuss in more detail below, this was just a final step after a long process of tighter retail and wholesale roaming price regulation in the previous decade. So the overall welfare gains of regulating roaming bottlenecks over the past two decades are likely substantially larger.

In sum, these findings imply that the regulation created consumer surplus gains that are potentially much larger than the operators' profit reductions. Hence, the benefits from reduced market power more than outweigh any distortion from overconsumption as roaming became free of surcharge. Intuitively, roaming markups were large before the regulation for two possible reasons: the existence of double marginalization and the existence of capacity constraints due to insufficient investment in roaming capacity. The zero surcharge caps eliminated these sources of market power, while the extra costs of providing roaming services were low. In principle, operators may have attempted to compensate for their roaming losses by raising domestic tariffs. To assess this possibility, we extend our analysis to examine whether such a waterbed effect has been present, but we cannot detect evidence for this.

Related literature Our research relates to several strands of literature. First, there is a well-established theoretical literature on wholesale pricing in network industries. One insight from this literature is that competing mobile network operators may still charge monopoly wholesale prices for terminating calls on their networks, e.g. Armstrong (2001) and Wright (2002). The reason is that mobile operators have a monopoly for delivering calls from other networks to their own subscribers. This bottleneck issue of terminating access concerns domestic calls. It is related to, but distinct from, the wholesale pricing issues in international roaming. Lupi and Manenti (2009) provide a theoretical analysis of wholesale pricing by competing foreign visited networks to the home networks of the roaming consumers.[6] With random traffic distribution to foreign networks, a traditional double marginalization problem arises: visited networks charge monopoly wholesale prices, and home networks add their own (oligopolistic) markup. When traffic can be redirected to the least-cost foreign network, the double marginalization problem is mitigated. However, as Lupi and Manenti (2009) show, this is no longer the case when the home and foreign operators can form alliances that include discounts for redirecting traffic. In practice, such alliances have been common, so the monopoly double marginalization problem under random traffic distribution remains relevant under traffic redirection. In our own empirical analysis, we will not explicitly model the precise equilibrium wholesale and retail pricing strategies of the operators, as in Lupi and Manenti (2009). We will instead provide a more flexible empirical framework with less structure that enables us to relate our empirical findings to this theoretical literature.

Second, there is a literature on the waterbed effect in network industries, studying the impact of price regulation in one market on the prices in related markets. Genakos and Valletti (2011) studied theoretically and empirically how tighter regulation of wholesale prices for terminating calls induced operators to raise their mobile retail prices.[7] Genakos and Valletti (2011) find a large waterbed effect, consistent with the high profits earned on terminating calls.[8] Recently, Grzybowski and Munoz-Acevedo (2021) studied whether the RLAH regulation involved a waterbed effect by inducing operators to raise their domestic prices, but they do not find a significant effect. As an extension to our main analysis, we also studied the waterbed effect and find small and insignificant effects, consistent with Grzybowski and Munoz-Acevedo (2021). Our interpretation is that the EEA roaming market is relatively small compared with the domestic mobile market (about 4% of domestic retail revenues before the regulation). Furthermore, domestic and international roaming services do not show an obvious channel through which prices would be related.

[6] See also Salsas and Koboldt (2004) for an earlier analysis.

[7] Intuitively, unregulated operators could charge monopoly prices for terminating calls, and would compete vigorously through retail prices. When regulation reduces profits from terminating calls, competition through retail prices becomes less intense.

[8] Genakos and Valletti (2015) revisit their analysis in light of the shift from fixed-line to mobile traffic. They find that there was no waterbed effect in countries that introduced their regulation when mobile traffic was already high.

Third, there is a literature on price regulations in an international context. Dubois, Gandhi, and Vasserman (2019) study the impact of a regulatory reference pricing policy that would cap the prices in the US pharmaceutical market to those in Canada. Based on a structural model, they show how this leads to a new pricing regime, with a slight drop in US prices and a substantial increase in Canadian prices. Duch-Brown, Grzybowski, Romahn, and Verboven (2020) use a structural model to evaluate the effect of removing international price differences after a ban on geo-blocking restrictions that impede cross-border shopping in the EU electronics market. In this paper we take a complementary approach. We do not estimate a structural model of the current situation, but instead use a difference-in-difference approach to evaluate the causal impact of a regulation. We subsequently add structure to evaluate the implications for consumer surplus, firm profits and total welfare.

Most closely related to our research, a recent paper by Quinn, de Matos, and Peukert (2022) has also evaluated the effects of the roam-like-at-home regulation. The scope of their analysis is complementary to ours: they have a data set on outbound roaming retail traffic for data consumption, originating from a single operator in one European country. They largely focus on the impact of the regulation on consumers, the role of usage heterogeneity and the indirect impact on content providers (through a supplementary online survey on various types of data use). In contrast, we observe both outbound retail traffic and inbound wholesale traffic and revenues, for essentially all operators in all countries of the EEA. We develop an integrated economic framework to incorporate these additional data. This enables us to systematically quantify the relative importance of various welfare effects (i.e., consumers, retail profits and wholesale profits) and assess the role of cross-country distributional effects.

From a methodological perspective, our work relates to approaches to evaluate the welfare effects of policy reforms, as in Einav, Finkelstein, and Cullen (2010) and Hackmann, Kolstad, and Kowalski (2015). The latter starts from a theoretical framework that decomposes the welfare effect of a policy reform into various parts, and then applies a difference-in-differences analysis to quantify the various effects. We adopt a related approach, albeit in a quite different economic context. We first show how to decompose the total welfare effects of the RLAH regulation into the effects on consumers, retail profits and wholesale profits.

We subsequently perform a difference-in-differences analysis to quantify the various components and apply the framework for our welfare analysis.

Quantifying consumer surplus effects typically relies on the functional form of demand connecting the outcome before and after the policy reform. Here, we follow recent insights of Kang and Vasserman (2022), who obtain bounds on consumer surplus effects for families of demand functions. Specifically, we use interpolation based on a constant elasticity demand to obtain a lower bound on the consumer surplus gain for the family of increasing elasticity demand functions (following Marshall's second law); and interpolation based on linear demand to obtain an upper bound on the consumer surplus gain for the family of convex demand functions.

The outline of the paper is as follows. Section 2 describes the relevant institutional background, including the functioning of the mobile roaming market and the introduction of the RLAH regulation. Section 3 outlines our theoretical framework to study the welfare effects of the regulation. Sections 4 and 5 describe our econometric approach and the dataset. Section 6 discusses the empirical results: the estimated effects of the regulation on roaming traffic, and the quantification of the effects on consumer surplus, retail and wholesale profits and total welfare. Section 7 analyzes the possible existence of a waterbed effect and Section 8 concludes.

2 Institutional background

We first describe the functioning of the international roaming market. Next, we discuss regulations and specifically the introduction of the Roam-Like-At-Home (RLAH) regulation, which affected both retail and wholesale prices. The discussion is partially based on European Commission (2016a) and on European Commission (2016b).

2.1 The functioning of the mobile roaming market

In most countries there are two types of operators in the mobile telecom services market. Mobile Network Operators (MNOs) have national licenses for the use of spectrum, and have built their own network infrastructure to offer mobile services. In contrast, Mobile Virtual Network Operators (MVNOs) do not have spectrum licences, and instead rely on supply agreements with MNOs to offer mobile services to their customers.

Both the MNOs and the MVNOs provide international roaming services to their customers to allow them to use their mobile phone while travelling abroad. To enable these services across the whole EEA, operators make contracts for wholesale roaming services with (at least) one MNO in each EEA country. These contracts typically involve an agreed wholesale roaming charge for the unbalanced part of the roaming traffic, i.e. for the net traffic from one operator to the other (if positive). For the balanced part of the traffic, the price is typically zero or of a smaller amount with respect to the one for unbalanced traffic. For MVNOs, who do not have their own network to host foreign operators, all traffic is unbalanced.

Operators located in countries that are net receivers of roaming traffic tend to have higher wholesale revenues than operators who are net senders. MVNOs are always net senders as they do not earn any wholesale revenue. Bilateral agreements between MNOs from different countries were usually written under the Standard Terms for International Roaming Agreements (STIRA) framework. As of 2016, only members of the Global System for Mobile communications Association (GSMA) were allowed to use the STIRA. Since MVNOs could not belong to the GSMA, they were almost prevented from signing bilateral agreements and could rely on unilateral arrangements only. Finally, it is common for mobile operators to establish bilateral wholesale roaming agreements with more than one MNO in each hosting country to ensure network coverage and quality of service in the whole country to their consumers.

2.2 The European roaming regulation

To recover their wholesale costs, operators imposed high retail prices for international roaming services. According to the European Commission, this posed serious barriers to free movements of people and services, so it decided to take action. The Commission introduced retail price caps for roaming services to bring market prices closer to the estimated costs. In the framework of the Eurotariff regime, caps were introduced in 2007, 2009, 2012 and 2016 for voice services, and subsequently also for SMS services. For data services, a maximum bill threshold was implemented in 2009, which was changed into a price cap in 2012.[9] In addition, the Commission gradually introduced caps on wholesale prices for roaming.

The Eurotariff regime presented a threat to the MVNOs' profitability, since its implementation often resulted into a margin squeeze. Indeed, mainly because of the STIRA, MVNOs were usually buying roaming traffic from their host MNO at high wholesale rates, while at the same time competing with their host MNO in the retail roaming market.

The Commission finally implemented the Roam-Like-At-Home (RLAH) regulation in June 2017 concerning the entire EEA. The RLAH regulation abolished all retail surcharges for international roaming, allowing consumers to use roaming services as if they were domestic services. Since the regulation could have had important implications for the operators' profitability, several accompanying measures were also introduced.

First, roaming services are subject to a Fair Use Policy (FUP). This was intended to prevent misuses in the form of permanent roaming, whereby consumers would directly subscribe to a foreign operator with low prices.[10]

Second, the regulation intervened in the wholesale market by imposing caps on wholesale prices that were already decreasing over time. This measure was conceived in an attempt to compensate smaller operators that could have suffered the most from the lost revenues connected to roaming surcharges. At the same time, caps were not set too low in order to preserve the operators' incentives to invest in infrastructure.

Third, a system of sustainability derogations has been implemented. Operators who can demonstrate

[9] See Spruytte et al. (2017) for a description of the price cap evolution during this period.

[10] The most common FUP measure is the "4-months window", which consists of monitoring a consumer's domestic and roaming consumption over a period of at least 4 months. If an operator detects a possible abusive or anomalous use of its roaming services, it may send an alert to the customer and after a 14 days notice apply small roaming surcharges, if the customer continues to consume roaming services abroad. In addition, an operator may apply a maximum volume to data roaming consumed at domestic tariffs, and apply a small surcharge to the overconsumption.

the impossibility to afford the provision of roaming services under the RLAH regime may be granted a sustainability derogation from their National Regulatory Authority (NRA). If granted, they are allowed to apply roaming surcharges on a yearly basis.[11]

Even before its implementation, the RLAH regulation generated an intensive debate. On the supply side, operators were expressing conflicting interests. Operators located in countries that were net senders of roaming volumes feared to be extremely hit by the revenue losses from roaming surcharges, which would no longer compensate for the outbound wholesale costs to be paid to foreign operators. Conversely, operators from net receiving countries alleged that the expected increase in inbound volumes after the RLAH regulation would require extensive investments to expand their network infrastructures.

On the consumers' side, a main concern was the risk that mobile providers would increase their domestic retail prices to compensate for the roaming revenue losses. This is the "waterbed effect", as discussed in the Introduction.

Despite anecdotal evidence that the RLAH regulation has been a success and led to large increases in international roaming traffic in the European Union, there has not yet been a systematic empirical assessment of the various effects on consumers and firms, including a possible waterbed effect (Cave, Genakos, and Valletti, 2019).

3 Theoretical model

This section introduces a framework to study the impact of the RLAH regulation on welfare. This will serve as the basis for our empirical approach developed in the next section. We first discuss the various components of total welfare. Next, we discuss how the RLAH regulation may affect these different components. We do not make any equilibrium assumptions on firms' optimal pricing (as would be done in a structural approach). We will instead interpret our findings based on equilibrium models when discussing the results.

[11]The Commission Implementing Regulation (EU) 2016/2286 prescribes the rules for the application of fair use policies and the eventual granting of sustainability derogations.

3.1 Domestic welfare

Consider a domestic operator providing international roaming services to its consumers when travelling to other EEA countries. These roaming services may be either voice or data.

Total domestic welfare W from an operator's roaming services is the sum of three components, i.e. domestic consumer surplus (CS), retail profits (π_{retail}) and wholesale profits ($\pi_{wholesale}$):

$$W = \underbrace{\int_p^\infty q_{out}(u)du}_{\substack{CS \\ \text{(outbound traffic)}}} + \underbrace{(p - w_{out})\, q_{out}(p)}_{\substack{\pi_{retail} \\ \text{(outbound traffic)}}} + \underbrace{(w_{in} - c)\, q_{in}}_{\substack{\pi_{wholesale} \\ \text{(inbound traffic)}}}. \tag{1}$$

First, domestic consumer surplus is the surplus to the operator's own customers from using the international roaming services abroad. This is the usual area under the retail demand function for outbound roaming services, $q_{out}(p)$, where p is the retail price for roaming services. Note that $p = p_{dom} + p_{sur}$, i.e. the retail price for roaming services is the domestic retail price p_{dom} plus the roaming surcharge p_{sur}, as applicable before the RLAH regulation. Retail roaming demand, $q_{out}(p)$, may be decreasing in price because of either reduced roaming usage of traveling consumers ("intensive margin") or reduced cross-border traveling ("extensive margin"). In practice, the intensive margin is likely the most important channel because roaming is a small share of foreign travel expenditures, although this interpretation is not required for our purposes. Second, the operator earns retail profits on its own customers when they are using the international roaming services abroad. These retail profits are equal to the operator's retail demand, $q_{out}(p)$, multiplied by the retail margin, $p - w_{out}$, where w_{out} is the average wholesale price on outbound traffic as paid to foreign operators to obtain access to their networks. Third, the operator earns wholesale profits on foreign operators from providing them network access to enable international roaming by the foreign operators' customers. These wholesale profits are equal to the domestic operator's inbound wholesale demand, q_{in}, multiplied by the wholesale margin, $w_{in} - c$. This wholesale margin is the wholesale price received on inbound traffic, w_{in}, minus the (constant) marginal costs of providing these network services, c, to foreign operators.

A few clarification remarks regarding the domestic welfare equation (1) are in order. First, "consumer surplus" may consist of surplus to both private and business users. With our data we cannot separately distinguish between both types of users, so we focus on evaluating aggregate effects. As such, any distributional effects from operators to consumers includes redistribution from the telecom industry to other businesses. Second, outbound and inbound traffic (relating to respectively retail demand $q_{out}(p)$ and wholesale demand q_{in}) refer to intra-EEA traffic.[12] There is of course also outbound and inbound traffic to the rest of the world (outside the EEA), but the regulation did not apply to this traffic. Second, q_{in} is an operator's aggregate inbound wholesale demand, which sums over the inbound demands from all foreign operators within the EEA. And similarly, the outbound wholesale price w_{out} is the average wholesale price that an operator pays to all foreign operators for enabling its customers to roam abroad. Third, equation (1) considers only the domestic welfare generated by an operator. In our analysis below, we will eventually aggregate the domestic welfare over all operators in all EEA countries.

Assumptions The use of equation (1) to evaluate the welfare impact of the RLAH regulation is based on several assumptions. First, equation (1) considers the separate welfare from a single domestic operator. So it assumes that domestic operators do not compete with each other through the prices of their international roaming services. This appears reasonable as a first approximation because international roaming services are a relatively small part of the mobile telecom market.[13] Furthermore, consumers may not pay attention to these roaming charges as they are add-on prices about which there may be limited information at the time of choosing an operator.[14] In practice, empirical studies have also focused on the role of domestic tariffs in the competitive process, thus abstracting from roaming charges as a way to compete.

[12] More specifically, this is traffic generated by roaming customers, which originates and terminates voice and data inside the EEA.

[13] International roaming for voice and data each made up about 2% of total retail volume during the considered period, and about 4% of total retail revenue during the last two quarters before the regulation.

[14] For models of add-on pricing with prices that do not depend on competitors, see for example Verboven (1999) and Ellison (2009).

Second, equation (1) applies separately to an operator's voice and data services. As such, this assumes that both service types are independent goods. To the extent that they are substitutable, the expression for consumer surplus would need modification because changes in the price of one good may shift the demand of the other good. However, the extent of substitution between voice and data roaming services has been found to be small, see the report of the European Commission (2011) (in particular, its Annex V - Retail Roaming Model). Furthermore, in our setting the RLAH regulation alters both voice and data prices in the same direction (a drop to zero), so any substitution (if present) would tend to cancel each other out.

Third, equation (1) considers only the welfare generated from international roaming services, and not from domestic services. In practice, the RLAH regulation may induce operators to adjust their prices on domestic services. Empirical evidence for the so-called waterbed effect has been found in the context of regulation of mobile termination rates, notably Genakos and Valletti (2011). In our setting, a negative waterbed effect (hence an increase in the price of domestic services) would exist if domestic and international roaming services are substitutes, and a positive waterbed effect would exist in the reverse case.[15] Given the relatively small share of roaming revenues in total revenues discussed above, we do not expect a large size of the waterbed effect. Nevertheless, to the extent that the RLAH regulation would involve a waterbed effect, our framework would also need to incorporate the welfare from domestic services. This would considerably complicate the analysis, and require data that are not available at the level of all operators. As an alternative, we perform a separate analysis to evaluate the possible presence of such a waterbed effect in Section 7. We find that this turns out to be insignificant or small in our setting, and we will discuss the implications for our analysis.

Finally, our welfare analysis abstracts from further potential benefits that private and business users may create to other parties when using roaming services for voice or data. Quinn, de Matos, and Peukert (2022) highlight benefits to content providers from increased data traffic. To the extent that such effects

[15]This can be verified in a simple model with a single operator, setting the price for two services under linear demand. And this generalizes to other demand forms under suitable regularity conditions for the second-derivatives of demand. A related negative waterbed effect may arise from the elimination of the possibility to price discriminate between local and travelling consumers.

are important, our estimates would underestimate the actual welfare effects.

3.2 Impact of the RLAH regulation

We will use the superscripts 0 and 1 to denote the value of variables before and after the regulation. As discussed in Section 2, the RLAH regulation has affected both the retail and the wholesale prices for international roaming services. First, it has removed the retail surcharges p_{sur} (with a few exceptions). This means that retail price for roaming services has dropped from $p^0 = p_{dom} + p_{sur}$ to $p^1 = p_{dom}$. This may, in turn, have raised outbound and inbound roaming traffic (from respectively q^0_{out} to q^1_{out} and q^0_{in} to q^1_{in}). Second, the regulation may have affected the wholesale prices because of the reduced wholesale caps, from w^0_{out} to w^1_{out} for outbound traffic, and from w^0_{in} to w^1_{in} for inbound traffic. Finally, the regulation may have indirectly affected the marginal cost of providing the roaming services, from c^0 to c^1 (e.g. because of scale effects or additional investment requirements).

Consumer surplus The impact of the RLAH regulation on consumer surplus stems from the drop in price from p^0 to p^1, and is given by:

$$\Delta CS = \int_{p^1}^{p^0} q_{out}(u)du$$

where we use the operator Δ to denote the change in a variable x, $\Delta x \equiv x^1 - x^0$.

When the price drop leads to a large increase in traffic, a parametric model such as linear demand may give misleading results. To deal with this inherent uncertainty, we use a bounds methodology as recently introduced by Kang and Vasserman (2022). They derive bounds to consumer surplus changes for families of demand functions.[16] More specifically, we assume that demand belongs to the family of demand functions that is convex but still satisfies Marshall's second law (according to which the price elasticity of demand is increasing in price). A linear demand function then provides an upper bound on

[16] Their approach applies regardless of whether demand changes on the intensive margin (increased usage) or on the extensive margin (increased cross-border traveling).

ΔCS for the family of demand functions that is convex between (p^0, q^0_{out}) and (p^1, q^1_{out}). Similarly, a constant elasticity demand function (CES) provides a lower bound on ΔCS for the family of demand functions that satisfies Marshall's second law.[17]

Concretely, with linear demand the change in consumer surplus is

$$\Delta CS^{lin} = (p^0 - p^1)q^0_{out} + \frac{1}{2}(p^0 - p^1)(q^1_{out} - q^0_{out}). \tag{2}$$

The first term captures the gain to the infra-marginal consumers, while the second term consists of the gain from increased roaming demand $\Delta q_{out} = q^1_{out} - q^0_{out}$. In a graphical representation, these two terms are of course the typical rectangle and triangle. With constant elasticity demand (CES), the change in consumer surplus is:

$$\Delta CS^{ces} = \frac{(p^0 q^0_{out} - p^1 q^1_{out}) \log(p^0/p^1)}{\log(p^0 q^0_{out}) - \log(p^1 q^1_{out})}, \tag{3}$$

as shown by Kang and Vasserman (2022).[18]

One may consider the linear demand function to provide a relatively conservative upper bound on the consumer surplus increase, because it rules out the possibility that demand is concave between (p^0, q^0_{out}) and (p^1, q^1_{out}). Conversely, the CES demand function appears to provide a relatively conservative lower bound, because demand functions that are so convex that they would violate Marshall's second law of demand may not be very likely. The two bounds are nevertheless tighter than the most conservative bounds suggested by Varian (1985), which assume only that demand is decreasing in price:

$$\Delta CS \in [(p^0 - p^1)q^0_{out}, (p^0 - p^1)q^1_{out}]. \tag{4}$$

The lower bound in (4) obtains when demand is perfectly inelastic at (p^0, q^0_{out}), while the lower bound obtains when demand is perfectly elastic between (p^0, q^0_{out}) and (p^1, q^1_{out}).

[17] Kang and Vasserman (2022) also obtain bounds for other families of demand functions, such as exponential demand for the family of log-concave and log-convex demand functions, and constant marginal revenue demand for the family of decreasing marginal revenue demand functions.

[18] We slightly rewrite their expression and multiply it by -1.

Retail profits The impact of the regulation on retail profits is the combined effect of the changed retail price (from p^0 to p^1), the resulting change in retail demand (from q^0_{out} to q^1_{out}) and a possible change in the average outbound wholesale price paid to the foreign operators (from w^0_{out} to w^1_{out}):

$$\Delta\pi_{retail} = \left(p^1 - w^1_{out}\right) q^1_{out} - \left(p^0 - w^0_{out}\right) q^0_{out}.$$

We can rewrite this as the sum of the following terms:

$$\Delta\pi_{retail} = -(p^0 - p^1)q^0_{out} - \left(w^1_{out} - p^1\right) \Delta q_{out} - q^0_{out}\Delta w_{out}. \tag{5}$$

The first term is the operator's direct revenue loss from eliminating the roaming surcharges ($p^0 - p^1 = p_{sur}$). This loss is of course equal to the consumer surplus gain to infra-marginal consumers (the first term in (2) under linear demand). The second term is the operator's additional loss from having to serve increased retail roaming demand, evaluated at the new wholesale price after the regulation (and net of the small domestic price it may still charge after the regulation). Finally, the third term is a potential compensating gain arising from the possibility that the outbound wholesale price drops due to the regulation (if $\Delta w_{out} < 0$).

Wholesale profits The impact of the regulation on inbound wholesale profits may also stem from different sources: a change in inbound wholesale demand (from q^0_{in} to q^1_{in}), a possible change in the inbound wholesale price charged to foreign operators (from w^0_{in} to w^1_{in}), and a possible change in the marginal cost of providing access to foreign operators for international roaming services. The change in wholesale profits is:

$$\Delta\pi_{wholesale} = \left(w^1_{in} - c^1\right) q^1_{in} - \left(w^0_{in} - c^0\right) q^0_{in}.$$

For further economic intuition, it is again informative to rewrite this as the sum of three components. Defining the inbound wholesale revenue as $r_{in} \equiv w_{in} q_{in}$ and rearranging gives the following expression:

$$\Delta\pi_{wholesale} = \Delta r_{in} - c^1 \Delta q_{in} - q_{in}^0 \Delta c. \tag{6}$$

The first term is the increase in inbound wholesale revenues after the regulation.[19] This mainly stems from an increase in inbound wholesale demand q_{in}, but it may be partly compensated by a decrease in the inbound wholesale price.[20] The second term is the increased cost from the higher wholesale inbound demand (evaluated at the marginal costs after the regulation). Finally, the third term is a potential efficiency gain in providing roaming services to foreign operators (if $\Delta c^1 < 0$).

Total domestic welfare The change in total domestic welfare is simply the sum of the change in consumer surplus, retail profits and wholesale profits:

$$\Delta W = \Delta CS + \Delta\pi_{retail} + \Delta\pi_{wholesale}.$$

To appreciate the various effects, consider the case of linear demand, so that the welfare change is the sum of (2), (5) and (6):

$$\begin{aligned} \Delta W &= \frac{1}{2} p^0 \Delta q_{out} \\ &\quad + (p^1 - w_{out}^1) \Delta q_{out} - q_{out}^0 \Delta w_{out} \\ &\quad + \Delta r_{in} - c^1 \Delta q_{in} - q_{in}^0 \Delta c. \end{aligned} \tag{7}$$

The terms $(p^0 - p^1) q_{out}^0$ in (2) and (5) thus cancel as they involve a transfer from firms to the infra-marginal consumers. It is instructive to see how the expression simplifies under two conditions: (i) the domestic

[19] We do not decompose the change in inbound wholesale revenues, as we did for the change in outbound wholesale expenses in the second and third term of (5). The reason is that we directly observe inbound wholesale revenues, and not outbound wholesale expenses (only outbound demand).

[20] In principle, inbound wholesale revenues could decrease if the drop in the inbound wholesale price more than compensates for the increased wholesale demand. But this is unlikely and we do not find this in our empirical analysis.

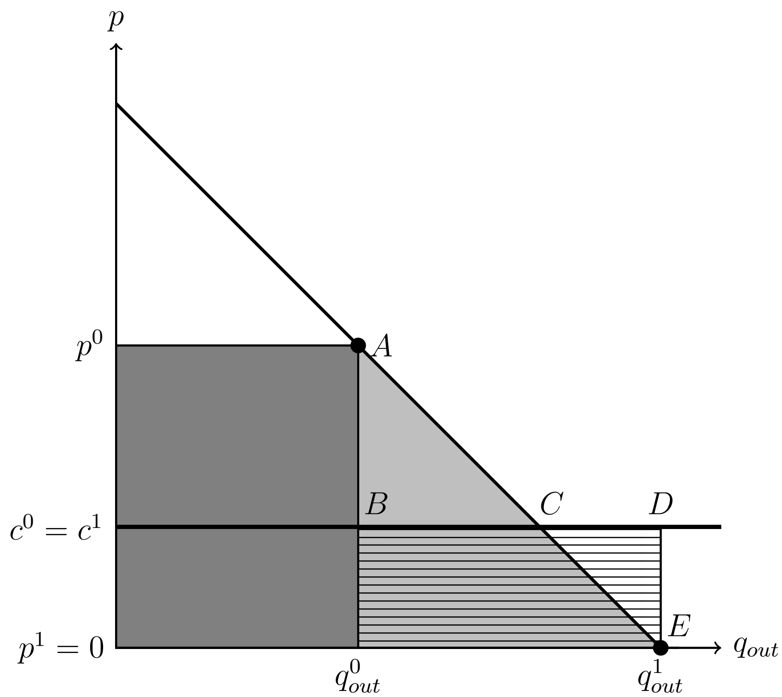
price is negligible relative to the roaming surcharge, i.e. $p^1 = 0$; and (ii) the regulation keeps the change in outbound wholesale costs and inbound wholesale revenues balanced, i.e. $w_{out}^1 \Delta q_{out} + q_{out}^0 \Delta w_{out} = \Delta r_{in}$. The impact of the regulation on domestic welfare then simplifies to:

$$\Delta W = \frac{1}{2} p^0 \Delta q_{out} - c^1 \Delta q_{in} - q_{in}^0 \Delta c. \quad \text{(under "wholesale balancedness")}$$

The first term is the (approximate) gross welfare gain from serving additional demand after the regulation. The second term shows the costs from serving extra consumers, evaluated at the post-regulation marginal costs. Finally, the third term shows a potential welfare gain from possible improved efficiencies after the regulation.

Figure 1 illustrates this under the additional condition of no efficiencies ($\Delta c = 0$). The increase in consumer surplus is equal to the sum of the dark shaded rectangle and light shaded triangle. The change in total domestic welfare is the difference between the light shaded triangle (additional consumer surplus from extra demand) and the horizontally shaded rectangle (losses from serving the extra demand). This difference amounts to the difference between the upper triangle ABC and the lower triangle CDE. The net welfare gain will thus be large if the roaming price before the regulation was much above marginal cost, as under monopoly double marginalization (Lupi and Manenti, 2009). But in the opposite case, it is possible that the net welfare gain is negative. In either case, the gains to consumers will likely be considerably higher than the total welfare gains.

Figure 1: Consumer surplus and total welfare change after the regulation (from p^0 to $p^1 = 0$)



Note: This figure illustrates the consumer surplus and welfare change from the RLAH regulation under linear demand and the following simplifying assumptions discussed in the text: $p^1 = 0$, wholesale unbalancedness, and no efficiencies ($c^0 = c^1$). Welfare would increase if the triangle ABC exceeds the triangle CDE.

4 Empirical framework

In this section we develop an empirical framework that applies the theoretical model of Section 3 to the data. We first discuss the econometric model, which estimates the causal effects of the RLAH regulation on those outcome variables for which we have systematic information across operators and over time. Next, we describe how we use these estimated effects to implement the theoretical model, incorporating also the effects not captured through the econometric model.

4.1 Econometric model

We define operators as national operators in the country where they are active. The outcome variables for which we have systematic information across operators and over time are: outbound retail demand

(q_{out}), inbound wholesale demand (q_{in}) and inbound wholesale revenue ($r_{in} \equiv w_{in}q_{in}$). We observe these variables separately for voice and data services.

To estimate the effects of the regulation on these variables, we exploit the fact that the RLAH regulation applies only to consumers who are roaming within the EEA. It does not apply to traffic that relates to the Rest of the World (RoW), i.e. European consumers travelling outside the EEA (outbound RoW), or non-European consumers travelling to the EEA (inbound RoW). We can thus use our data on demand and revenues in a Difference-in-Differences (DiD) framework, where the treatment group relates to an operator's EEA traffic and the control group relates to its RoW traffic. Note that Quinn, de Matos, and Peukert (2022) follow a similar identification approach.

There are several reasons why RoW traffic is a good candidate for the role of control group. First, this type of traffic is subject to the same confounding factors that could have altered EEA roaming consumption apart from the RLAH regulation. This includes technological changes over time influencing how mobile phones are used (e.g. increase of data consumption, reduction in voice and sms traffic due to VOIP, etc.), regulatory interventions that applied before RLAH and seasonal effects. Moreover, RoW and EEA outbound volumes come from comparable users, and it appears reasonable to assume the RLAH regulation has not affected their travel habits.

Overall, it appears reasonable to assume that RoW traffic would have followed similar trends to EEA traffic prior to the intervention. We will also formally present evidence for the parallel trend assumption when we discuss our empirical results.

More specifically, our econometric specification for the outcome variable k of mobile telecom operator i in group $s \in \{EEA, RoW\}$ in quarter t is:

$$\ln Y_{ist}^k = \alpha^k + \beta^k (EEA \times Post)_{st} + \gamma_{is}^k + \theta_t^k + \varepsilon_{ist}^k, \tag{8}$$

where Y_{ist}^k is the outcome variable k, $(EEA \times Post)_{st}$ is a dummy variable equal to one if the observation concerns the treatment group after the regulation (i.e. intra-EEA traffic after 2017Q2), and ε_{ist}^k is the error term. Our main interest is in the coefficient of the treatment variable, β^k, after controlling for a full set of operator-group fixed effects γ_{is}^k and quarterly time fixed effects θ_t^k. We cluster the standard errors at the level of the operator. This is at a higher level than the included operator-group fixed effects γ_{is}^k.[21]

We have six outcome variables k, all transformed in logs: q_{out}, q_{in} and r_{in}, each for voice and data services. Hence, q_{out} refers to an operator's own customers travelling to other EEA countries for the treatment group ($s = EEA$), and travelling outside the EEA for the control group ($s = RoW$). Similarly, q_{in} and r_{in} refer to foreign consumers travelling from another EEA country for the treatment group, and travelling from a non-EEA country for the control group.

The coefficient β^k measures how the outcome variable k changes for intra-EEA related traffic, against the benchmark of the same variable for RoW related traffic. It can be interpreted as the causal effect of the regulation on the outcome variable in a DiD identification strategy. The identifying assumption is that the average change in the outcome variable for the treatment group ($s = EEA$) in the absence of the regulation would have been equal to the average change for the control group ($s = RoW$). When the outcome variable refers to outbound traffic, it is assumed that without the regulation the change in outbound traffic would on average have been the same to other EEA countries as to the RoW. Conversely, when the outcome variable refers to inbound traffic, it is assumed that without the regulation the change of inbound traffic from other EEA countries would have been the same as from the RoW. Since the RLAH regulation applies only to intra-EEA and not to RoW traffic, it seems plausible that both groups would have been subject to similar technological and seasonal factors in the absence of the regulation.

If this parallel trends assumption holds, we expect the effect at each lead (quarters before the event of the regulation) to be insignificantly different from zero. This would rule out the presence of any anticipatory effect. In addition, we would expect the effects after the event to be insignificantly different from each other because there is no reason to expect a gradual response to the regulation. We will evaluate this through an event study, where we allow β^k to vary by time (so we estimate the β_t^k for each t).

Our specification (8) assumes that the treatment effect β^k is common across all operators. We will

[21]Hence, although we only exploit variation within the operator-group, we take a conservative assumption and allow for the possibility that the error term of an operator in the treatment group is correlated with the error term of the same operator in the control group.

extend this specification to allow for heterogeneity between countries, groups of countries (South, North, West and Central-East) and types of operator (MNO versus MVNO). We also consider a flexible model with full heterogeneous effects β_i^k for each operator i. To obtain some further intuition on the role of the control group, we will also compare our DiD approach to a simple "before-and-after" model. In this approach, we essentially re-estimate (8) for the subsample of observations in the treatment group, i.e. the observations refer to the operators' intra-EEA traffic ($s = EEA$). In this model, the coefficient β^k may, of course, also capture other factors that have affected the outcome variables after the regulation, such as a general increased demand for data services, etc.

4.2 Implementing the theoretical model

Our main interest is in quantifying the components of the changes caused by the regulation: the change in consumer surplus (2) or (3) (and their reinterpretation as bounds under families of demand functions), retail profits (5), wholesale profits (6), and ultimately total welfare (7). This requires measuring the *level* of several operator-level variables, for which our data provide direct information. In addition, we need estimates of how the regulation has led to a *change* of several variables.

Our econometric model will provide such estimates for the operators' affected outbound retail demands, Δq_{out}, entering (2)-(3) and (5); and for their affected inbound wholesale demand and revenues, Δq_{in} and Δr_{in}, both entering (6). Since each outcome variable is expressed in logs, the estimated β^k is approximately a percentage effect. To convert these into absolute changes, we use the following expression for the impact on outbound retail demand:

$$\Delta q_{out} = \frac{\Delta q_{out}}{q_{out}} q_{out} = \left(\exp(\beta^{q_{out}}) - 1\right) q_{out}, \tag{9}$$

and similarly for the impact on inbound wholesale demand and revenues, Δq_{in} and Δr_{in}.

We also need an estimate for how the RLAH regulation has affected the operators' retail prices for international roaming services (entering (2) or (3) and (5)). Since the regulation eliminates the roaming surcharges, we measure retail prices as drops to domestic retail prices, i.e. a change from $p^0 = p_{dom} + p_{sur}$ to $p^1 = p_{dom}$.

Finally, we need to quantify the change in the average outbound wholesale price Δw_{out} (entering (5)) and in the marginal costs of providing network services to foreign operators Δc (entering (6)). Since we do not have systematic information for these variables across operators and over time, we cannot perform a causal analysis. We instead measure both variables at one point in time before and after the regulation, and perform a sensitivity analysis with respect to different assumptions regarding their change. We provide more details in the data section.

5 Data

5.1 Main dataset

Construction of the dataset The implementation of the econometric model is based on data about roaming consumption, collected by the National Regulatory Authorities (NRAs) twice a year from the operators. This data collection process is coordinated by the Body of European Regulators in Electronic Communications (BEREC), who provides a template for the questionnaire. The Directorate-General for Communication Networks, Content and Technology (DG CNECT) of the European Commission submits the request to the NRAs, and uses the obtained operator-specific data for its monitoring, evaluation and reviewing purposes.[22]

Based on five waves of the questionnaires (each wave covering two quarters), we built a detailed quarterly data set at the operator level, for all MNOs and the most important MVNOs in the EEA during 2016Q4 up to 2019Q1.[23] Each operator is active in two roaming markets: intra-EEA and RoW. As discussed, these markets will be our treatment and control group. We have information on the following variables: outbound retail volume, outbound retail revenues from roaming surcharges, inbound whole-

[22] BEREC publishes aggregate country-level information on the evolution of roaming traffic on a regular basis in the form of the International Roaming Benchmark Data Report (BEREC (2020)), based on the country level aggregated data it collects.

[23] We obtained the data based on the collaboration with DG-CNECT on the Impact Assessment for the prolongation of the roaming regulation, as described on the cover page of this paper.

sale volume and inbound wholesale revenues. We observe each of these variables separately for voice and data services. We compute average retail roaming surcharges and average inbound wholesale prices by dividing the retail and wholesale roaming revenues by their volumes. Note that outbound retail revenues from roaming surcharges, and hence average retail roaming surcharges, essentially drop to zero for intra-EEA traffic after the regulation. Roaming consumers then only pay the domestic retail price, and we discuss this variable separately in the next subsection 5.2.

The unit of observation in our panel data set is the operator i, the group s (i.e. intra-EEA or RoW roaming market) and the quarter t (10 quarters between 2016Q4 and 2019Q1). Each operator belongs to one of the 28 EEA countries we observe, and may be either an MNO (with its own national network) or an MVNO (purchasing access to the network of an MNO). The number of operators replying to each wave of the questionnaire is not constant: it varies between 137 and 140, depending on the quarter, of which between 90 and 91 are MNOs and between 47 and 50 are MVNOs. We therefore decided to retain only operators that have replied to all five waves of the BEREC questionnaire. This results in a total of 119 operators, 90 MNOs and 29 MVNOs. In order to estimate the DiD model, we further restrict the sample to operators with non-missing traffic information for both the EEA and RoW markets. We end up with a sample of 105 operators for the retail data (giving a total of 2100 observations over 10 quarters and two markets) and 87 operators for the wholesale data (giving 1740 observations over 10 quarters and two markets).[24]

Summary statistics Table 1 provides summary statistics of our main variables, i.e. averages and standard deviations across operators and quarters. We show the information separately for the intra-EEA and the RoW market, before and after the regulation.

Notice first that the volume of roaming traffic is much higher for intra-EEA than for RoW traffic. But in revenue terms the intra-EEA market has been less important than the RoW market (before the regulation in the case of retail). This is because the retail roaming prices were regulated quite restrictively within the EEA already before the RLAH regulation. For example, before the RLAH regulation to-

[24] There is no perfect overlap between the two samples - i.e. the wholesale one is not a perfect subsample of the retail one.

tal quarterly intra-EEA retail roaming surcharge revenues amounted to 101.2 million Euro for voice and 140.7 million for data, compared with RoW retail roaming surcharge revenues of 217.2 million Euro and 282 million Euro for voice and data respectively.[25] Of course, this reflects the fact that average roaming surcharges are much higher for RoW than for intra-EEA traffic, already before the regulation. For example, for voice the average retail surcharge was 4.6c/min (=0.964/21.524) for intra-EEA roaming and nearly 77c/min for RoW roaming before the regulation. For data, it was 9.6 Euro/GB for intra-EEA roaming and 145.8 Euro/GB for RoW roaming. Similar remarks hold for wholesale volumes and revenues. Finally, it is useful to put the international roaming revenues in perspective by comparing them to domestic revenues.[26] Before the RLAH regulation, roaming generated quarterly total revenues of 241.9 million Euro for intra-EEA and 499.2 million Euro for RoW traffic, which was respectively only about 4% and 8% of total domestic revenues earned by mobile operators.

Table 1: Summary statistics of roaming outcome variables.

	Intra-EEA				RoW			
	Pre-RLAH		Post-RLAH		Pre-RLAH		Post-RLAH	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Retail Voice Volumes	21.524	29.128	45.703	63.784	2.672	5.223	3.421	9.203
Retail Voice Revenues [a]	0.964	3.343	-	-	2.069	4.537	1.729	3.832
Retail Voice Price	0.046	0.154	-	-	0.764	1.351	-	-
Wholesale Voice Volumes	28.832	39.591	59.514	84.374	3.249	5.760	4.209	7.538
Wholesale Voice Revenues	0.905	1.424	1.330	2.001	0.581	1.210	0.534	1.097
Wholesale Inbound Voice Price	0.031	0.017	-	-	0.179	0.109	-	-
Retail Data Volumes	0.139	0.244	0.823	1.321	0.018	0.063	0.048	0.161
Retail Data Revenues [a]	1.340	3.040	0.032	0.139	2.686	6.495	3.375	8.494
Retail Data Price	9.657	33.198	-	-	145.847	420.542	-	-
Wholesale Data Volumes	0.192	0.254	1.080	1.677	0.050	0.177	0.090	0.198
Wholesale Data Revenues	1.871	2.812	3.199	5.210	0.958	1.919	1.240	2.928
Wholesale Inbound Data Price	9.732	6.426	-	-	19.345	97.368	-	-

Note: Pre-RLAH refers to 2016Q4-2017Q1, and Post-RLAH refers to 2017q2-2019q1. Means and standard deviations for the retail market are taken across 105 operators (MNOs and MVNOs) and the reference quarters. The same statistics for the wholesale market are taken over 87 operators (MNOs) and the reference quarters. Revenues are in million Euros. Voice volumes are in million minutes of calls. Data volumes are in million GB. "Intra-EEA" refers to intra-EEA roaming traffic; "RoW" refers to roaming traffic from the EEA to the rest of the world, and vice versa.

[a] Retail revenues - both for voice and data - in the post implementation period can be calculated only for operators being granted a derogation (See section 2 for details). On average they amount to 0.019 (St. Dev. 0.092) and to 0.032 (St. Dev. 0.139) million Euros for voice and data respectively.

[25] This can be verified from multiplying the averages per operator by the number of operators. For example, for voice we obtain 101.2 million Euro = 0.964 million Euro per operator times 105 operators.

[26] Table 1 does not report domestic revenues, because the information is not separately available for voice and data.

Now consider how volumes and revenues changed after the regulation. The average retail and wholesale roaming *volume* per operator increased considerably in the intra-EEA roaming market, especially for data. For example, average quarterly retail voice volume more than doubled (from 21.524 to 45.703 million call minutes), whereas average quarterly retail data volumes increased more than fivefold (from 0.139 to 0.823 million GB). Average retail and wholesale roaming volume also increased in the RoW control group, but by much less than in the intra-EEA roaming market. This would be expected since this market has not been affected by the RLAH regulation. The average retail roaming surcharge *revenues* per operator essentially dropped to zero on the intra-EEA market because of the RLAH regulation.[27] Average wholesale revenues per operator increased for intra-EEA traffic, but by less than the wholesale volumes because average wholesale prices decreased. In contrast, average wholesale revenues for RoW traffic hardly changed (for data) or even slightly fell (for voice). We will make these comparisons between changes in the intra-EEA market and in the RoW control group more rigorously in our DiD analysis below.

5.2 Other information

To implement the theoretical model we require three additional pieces of information (in addition to the variables described in the previous subsection). First, we need a measure of the domestic retail price (which is added to the retail roaming surcharge before the RLAH regulation, and is the remaining price paid for roaming after the regulation). To construct the domestic retail prices we make use of information on the price of mobile bundles and the allowance for voice (in min) and data (in GB) from the report produced by Empirica for the European Commission (Commission et al., 2020). We then construct country-level unit prices using a hedonic regression. Generally speaking, domestic prices are very small compared with the roaming surcharges, so they do not affect our analysis by much.

Second, we need a measure of an operator's average outbound wholesale price. This is a weighted average of the outbound wholesale prices an operator pays to all foreign operators to enable its customers

[27] There was just a neglible amount of retail revenues for operators which were granted derogations (as discussed in Section 2), and we abstract from this in our analysis.

to roam abroad. It will depend on the travel patterns of the operators' customers, and it will generally differ from the inbound wholesale price the operator charges to foreign operators. If we would directly observe the outbound wholesale expenses per operator (just like we observe the inbound wholesale revenues), we could simply compute the average outbound wholesale price from dividing outbound wholesale expenses by outbound retail volumes. Since this information is not available, we estimate outbound wholesale prices as a weighted average of the inbound wholesale prices across countries (which we directly observe) following the procedure described in Appendix A.1.

Third, we need a measure of the marginal costs of providing network services to foreign operators. These costs are especially relevant to operators who face a much increased inbound demand, for example those active in very touristic areas. We make use of detailed cost information as estimated by an external study commissioned by the European Commission to Axon Consulting. More details on the Axon cost model are provided in Appendix A.1.

6 Empirical results

We first present our DiD estimates of how the regulation affected retail and wholesale traffic. We then use these estimates to calculate the effects on consumers across different countries and the total welfare effects in the EEA.

6.1 Econometric estimates

Table 2 shows the estimated effects of the regulation on the various outcome variables Y_{ist}^k, where k refers to outbound retail volume, inbound wholesale volume and inbound wholesale revenues, separately for voice and data. The estimates are based on our DiD specification (8): the top panel assumes homogeneous effects β^k across operators; the middle and bottom panel allow for heterogeneous effects β_i^k, according to the operators' country and operator type. Recall that the outcome variable Y_{ist}^k enters in logs, so the estimated β^k are effects in log points. Since the effects are often large, we will convert them later into percentage effects using $\exp(\beta^k) - 1$, as in (9).

Homogeneous effects First consider the homogeneous effects estimates in the top panel of Table 2. The regulation had a very strong impact on intra-EEA roaming volumes for voice services, and an even stronger impact for data services. Note that the smaller estimated effects for wholesale than retail volumes stem from the assumed homogeneity across operators. When allowing for flexible heterogeneous effects per operator, we verified that the estimated total increase in the EEA is of a comparable magnitude for wholesale and retail volumes. The regulation also led to an increase in intra-EEA wholesale revenues, but less so for data services where average wholesale prices dropped due to the regulation.

Table 2: Empirical results

	Voice			**Data**		
	Outbound Retail Vol.	Inbound Whol. Vol.	Inbound Whol. Rev.	Outbound Retail Vol.	Inbound Whol. Vol.	Inbound Whol. Rev.
			Homogeneous Effects			
EEA X Post	0.770***	0.410***	0.450***	1.244***	0.643***	0.274***
	(0.074)	(0.062)	(0.064)	(0.152)	(0.119)	(0.092)
R-squared	0.981	0.976	0.946	0.970	0.953	0.907
			Heterogeneous Effects: by Country Group			
EEA X Post X South	0.821***	0.575***	0.660***	1.365***	1.020***	0.515***
	(0.176)	(0.121)	(0.119)	(0.238)	(0.173)	(0.148)
EEA X Post X North	0.453***	0.193	0.165	0.692***	0.200	-0.102
	(0.105)	(0.129)	(0.108)	(0.204)	(0.212)	(0.169)
EEA X Post X West	0.745***	0.274***	0.346***	1.183***	0.404***	0.151
	(0.131)	(0.080)	(0.079)	(0.200)	(0.151)	(0.124)
EEA X Post X Central-East	1.021***	0.615***	0.651***	1.679***	0.994***	0.557***
	(0.106)	(0.096)	(0.089)	(0.198)	(0.137)	(0.138)
R-squared	0.982	0.977	0.948	0.971	0.955	0.909
			Heterogeneous Effects: by Network Type			
EEA X Post X MVNO	1.291***	-	-	2.004***	-	-
	(0.208)			(0.225)		
EEA X Post X MNO	0.639***	-	-	1.054***	-	-
	(0.081)			(0.160)		
R-squared	0.982			0.971		
Observations	2,100	1,740	1,740	2,100	1,740	1,740

Note: Top panel refers to homogenous treatment effects β^k. Lower panels refer to heterogenous effects β_i^k, varying either by the operator's country or type (MNO or MVNO). European Countries have been grouped as per the following classification: South (CY, EL, IT, MT, PT, ES); North (DK, EE, FI, LV, LT, NO, SE); West (AT, BE, FR, DE, IE, NL, UK); Central-East (BG, CZ, HR, HU, PL, RO, SK, SI).
Clustered robust standard errors in parentheses. Clusters defined at country and operators' level.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

These estimated effects of the regulation on intra-EEA traffic are based on our DiD strategy, using RoW traffic as the control group. As such, they show that intra-EEA roaming traffic increased substantially compared to RoW traffic.[28] To obtain further intuition on the role of the control group, Table A.2 in the Appendix shows simple before-and-after estimates on the changes in intra-EEA traffic after the regulation (i.e. without using the RoW observations as control). The before-and-after estimates of the volume increases are even higher than our DiD estimates. This is especially the case for data traffic. Intuitively, this is because especially data traffic showed a strong independent growth after the regulation, i.e. also in the RoW (in contrast with voice traffic).

To evaluate the plausibility of the RoW as the control group, we conduct event studies for each outcome variable, where we estimate (8) with time-varying parameters β_t^k. Figure A.1 and Figure A.2 in the Appendix document the results. This shows that there was typically no significant change prior to the regulation. This is in line with the identifying parallel trends assumption in the absence of the regulation, and further supported by the findings of Quinn et al. (2022) for a longer period (for one operator).[29] Furthermore, the estimated changes usually do not differ significantly from each other in the quarters after the regulation, with the exception of one transition quarter. This shows that the impact of the regulation was almost immediate, and also that there remains a common trend after the regulation.

Heterogeneous effects The estimates in the top panel of Table 2 assumed homogeneous effects of the regulation across countries and operators. The middle and the bottom panels show the estimates from extensions, where we allow the regulation to have different effects across operators according to their geographic region in the EEA (South, North, West and Central-East) or according to their network type (MNO versus MVNO).

[28] The relatively high R-squared estimates across the different specifications mainly stem from the included operator-group fixed effects. Using more restrictive fixed effects reduces the R-squared estimates, but only has a small effect on our main results regarding the impact of the regulation.

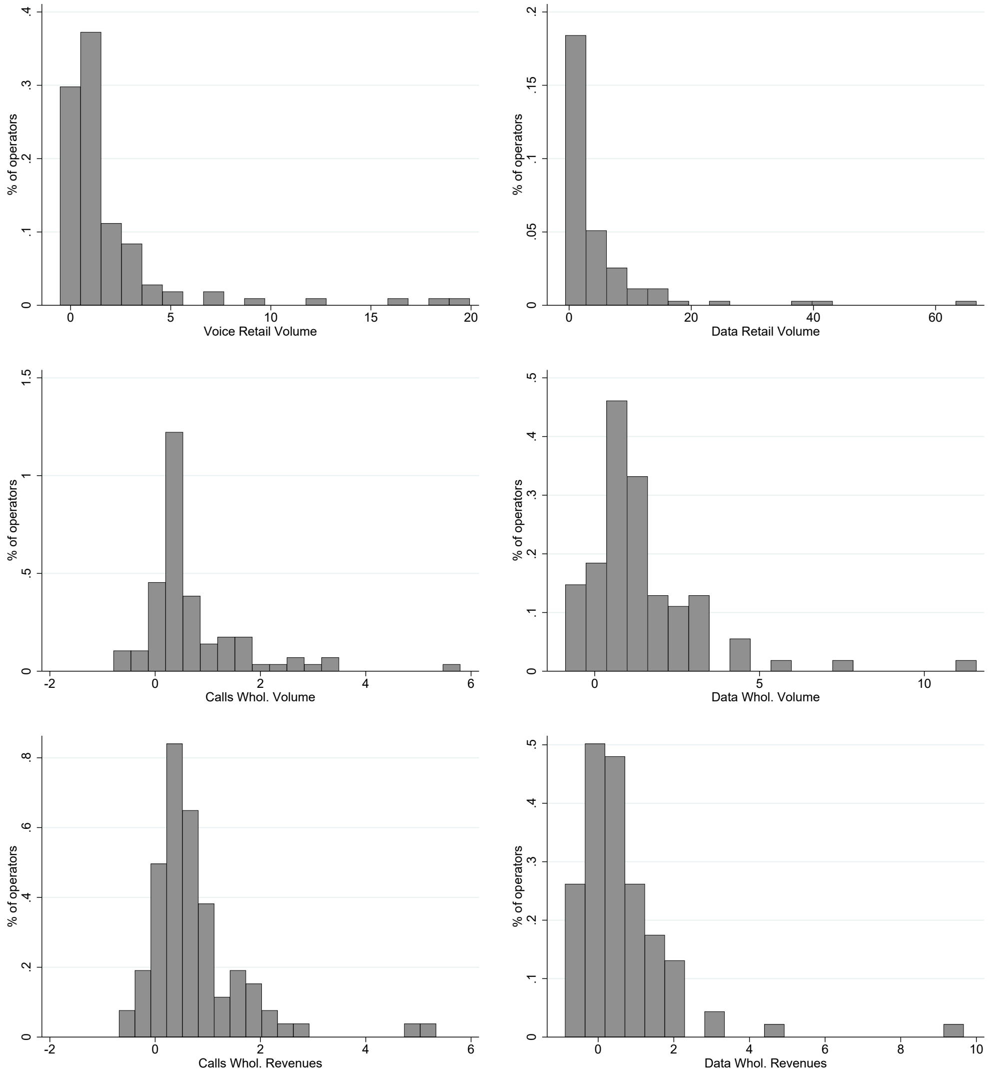
[29] We have only one quarter prior to the RLAH regulation to run the event study, because BEREC's roaming questionnaire was profoundly revised in 2016. However, aggregate data for 2013 and 2014 provide suggestive additional evidence on the existence of a common trend between RoW and EEA volumes. Indeed, between the first semester of 2013 and 2014, voice minutes decreased by a comparable 20% and 15% for EEA and RoW respectively; and data consumption increased by a comparable 184% and 166% for EEA and RoW. Similar findings are obtained between the second semester of 2013 and 2014 (i.e. voice minutes dropped by 18% and 9%, and data usage increased by 115% and 113%, respectively for EEA and RoW).

According to the middle panel of Table 2, the impact of the regulation on roaming traffic was the strongest in the Central-East and the South country groups, and it was the weakest in the North group. This conclusion applies to all outcome variables (retail and wholesale, voice and data services). We also considered more flexible specifications with separate treatment effects per country. This confirms the conclusions based on our four country groups. Countries with the top 3 highest effects are most often from the Central-East and South (e.g. Hungary, Greece and Bulgaria), whereas the countries with the three lowest effects most often come from the North (e.g. Norway, Sweden and Estonia).

According to the bottom panel of Table 2, the impact of the regulation on voice and data retail volumes was higher for MVNOs than for MNOs. This is as it could be expected. Since MVNOs do not have their own network, they had been more constrained in facilitating international roaming to their customers before the regulation, and these constraints are partly lifted after the regulation (except for possible derogations to some MVNOs). This also explains the MVNOs' prior concerns with the RLAH regulation, as their retail roaming losses cannot be (partly) compensated through wholesale revenues on increased inbound traffic. Note that our finding of a stronger effect on MVNOs has mainly distributional implications (between firms), and only limited implications for consumers and total welfare (as MVNOs are small and have a limited impact on competition).

Finally, we also estimated DiD specifications for our six outcome variables using fully flexible effects β_i^k per operator i. Recall that our final dataset covers 119 operators, of which 87 are MNOs also active in the wholesale market. Figure 2 plots the distribution of the estimated effects, transformed in percentage terms. Heterogeneity appears to be larger for retail than wholesale variables. For example, retail volume increased by 193% on average for voice and 485% for data across operators, with standard deviations almost twice as large.

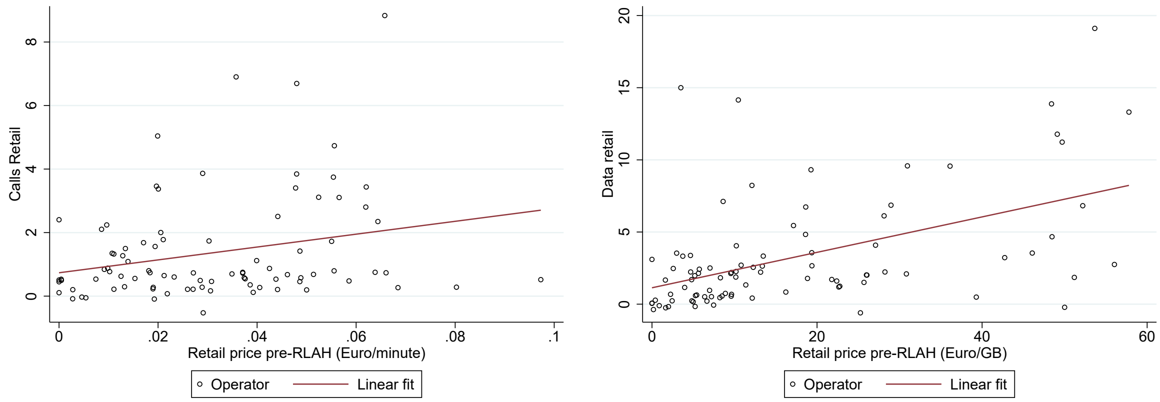
Figure 2: Operators' treatment effects



Note: The x axis shows DiD operators' treatment effects

To shed further light on the heterogeneous retail effects, Figure 3 plots the operators' estimated retail volume effects against their average pre-RLAH retail prices. For both voice and data the correlation is positive: the retail volume increases tend to be higher for operators that charged higher retail prices before the regulation. This is intuitive as consumers paying high prices were more constrained in their roaming practices before the regulation. But these plots also show that there is a lot of remaining heterogeneity, conditional on the pre-RLAH retail prices.

Figure 3: Relationship between operators' treatment effects and retail prices pre-RLAH



Note: The x axis shows DiD operators' treatment effects

6.2 Impact of the regulation on consumers and welfare

We now use our estimates to evaluate the impact of the regulation. We first discuss how the regulation has affected consumers differently across countries. Next, we discuss the effects on total EEA welfare, accounting for consumer surplus, retail profits and wholesale profits.

Impact on consumers across countries After the RLAH regulation the surcharge of international roaming services has essentially dropped to zero, so that roaming consumers only need to pay domestic fees when travelling abroad. As discussed in section 3, we can use our estimated retail volume effects to measure the resulting change in consumer surplus. Recall that the change in consumer surplus under linear and CES demand, as given by equations (2) and (3), can be interpreted as bounds on the change in consumer surplus for the family of demand functions that are convex but still satisfy Marshall's second law of demand. Furthermore, the interval (4) provides more conservative wider bounds for all decreasing demand functions.

Table 3 summarizes the results, aggregating over four geographic areas in the EEA. First, consider the estimated consumer surplus effects for the entire EEA, shown in the last column. Under CES demand, the RLAH regulation raised consumer surplus by 320.0 million Euro for voice services, and by 836.7

million Euro for data services, adding up to a total annual consumer gain of about 1.2 billion Euro. Under linear demand, the increase in consumer surplus amounts to 377.5 million Euro for voice and 1.6 billion Euro for data services, which adds adds up to a total annual consumer gain of almost 2 billion Euro. Put differently, consumer surplus increases by between 1.2 and 2 billion Euro for the family of convex demand functions that also satisfies Marshall's second law. Note that these bounds from Kang and Vasserman (2022) are considerably tighter than those from Varian (1985), which assume only decreasing demand (as shown in the remaining cells of the last row). In general, we also observe wider bounds for data than for voice services. This is because the estimated increase in retail volume was especially high for data, as documented in Section 5.

Second, consider a comparison across the different regions. According to the columns "Lower bound", countries in the West region obtain the largest consumer surplus gains. This is not surprising as the West region includes the largest countries. More interestingly, the additional consumer gains under the other bounds (as compared with the column "Lower bound") are proportionately larger for the three other regions. For example, in the South region the lower bound for data consumption is 80.9 million Euro, while the extra consumer gains under linear demand are 437.7-80.9=353.8 million Euro. Intuitively, this is because the RLAH regulation raised demand in the three other regions by more, and the gains from this new consumption are measured to be stronger for less convex demand functions.

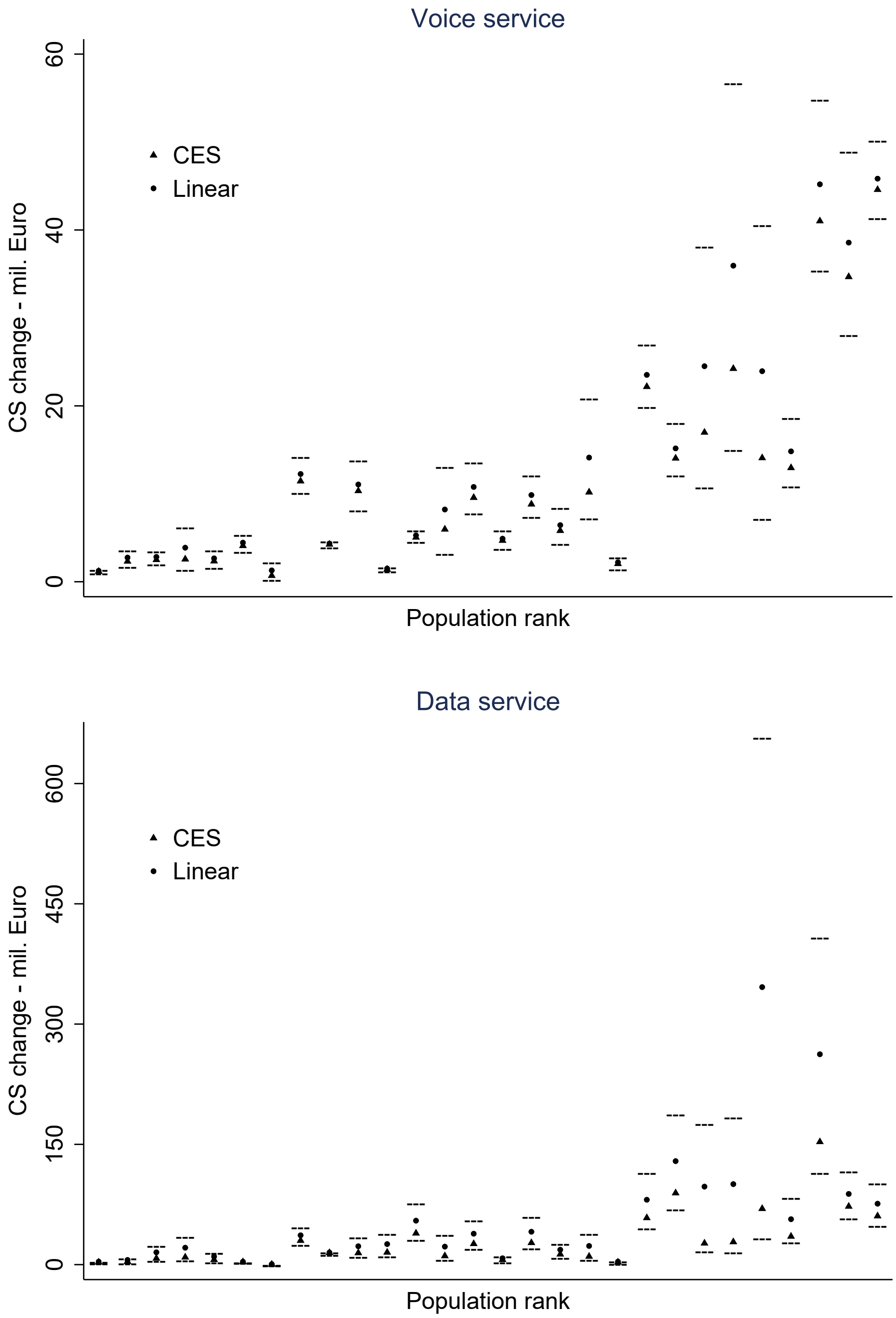
Table 3: Consumer surplus changes by region

	Voice				**Data**			
	Lower bound	CES bound	Linear bound	Upper bound	Lower bound	CES bound	Linear bound	Upper bound
South	27	38	51	76	81	128	435	788
North	24	29	32	40	94	117	177	259
West	155	178	191	227	387	490	712	1037
Central-East	51	75	103	155	67	103	285	503
EEA	257	320	378	498	629	837	1608	2588

Note: "Lower bound" and "Upper bound" respectively refer to changes in consumer surplus if demand is perfectly inelastic at (p^0, q^0_{out}) or perfectly elastic between (p^0, q^0_{out}) and (p^1, q^1_{out}), based on equation (4); "CES bound" (constant elasticity demand) is a lower bound for the family of demand functions satisfying Marshall's second law of demand (equation (3)); "Linear bound" (linear demand) is an upper bound for the family of convex demand functions (equation (2)). European countries have been grouped in four regions according to the classification in Table 2. All figures are in millions of Euro.

Figure 4 provides a more disaggregated overview by country, ranked according to their population size (from low to high). This shows there is considerable heterogeneity in the consumer gains across countries. As could be expected, the largest countries have the highest consumer gains. More interestingly, despite fairly wide absolute lower and upper bounds, the CES lower bound and the linear upper bound tend to be much smaller for most countries.

Figure 4: Bounds on consumer surplus



Note: "Lower bound" and "Upper bound" (horizontal dashed bars) respectively refer to changes in consumer surplus if demand is perfectly inelastic at (p^0, q^0_{out}) or perfectly elastic between (p^0, q^0_{out}) and (p^1, q^1_{out}), based on equation (4); "CES bound" (constant elasticity demand) is a lower bound for the family of demand functions satisfying Marshall's second law of demand (equation (3)); "Linear bound" (linear demand) is an upper bound for the family of convex demand functions (equation (2)). Countries are ranked according to their population size.

Figure 3 documented considerable heterogeneity in the consumer surplus gains across countries. Figure 5 and Figure 6 further explore two sources of this heterogeneity, based on the linear demand bound; the patterns are very similar for the CES demand bound. Figure 5 relates the countries' total consumer surplus gains to their population. This confirms that larger countries typically achieve larger consumer surplus gains, but it also shows that the gains are not proportional to their population size.[30] This indicates that the consumer gains tend to be comparatively larger for small open economies with proportionately more international travelling.

Figure 5: Relationship between CS and country population

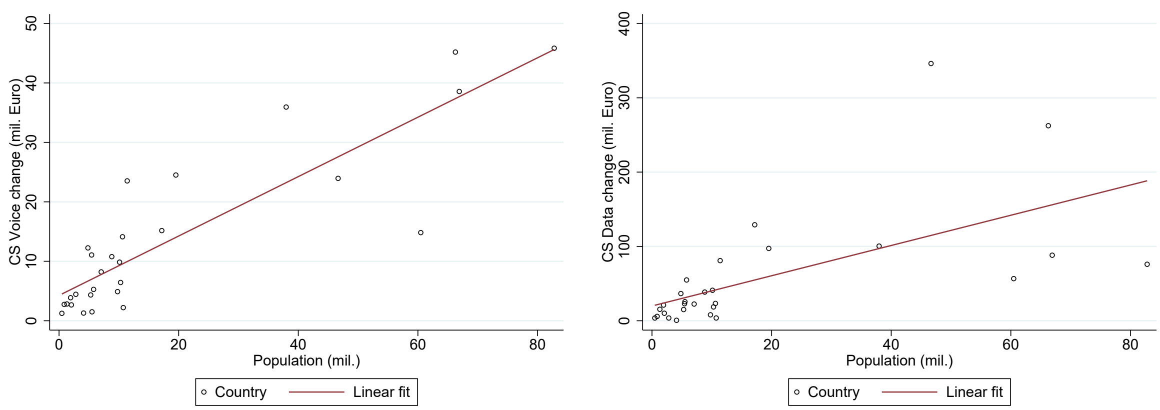


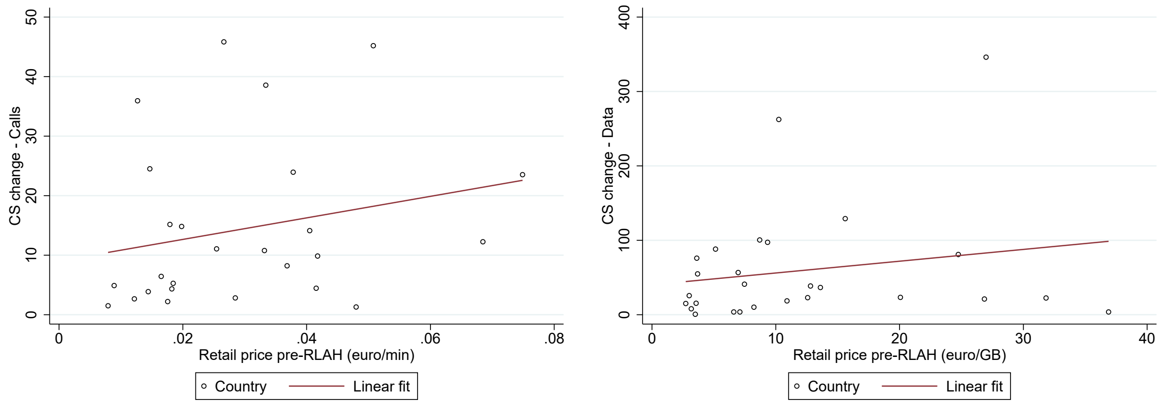
Figure 6 relates the total consumer surplus gains to the retail roaming price before the regulation.[31] This shows that consumer surplus gains indeed tend to be larger in countries that were more constrained, i.e. those with high retail roaming prices before the regulation. Nevertheless, the relationship is weaker than that between the consumer surplus gains and population size in the previous Figure 5.

In sum, this analysis has shown that there are large total consumer surplus gains from the RLAH regulation, but also that the gains are unevenly distributed across countries. We now turn to the total welfare effects of the regulation.

[30] According to a logarithmic regression, a 1% larger population size is associated with a larger consumer surplus gain of 0.68% for voice and of 0.74% for data.

[31] Figure 6 relates to, but is distinct from Figure 3, which plotted the estimated change in retail demand and used operator-level instead of country-level numbers.

Figure 6: Relationship between Consumer Surplus change and retail prices pre-RLAH -country level



Impact on total welfare As shown in Section 3, the change in total domestic welfare due to the regulation is given by (7), which is the sum of the change in consumer surplus, retail profits and wholesale profits. For consumer surplus, we use the CES demand lower bound (2) and linear demand upper bound (3). For retail profits we use (5), and for wholesale profits we use (6). We compute these gains per operator and service type (voice or data), and then aggregate over all operators and both service types to obtain the total EEA welfare effects of the regulation. The computations are based on our DiD estimates of the impact of the regulation on outbound retail volume and inbound wholesale volume and revenues, together with information on outbound wholesale prices and marginal costs as detailed in section 5.2.

Table 4 summarizes our findings. As already shown in the bottom row of our previous Table 3, the total gains to consumers in the EEA amount to between 1.2 and 2.0 billion Euro annually, of which between 840 million and 1.6 billion Euro stems from data, and between 320 and 380 million Euro stems from voice services. The range of consumer surplus gains is comparatively larger for data than for voice. This is because we had estimated a larger impact of the regulation on data traffic, so that the shape of the demand function over the newly generated traffic plays a more important role for data than for voice.

Table 4: Total welfare effects

	Voice	Data	Total
Consumer Surplus	[320 , 378]	[837 , 1608]	[1157 , 1986]
Retail Profit (outbound)	-448	-825	-1273
Loss at given retail volume	-257	-629	-886
Extra loss from higher retail vol.	-224	-447	-671
Gain from reduced wholesale price	33	251	284
Wholesale Profit (inbound)	173	136	308
Wholesale revenues change	167	110	277
Loss from higher wholesale vol.	-31	-133	-164
Gain from reduced wholesale cost	36	159	195
Total Profit	-276	-689	-965
Total Welfare	[44 , 102]	[148 , 919]	[192 , 1021]

Note: Calculations are based on the operator-level effects $\hat{\beta}_i^k$ and the economic framework provided in Section 4. The lower and upper bounds for consumer surplus and total welfare are based on the CES and linear bounds, as explained in Table 3. All figures are in millions of Euro.

The annual 1.2–2.0 billion Euro gains to consumers come at the expense of the operators' profits. Outbound *retail profits* drop by almost 1.3 billion Euro. This stems in part from losses on existing consumers who no longer need to pay a roaming surcharge (886 million Euro). Furthermore, there are extra losses on new consumers, who can roam without a surcharge while the operator still has to pay a wholesale price to the foreign operator (671 million Euro). These two sources of retail loss are insufficiently compensated by the retail profit gain from the reduced wholesale prices after the regulation (284 million Euro). Inbound *wholesale profits* increase by 308 million Euro. This is insufficient to compensate for the drop in outbound retail profits, so the total profit drop of the operators amounts to an annual 965 million Euro.

The impact of the regulation on total welfare is positive and mainly stems from data services. The total annual welfare gain is bounded between 192 million and 1.0 billion Euro. This may be viewed as a sizeable amount (CES lower bound) or a rather substantial amount (linear demand upper bound), when compared to for example the 886 million Euro roaming revenues before the regulation.

To further interpret the magnitude of the welfare increase, it is useful to go back to our stylized representation of the welfare gains under linear demand (Figure 1 of Section 3). We discussed there that the size of the welfare gains depends on the extent to which the roaming price before the regulation was above marginal cost, and on the size of the marginal costs. On the one hand, regulating roaming surcharges to zero reduces a distortion from market power, including a potential double marginalization problem as stressed by Lupi and Manenti (2009). On the other hand, it creates a new distortion because of excessive roaming consumption at zero surcharges. Our findings imply that under linear demand the reduction in market power far outweighs the new distortion from excessive consumption when roaming surcharges are eliminated. The high pre-regulation market power may stem from a combination of double marginalization and/or capacity constraints due to insufficient investments in roaming capacity. Under CES demand, the reduction in market power also outweighs the distortion from excessive consumption, but to a smaller degree because the welfare consequences of double marginalization are less important.

The estimated welfare effects were based on our DiD estimates, but in addition we made assumptions regarding the average outbound wholesale price (as discussed in section 5.2). Since we had no direct measure of the outbound wholesale price paid by the MVNOs, our main analysis assumed that MVNOs pay the average EEA wholesale prices. To evaluate the role of this assumption, we perform a robustness analysis and assume that the MVNOs pay a wholesale outbound price equal to the wholesale cap. The results from this analysis are reported in Table A.3 in the Appendix. We find that the results are very similar: total profits drop by slightly less (1040 million instead of 1053 million Euro), so that the welfare effects are slightly higher.

To summarize, we find that the large consumer gains from the RLAH regulation are partly compensated by retail profit losses, which may especially be detrimental to the MVNOs (as they have no wholesale profits). Nevertheless, the total welfare gains of almost 1 billion Euro annually are quantitatively important, indicating large gains from the elimination of market power in the roaming market.

7 Evaluating waterbed effects in the domestic market

Our previous analysis assumed that the RLAH regulation did not affect the domestic market. However, as discussed in section 3, it is possible that the regulation involves a waterbed effect on the prices for domestic services. A negative waterbed effect (hence an increase in domestic prices) would exist if domestic and international roaming retail services are substitutes, and a positive waterbed effect would exist in the reverse case.

To evaluate the assumption of no waterbed effect, we use quarterly data on domestic mobile retail prices for representative consumption baskets (excluding roaming services). The baskets are defined according to the methodology of OECD (2017) on the basis of the price data collected by Teligen.[32] The data cover the two largest operators in 36 OECD countries: it includes 24 EEA countries, which are the treatment group, and 12 non-EEA countries, which form the control group. The quarterly data cover the period 2016Q3-2017Q4, hence three quarters before and three quarters after the RLAH regulation. We use the 2006 consumption baskets defined by the OECD for high, medium and low voice volume users. Prices refer to hypothetical bills for the given volume usage in each basket. More specifically, we take the minimum price per basket and country among the two covered operators.

We estimate the following specification for the domestic retail price P_{jct} of basket j in country c (either EEA or non-EEA country) at time t:

$$\ln P_{jct} = \beta_j \times (EEA \times Post)_{ct} + \phi_{jc} + \psi_{jt} + \varepsilon_{jct}, \tag{10}$$

where $(EEA \times Post)_{ct}$ is a dummy variable equal to one for countries in the treatment group (EEA countries) after the regulation, and ε_{jct} is the error term. We cluster standard errors at the level of the country and basket.

The coefficients β_j measure the impact of the regulation on domestic prices in the treatment group (EEA countries) relative to the control group (other OECD countries), after controlling for a full set of basket-country and basket-quarter fixed effects. We allow these coefficients to differ by consumption basket j. In an extension we allow for additional heterogeneous effects by distinguishing between net inbound and net outbound countries. Indeed, operators from countries that typically have a larger out-

[32] Teligen is a private firm that collects data on prices of telecommunication packages advertised on mobile operators' websites.

bound retail than inbound wholesale roaming traffic (net outbound countries) might have suffered from a larger revenue loss after the regulation than operators from the other countries (net inbound countries). As a result, net outbound countries may have had a larger incentive to raise domestic prices than net inbound countries. Failing to account for such heterogeneity may incorrectly result in an insignificant impact of the regulation on domestic retail prices.[33]

Table 5 shows summary statistics for the domestic price per consumption basket. The means and standard deviations are broken down by period (before and after the regulation) and control group (24 EEA countries versus 12 other countries). Average prices are higher for the high consumption basket. Prices appear to be declining over the two periods, but it is not clear from this table whether they are declining less strongly in the treatment group (as it would be expected if there was a negative waterbed effect).

Table 5: Summary statistics of domestic prices.

	Pre-RLAH			Post-RLAH		
	Obs.	Mean	St. Dev.	Obs.	Mean	St. Dev.
EEA Countries High	72	15.136	8.055	72	13.995	6.361
Non-EEA Countries High	36	17.839	9.018	36	16.132	7.611
EEA Countries Medium	72	12.020	5.373	72	10.898	4.493
Non-EEA Countries Medium	36	14.683	6.545	36	13.629	7.192
EEA Countries Low	72	8.318	3.744	72	7.880	3.563
Non-EEA Coutries Low	36	10.428	4.971	36	9.081	4.906

Note: Pre-RLAH refers to 2016Q4-2017Q1, and Post-RLAH refers to 2017Q2-2019Q1. High, Medium and Low are the respective volume categories of the basket. EEA stands for European Economic Area and q for quarter. Domestic prices are measured in US dollars and purchasing power parity.

To assess this, Table 6 shows the empirical results from estimating specification (10). According to the left column, the domestic prices of the three consumption baskets show small but insignificant increases in the EEA countries after the regulation, relative to the other OECD countries. P-values of a Wald-test further confirm that the coefficients are jointly not significantly different from zero. The right column of Table 6 allows for additional heterogenous effects for outbound countries. This confirms the findings

[33] To construct the group of inbound and outbound countries, we use our BEREC data on wholesale and retail roaming traffic flows, and distinguish between the two groups based on the traffic flows over the entire period.

of the left column: the main effects are still statistically insignificant, and there is also no significant extra effect for outbound countries. Note that these results are also in line with the evidence of Grzybowski and Munoz-Acevedo (2021).[34]

To summarize, these findings indicate that the regulation did not imply statistically significant waterbed effects on the domestic market, in line with the assumptions of our main framework in the previous sections. One explanation is that domestic and international roaming services are only very weak substitutes or complements, so that operators have no incentives to adjust their domestic prices. A second explanation is that the intra-EEA roaming market is only a relatively small part of the overall business of mobile operators, i.e. about 4% of domestic revenues as discussed above. As a result, any adjustments in price strategies would be small. Note that our finding of statistically insignificant waterbed effects may be due to the fact that the waterbed effect is small, and therefore difficult to detect. Nevertheless, it appears that such a possible waterbed effect would likely be insufficient to undo the large positive welfare effects we found on the roaming market in the previous section.

[34]Using tariff level data from Tarifica, they estimate a quality-adjusted hedonic price index, to assess the impact of the RLAH regulation on this index in a Difference-in-Differences model. They find no evidence of a price increase after the implementation of the RLAH regulation.

Table 6: Domestic prices regression results.

	(1) Baskets	(2) Outbound
High Coefficient	0.012	0.072
	(0.063)	(0.050)
Medium Coefficient	0.016	0.080
	(0.077)	(0.065)
Low Coefficient	0.106	0.170
	(0.089)	(0.088)
High Outbound		-0.091
		(0.090)
Medium Outbound		-0.097
		(0.107)
Low Outbound		-0.079
		(0.110)
Country-Basket FE	Yes	Yes
Basket-Period FE	Yes	Yes
R-squared	0.926	0.934
Observations	648	612
Jointly Zero	0.684	0.225
Outbound Zero		0.504

Note: Standard errors clustered at the country-basket level in parentheses. The last two statistics are p-values of Wald tests: "jointly zero" indicates if all reported coefficients are jointly zero; "outbound zero" indicates if basket-outbounder coefficients are jointly zero.

8 Conclusions

We have studied the impact of the European Roam-Like-At-Home (RLAH) regulation, implemented as a final step after an earlier reform process of ever tighter regulations. This regulation banned all mobile roaming surcharges to consumers travelling within the EEA, and at the same time further tightened the wholesale price caps applicable to foreign operators when enabling international roaming services to travellers.

We have estimated the causal impact of the regulation on EEA roaming traffic, using the Rest of the World as a control group. We find that the regulation substantially raised international roaming volumes, even more strongly for data than for voice services. Wholesale revenues also increased, but by less than wholesale volumes in the case of data services. The estimated impact shows substantial heterogeneity between operators, with larger traffic increases for operators from countries in the Central-East and South of the EEA, and for MVNOs who constrained roaming traffic to their customers more strongly than MNOs before the regulation.

To evaluate the welfare effects of the regulation, we develop a framework that includes consumer surplus, retail and wholesale profits. Based on our estimates of the increase in roaming traffic attributed to the regulation, we find an annual increase in total consumer surplus in the EEA by between 1.4 and 2 billion Euro, of which a considerable part is due to newly generated demand. The gains mainly stem from data services, and they vary considerably across countries. Small open economies and countries with previously high roaming prices tend to benefit proportionately more.

Finally, the consumer surplus gains outweigh the profit losses caused by the regulation. As a result, annual total welfare increases by between 0.2 and 1 billion Euro, or up to 80% of EEA roaming revenues before the regulation. Hence, the benefits from the removal of market power more than compensate for a distortion from a possible overconsumption at zero surcharges. Intuitively, net welfare effects are large because the zero price caps eliminate market power due to double marginalization or insufficient network capacity, and because the extra costs of providing roaming services were low. In an extension of our analysis, we evaluate whether firms compensated for their roaming losses by raising domestic tariffs, but we cannot detect evidence of such a waterbed effect.

Our findings show how price cap regulation remains important in markets with competitive bottleneck problems. It is thus complementary to policy initiatives that liberalized markets through privatization, vertical separation and the promotion of competition. Furthermore, our findings show the delicate balance of the distributional effects of regulations: profit effects differ among types of operator (MNO versus MVNOs); consumer gains vary substantially across EEA countries; and overall consumer gains come at the expense of firms with differing network infrastructures. Finally, our findings illustrate how regulation may both improve efficiency and achieve the EEA's political objective of a common market, in particular the "Digital Single Market" in our setting. This may, however, not generally be the case, and it should be assessed on a case-by-case basis. Studying the impact of price regulations in an international context thus remains a high priority for further research.

References

Armstrong, M. (2001). The theory of access pricing and interconnection. In M. Cave, S. Majumdar, and I. Vogelsang (Eds.), *Handbook of Telecommunications Economics*. North-Holland.

Cave, M., C. Genakos, and T. Valletti (2019). The european framework for regulating telecommunications: a 25-year appraisal. *Review of Industrial Organization 55*(1), 47–62.

Commission, E., C. Directorate-General for Communications Networks, and Technology (2020). *Mobile broadband prices in Europe 2019 : final report and executive summary*. Publications Office.

Dubois, P., A. Gandhi, and S. Vasserman (2019). Bargaining and international reference pricing in the pharmaceutical industry. Technical report.

Duch-Brown, N., L. Grzybowski, A. Romahn, and F. Verboven (2020). Evaluating the impact of online market integration: Evidence from the eu portable pc market. Technical report.

Einav, L., A. Finkelstein, and M. R. Cullen (2010). Estimating welfare in insurance markets using variation in prices. *The Quarterly Journal of Economics 125*(3), 877–921.

European Commission (2011). Impact assessment of policy options in relation to the commission's review of the functioning of regulation (ec) no 54/2009 of the european parliament and the council of 18 june 2009 on roaming on public mobile telephone networks within the community. Technical report.

European Commission (2016a). Commission Staff Working Document Accompaining the document

Report from the Commission to the European Parliament and the Council on the review of the wholesale roaming market. Technical report, COM(2016) 398.

European Commission (2016b). Report from the Commission to the European Parliament and the Council on the review of the wholesale roaming market. Technical report, SWD(2016) 200.

Genakos, C. and T. Valletti (2011). Testing the "waterbed" effect in mobile telephony. *Journal of the European Economic Association 9*(6), 1114–1142.

Genakos, C. and T. Valletti (2015). Evaluating a decade of mobile termination rate regulation. *The Economic Journal 125*(586), F31–F48.

Grzybowski, L. and Á. Munoz-Acevedo (2021). Impact of roaming regulation on revenues and prices of mobile operators in the eu.

Hackmann, M. B., J. T. Kolstad, and A. E. Kowalski (2015). Adverse selection and an individual mandate: When theory meets practice. *American Economic Review 105*(3), 1030–66.

Head, K. and T. Mayer (2021). The united states of europe: A gravity model evaluation of the four freedoms. *Journal of Economic Perspectives 35*(2), 23–48.

Kang, Z. Y. and S. Vasserman (2022). Robust bounds for welfare analysis. Technical report, National Bureau of Economic Research.

Lupi, P. and F. M. Manenti (2009). Traffic management in wholesale international roaming: towards a more efficient market? *Bulletin of Economic Research 61*(4), 379–407.

OECD (2017). Revised oecd telecommunication price baskets. Technical report, Organisation for Economic Cooperation and Development, Directorate for Science, Technology and Innovation Committee on Digital Economy Policy.

Quinn, M., M. G. de Matos, and C. Peukert (2022). The welfare effects of mobile internet access-evidence from roam-like-at-home.

Salsas, R. and C. Koboldt (2004). Roaming free? roaming network selection and inter-operator tariffs. *Information Economics and Policy 16*(4), 497–517.

Spruytte, J., M. Van der Wee, M. de Regt, S. Verbrugge, and D. Colle (2017). International roaming in the eu: Current overview, challenges, opportunities and solutions. *Telecommunications Policy 41*(9), 717–730.

Varian, H. R. (1985). Price discrimination and social welfare. *The American Economic Review 75*(4), 870–875.

Wright, J. (2002). Access pricing under competition: an application to cellular networks. *The Journal of Industrial Economics 50*(3), 289–315.

Xiao, M. and Z. Yuan (2018). License complementarity and package bidding: The us spectrum auctions. *Available at SSRN 3266253*.

A Appendix

A.1 Details on variable construction

This Appendix provides further details on the measurement of two variables discussed in Section 5.2: the operators' average outbound wholesale price, and the marginal costs of providing network services to foreign operators.

A.1.1 Outbound wholesale prices

The outbound wholesale price corresponds to the price paid by each European operator (independently from it being an MNO or an MVNO) for the volumes consumed by its subscribers on the visited networks of other European MNOs. We do not directly observe the outbound wholesale prices paid to each foreign operator. But we can compute the average outbound wholesale price per operator because we have access to information on bilateral traffic flows of outbound wholesale roaming volumes from each operator to each EEA country.[35] More precisely, we compute the average outbound wholesale price of each operator i, $\overline{w}_{out,i}$, as the weighted average of the country-level *inbound* wholesale prices $w_{in,c}$ (which we observe) across the EEA countries c:

$$\overline{w}_{out,i} = \sum\nolimits_{c} \alpha_{ic} w_{in,c}.$$

Here, α_{ic} is the bilateral traffic share of operatpr i to country c such that $\sum_c \alpha_{ic} = 1$, and $w_{in,c}$ is the country-level wholesale price, computed as inbound wholesale revenues divided by inbound wholesale volumes.

We compute the outbound wholesale price before the regulation ($\overline{w}^0_{out,i}$) and after the regulation ($\overline{w}^1_{out,i}$). To compute it after the regulation, we assume the weights α_{ic} are not affected,[36] so that the inbound wholesale price after the regulation is the causal estimate given by $w^1_{in,c} = \exp(\beta^k_i) w^0_{in,c}$.

[35] As such, we observe bilateral traffic flows by operator-country pairs and not by operator-operator pairs.

[36] It indeed seems plausible that the regulation has not changed traveling habits and hence bilateral traffic flows between European countries.

Two caveats are in order. First, we can directly apply the approach only to data services and not to voice services, as there is no information on bilateral traffic flows for voice. We therefore use the ratio of inbound wholesale voice prices and inbound wholesale data prices to approximate outbound wholesale prices for voice services. Second, bilateral flows are reported only for the MNOs. To approximate average outbound wholesale prices paid by the MVNOs we make two alternative assumptions: (i) MVNOs pay an outbound wholesale price equal to the European average wholesale outbound prices; (ii) MVNOs pay the maximum outbound wholesale price, i.e. the wholesale cap. The welfare calculations in the main text are based on (i), while the Appendix provides a robustness analysis based on (ii).

A.1.2 Cost for providing wholesale services

The information about the cost for providing wholesale roaming services was retrieved from the cost model developed by Axon Consulting, as commissioned by the European Commission. The study is based on a Bottom-up Long-Run Incremental Cost (BULRIC) model. It takes into account all relevant cost determinants, including seasonally-adjusted volume forecasts and investments, as well as the strictly technical aspects related to the network infrastructure. The final outcome is a measure of the cost of providing international roaming services by a hypothetical efficient operator in each country under well specified assumptions.[37] Such cost estimates are available per country for the time interval 2015-2025. Table A.1 presents the country level estimates for 2015 and 2018.

[37] More details on the Cost Model can be found at https://ec.europa.eu/digital-single-market/en/news/finalisation-mobile-cost-model-roaming-and-delegated-act-single-eu-wide-mobile-voice-call

Table A.1: Estimates wholesale costs based on the Axon model

	Voice		Data	
	2015	2018	2015	2018
AT	0.005	0.005	1.51	0.82
BE	0.016	0.009	5.07	2.51
BG	0.006	0.004	2.59	1.03
CY	0.009	0.007	2.96	1.49
CZ	0.011	0.008	2.45	0.88
DE	0.013	0.009	3.82	2.17
DK	0.004	0.003	1.05	0.55
EE	0.005	0.004	1.46	0.85
EL	0.009	0.006	4.85	2.08
ES	0.009	0.005	6.11	2.57
FI	0.004	0.002	1.92	0.63
FR	0.008	0.005	3.18	1.76
HR	0.006	0.004	3.98	1.20
HU	0.015	0.009	7.86	2.52
IE	0.007	0.006	3.09	1.56
IT	0.008	0.005	2.28	1.29
LT	0.008	0.005	2.06	1.08
LV	0.010	0.004	2.27	0.57
MT	0.016	0.013	7.08	2.65
NL	0.009	0.005	3.46	1.56
NO	0.017	0.009	2.39	1.54
PL	0.002	0.002	0.79	0.44
PT	0.007	0.004	2.25	1.27
RO	0.006	0.003	1.79	0.75
SE	0.008	0.006	1.61	1.05
SI	0.009	0.006	3.01	1.11
SK	0.007	0.006	3.14	1.39
UK	0.008	0.005	2.73	1.38

Note: Costs are in Euro per minute (voice) and GB (data).

A.2 Additional empirical results

This Appendix provides additional empirical results relating to section 6 in the main text.

A.2.1 Before-after estimates

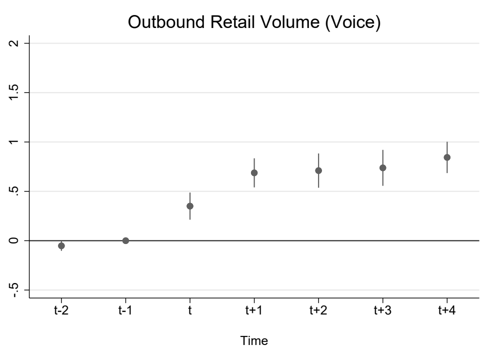
Table A.2: Before and after regulation comparison

	Voice			Data		
	Outbound Retail Vol.	Inbound Whol. Vol.	Inbound Whol. Rev.	Outbound Retail Vol.	Inbound Whol. Vol.	Inbound Whol. Rev.
Post RLAH	0.870***	0.725***	0.384***	2.133***	1.698***	0.507***
	(0.087)	(0.053)	(0.050)	(0.096)	(0.082)	(0.074)
Observations	1,110	890	890	1,050	880	880
R-squared	0.019	0.039	0.012	0.105	0.169	0.018

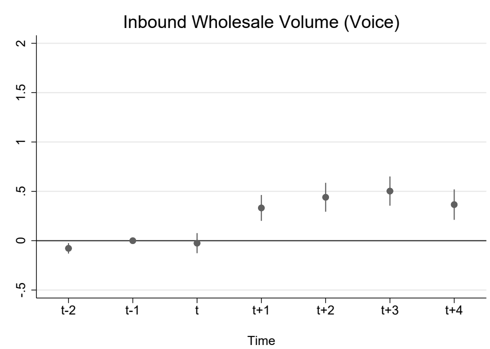
Note: Clustered robust standard errors in parentheses. Clusters defined at country and operators' level.
*** p<0.01, ** p<0.05, * p<0.1

A.2.2 Results from event study

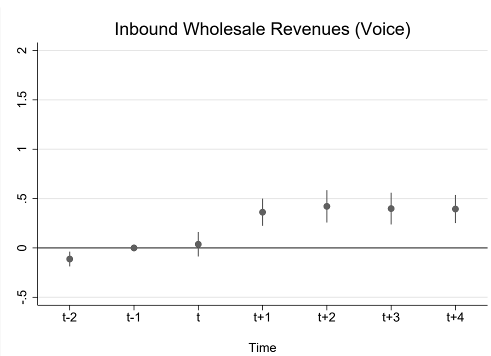
Figure A.1: Event study analysis



(a)

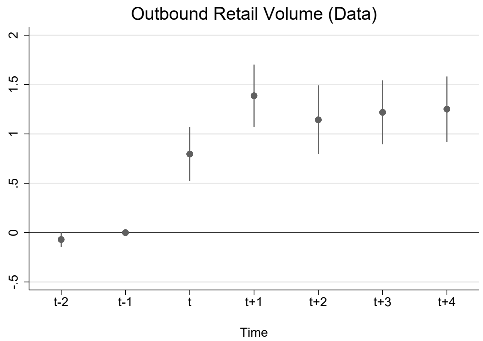


(b)

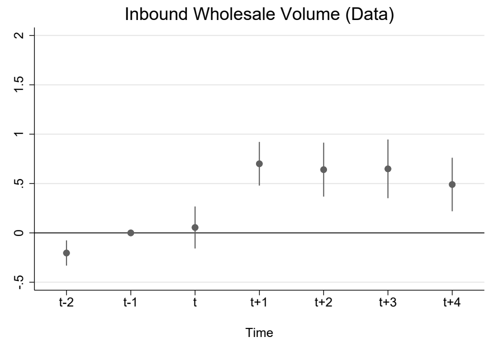


(c)

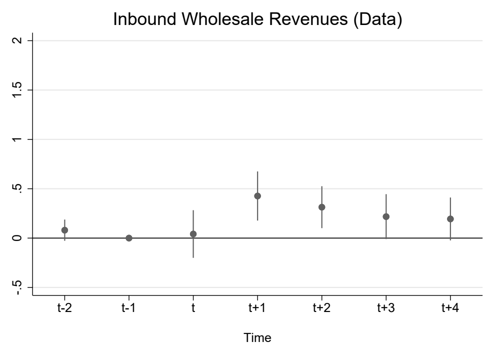
Figure A.2: Event study analysis



(a)



(b)



(c)

A.3 Robustness: alternative assumptions on outbound wholesale price

This Appendix provides a sensitivitiy analysis with respect to the outbound wholesale price for the total welfare analysis in section 6.

Table A.3: Total welfare effects

	Voice	Data	Total
a. Baseline scenario. MVNOs pay avg EEA wholesale price			
Consumer Surplus	[320 , 378]	[837 , 1608]	[1157 , 1986]
Retail Profit (outbound)	-448	-825	-1273
Loss at given retail volume	-257	-629	-886
Extra loss from higher retail vol.	-224	-447	-671
Gain from reduced wholesale price	33	251	284
Total Profit	-276	-689	-965
Total Welfare	[44 , 102]	[148 , 919]	[192 , 1021]
b. MVNOs' whol. outbound price = whol. cap			
Consumer Surplus	[320 , 378]	[837 , 1608]	[1157 , 1986]
Retail Profit (outbound)	-446	-814	-1260
Loss at given retail volume	-257	-629	-886
Extra loss from higher retail vol.	-223	-449	-672
Gain from reduced wholesale price	34	264	298
Total Profit	-274	-678	-952
Total Welfare	[46 , 104]	[159 , 930]	[205 , 1034]

Note: Authors calculations