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

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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 far outweigh profit losses. As such, the removal of market power more than compensates for a distortion from a possible overconsumption at zero surcharges.

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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 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 the wholesale prices that the domestic operators pay to the foreign operators for enabling international roaming 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 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.

One main motivation for the roaming price regulations had been the existence of very high prices during the unregulated period before 2007. The key bottleneck problem had been that foreign operators faced limited competitive constraints when charging wholesale prices to the domestic operators for enabling access to their networks.[4] Under certain conditions, foreign operators may charge monopoly wholesale prices. Domestic operators may, in turn,

[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.

[3] At that time, the EEA included all 28 Member States of the EU (including UK) plus 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.

pass these charges on to 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, in contrast, cautioned that the regulation would entail new distortions because of overconsumption as a retail price of zero is below the extra cost of providing 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 the 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 losses.

Note that the decision to remove all roaming surcharges also fits within the European Union's broader political goal to achieve a common market, with 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 to ensure 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.

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

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 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. We estimate an increase in total consumer surplus in the EEA by an annual 2 billion Euro, of which about half is due to existing demand and the remaining half due to 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 welfare. The total annual consumer surplus gains of 2 billion Euro 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 on total welfare thus amounts to an annual amount of almost 1 billion Euro, or about 80% of EEA roaming revenues before the regulation.

In sum, these findings imply that the regulation created consumer surplus gains that are 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 so 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 price 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, and we do not find 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

[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

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.

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 our analysis, we also start from cross-country differences in international roaming prices, and we evaluate the welfare effects when these surcharges are entirely removed.

Most closely related to our research, a recent paper by Quinn, Godinho de Matos, and Peukert (2021) has also evaluated the effects of the roam-like-at-home regulation. The scope of their analysis is different from ours: they have a data set on roaming retail traffic for data consumption, originating from a single operator in one European country. They obtain interesting insights in the regulation impact on consumers and the role of usage heterogeneity (supplemented with information from an 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. Furthermore, we systematically incorporate our empirical results in an economic framework to provide estimates of both consumer and total welfare effects across all EEA countries.

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,

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.

and Kowalski (2015). The latter starts from a theoretical framework that decomposes the welfare effect of a policy reform into various parts, and then apply 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.

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. The discussion is in part 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 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]

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 unregulated 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, the 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]

[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

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 most from the lost revenues connected to roaming surcharges. At the same time, the caps were not set too low to preserve the operators' incentives to invest in infrastructure.

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

domestic and roaming consumption over a period of at least 4 months. If an operator detects a possible abusive or anomalous use of the 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.

[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.

firms' optimal pricing (as in a structural approach). We will instead interpret our findings based on equilibrium models when discussing the results.

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[12] 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 these services, i.e. the roaming *surcharge* above the domestic price (the main subject of the RLAH regulation).[13] 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, outbound and inbound traffic (relating to respectively retail demand $q_{out}(p)$ and wholesale demand q_{in}) refer to intra-EEA traffic.[14] There is of course also outbound and inbound

[12]Operators' customers include both private and business users.

[13]In the following, we will use the terms "retail roaming price" and "surcharge" as synonyms when referring to the amount of surcharges consumers paid for their roaming consumption before the start of the RLAH.

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

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 three 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 because international roaming services are a relatively small part of the mobile telecom market.[15] 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.[16] 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.

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

[15] 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.

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

services are substitutes, and a positive waterbed effect would exist in the reverse case.[17] 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.

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 regulation has removed the retail surcharges for international roaming services, with a few exceptions. This means that retail price for roaming services (on top of the regular domestic price) has dropped from $p^0 > 0$ to $p^1 = 0$. This may, in turn, have raised the outbound and inbound roaming traffic (q_{out} and q_{in}). In addition, 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 $p^1 = 0$, and is given by:

$$\Delta CS = \int_0^{p^0} q_{out}(u)du$$

where we use the operator Δ to denote the change in a variable x, $\Delta x \equiv x^1 - x^0$. With a linear approximation of demand, we can write the change in consumer surplus as

$$\Delta CS = p^0 q^0_{out} + \frac{1}{2} p^0 \Delta q_{out}. \tag{2}$$

[17]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.

The first term captures the gain to the infra-marginal consumers, and simply equals the consumer expenditures on international roaming services before the regulation. The second term consists of the gain from increased demand for roaming services Δq_{out}, measured at the simple average of the price before (p^0) and after ($p^1 = 0$) the regulation. In a graphical representation, these two terms are of course the typical rectangle and triangle.

If demand is not linear, it is still possible to compute bounds on the change in consumer surplus. If demand is convex (concave), ΔCS will be smaller (larger) than (2). For general demand functions we can bound the change in consumer surplus to belong to the interval

$$\Delta CS \in [p^0 q^0_{out}, p^0 q^0_{out} + p^0 \Delta q_{out}]. \tag{3}$$

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}):

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

Using the fact that $p^1 = 0$, we can rewrite this as the sum of three terms:

$$\Delta \pi_{retail} = -p^0 q^0_{out} - \left(w^1_{out} \Delta q_{out} + q^0_{out} \Delta w_{out}\right). \tag{4}$$

The first term is the revenue loss from no longer being able to charge for roaming services. This is of course just the same as the above consumer surplus gain to infra-marginal consumers. The second and third terms capture the operator's additional loss from increased wholesale costs. The second term is the loss from having to serve increased retail demand, evaluated at the new wholesale price after the regulation. 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:

$$\Delta\pi_{wholesale} = \Delta r_{in} - c^1 \Delta q_{in} - q_{in}^0 \Delta c. \tag{5}$$

The first term is the increase in inbound wholesale revenues after the regulation.[18] 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.[19] 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 To obtain the change in total domestic welfare, we can add up the change in consumer surplus (2), retail profits (4) and wholesale profits (5):

$$\begin{aligned} \Delta W \;=\; & \frac{1}{2} p^0 \Delta q_{out} \\ & - w_{out}^1 \Delta q_{out} - q_{out}^0 \Delta w_{out} \\ & + \Delta r_{in} - c^1 \Delta q_{in} - q_{in}^0 \Delta c, \end{aligned} \tag{6}$$

where the terms $p^0 q_{out}^0$ cancel as they involve a transfer from firms to infra-marginal consumers. We will use (6) to compute the impact of the regulation on total welfare. But it is instructive to see how the expression simplifies if the regulation keeps the change in outbound wholesale costs and inbound wholesale revenues balanced, i.e. if $w_{out}^1 \Delta q_{out} + q_{out}^0 \Delta w_{out} = \Delta r_{in}$. We refer to this condition briefly as "wholesale balancedness". The impact of the regulation on domestic welfare then simplifies to

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

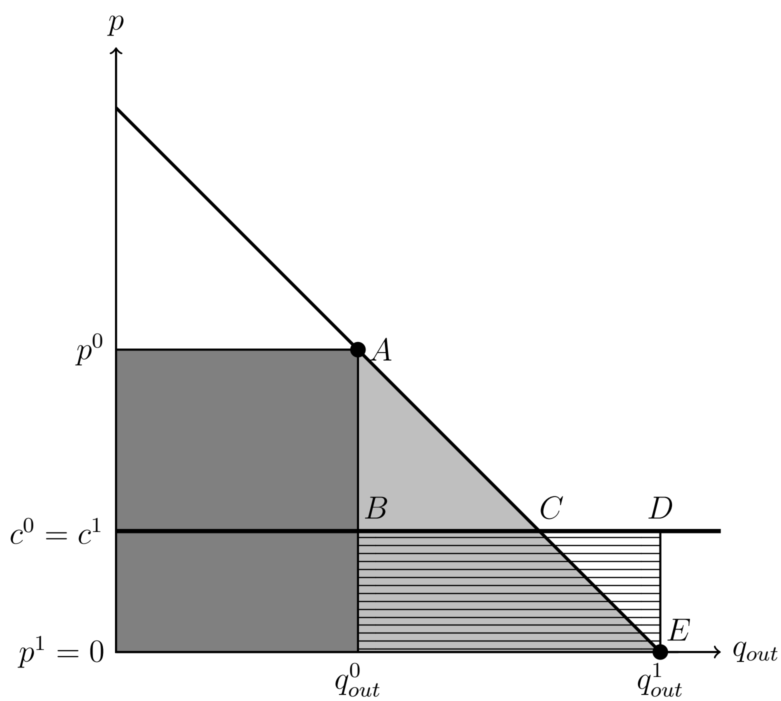
The first term is the (approximate) gross welfare gain from serving additional demand after the regulation. The second term shows the costs from serving these extra consumers, evaluated at the post-regulation marginal costs. Finally, the third term shows a potential welfare gain from possible improved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

[18] 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 (4). The reason is that we directly observe inbound wholesale revenues, and not outbound wholesale expenses (only outbound demand).

[19] 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.

To illustrate this, Figure 1 plots a linear demand and constant marginal cost function, and compares the consumer surplus change with the total welfare effects under the wholesale balancedness condition and under the assumption of no efficiencies ($\Delta c = 0$). The increase in consumer surplus is equal to the sum of the dark shaded rectangle (existing demand) and light shaded triangle (extra demand). 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 at zero price). This difference reduces 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)



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.

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:

$$\ln Y_{ist}^{k} = \alpha^{k} + \beta^{k}(EEA \times Post)_{st} + \gamma_{is}^{k} + \theta_{t}^{k} + \varepsilon_{ist}^{k}, \tag{7}$$

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}.[20]

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 EU 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.

[20]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.

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 assumption is that the average change in the outcome variable for the treatment group ($s = EEA$) in the absence of the regulation is equal to the average change for the control group ($s = RoW$). When the outcome variable refers to outbound traffic, it assumes 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 assumes that without the regulation the change of inbound traffic from other EEA countries would have been the same as from the RoW on average. Since the RLAH regulation applies only to intra-EEA and not to RoW traffic, it seems plausible that both groups are 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 will 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 β_t^k for each t).

Specification (7) assumes that the treatment effect β^k is common across all operators. We will extend this specification to allow for heterogeneity between countries 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 (7) 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 various components of the changes after the regulation: consumer surplus (2), retail profits (4), wholesale profits (5), and ultimately total welfare (6). This requires measuring the *level* of several variables, for which our data provide direct information. In addition, we need estimates for how the regulation has led to a *change* of several variables.

Our econometric model will provide such estimates for the affected outbound retail demand, Δq_{out}, entering (2) and (4); and for the affected inbound wholesale demand and revenues, Δq_{in} and Δr_{in}, both entering (5). Since each outcome variable enters 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:

$$\Delta q_{out} = \frac{\Delta q_{out}}{q_{out}} q_{out} = \left(\exp(\beta^{q_{out}}) - 1\right) q_{out}, \tag{8}$$

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

We also need an estimate for how the regulation has affected outbound retail revenues pq_{out}. However, since the RLAH regulation implies that the retail price has dropped to zero ($p^1 = 0$), this amounts to simply measuring the pre-regulation revenues $p^0 q^0_{out}$ (entering (2) and (4)).

Finally, we need to quantify the change in the average outbound wholesale price Δw_{out} (entering (4)) and in the marginal costs of providing network services to foreign operators Δc (entering (5)). Since we do not have systematic information for these variables across operators and over time, we cannot do 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.[21]

[21] 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 Re-

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.[22] Each operator is active in two roaming markets: intra-EEA and RoW roaming. As discussed, these markets will be our treatment and control group. We have information on the following variables: outbound retail volume, outbound retail revenues, inbound wholesale volume and inbound wholesale revenues. We observe each of these variables separately for voice and data services. We compute average retail roaming prices and average inbound wholesale prices by dividing the retail and wholesale roaming revenues by their volumes.[23] Note that, as expected, outbound retail revenues, and hence the average retail prices, essentially drop to zero for intra-EEA traffic after the regulation.

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 construct a balanced panel and 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.

port (https:$//berec.europa.eu/eng/document_register/subject_matter/berec/reports/9886-international-roaming-berec-benchmark-data-report-and-berec-report-on-western-balkan-roaming-april-2020-september-2020$) based on the country level aggregated data it collects.

[22] 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.

[23] The reported retail roaming revenues before the RLAH regulation stem from the surcharges to roaming consumption. Hence, dividing roaming revenues by volumes captures the amount of these surcharges.

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

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 already before the RLAH regulation, the retail roaming prices were regulated quite restrictively within the EEA. For example, before the RLAH regulation total quarterly intra-EEA retail roaming revenues amounted to 101.2 million Euro for voice and 140.7 million for data, compared with RoW retail 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 prices are much higher for RoW than for intra-EEA traffic, already before the regulation. For example, for voice the average retail price 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.

Now consider how volumes and revenues changed after the regulation. The average retail and wholesale roaming *volume* per operator increased considerably on 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 *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 (data) or even slightly fell (in the case of 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.

[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.

[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.

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.

[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.

5.2 Other information

To implement the theoretical model we require two additional pieces of information (in addition to the variables described in the previous subsection). First, 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 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.

Second, 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^k_{ist}, 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 (7): the top panel assumes homogeneous effects β^k across operators; the middle and bottom panel allow for heterogeneous effects β^k_i, according to the operators' country and operator type. Recall that the outcome variable Y^k_{ist} 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 (8).

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. To obtain more 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, especially for data. Intuitively, this is because especially data traffic showed a strong independent growth after the regulation, i.e. also in the RoW. To evaluate the role of the control group, we conducted event studies for each outcome variable, where we estimate (7) 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, in line with the identifying parallel trends assumption in the absence of the regulation. Furthermore, note that the estimated changes after the regulation were comparable across all quarters. This shows that the impact of the regulation was essentially immediate.

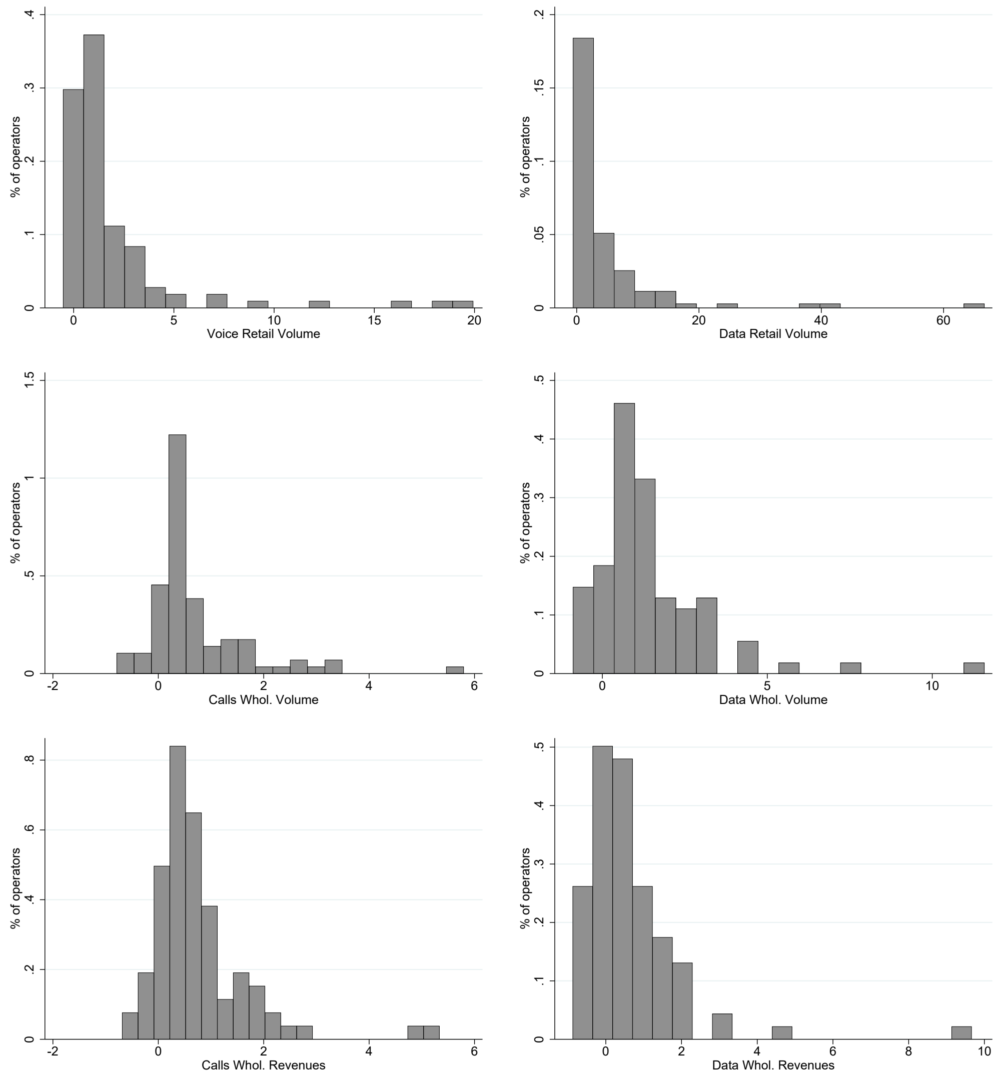
Heterogeneous effects The estimates in the top panel of Table 2 assumed homogeneous effects of the regulation across countries and operators. The middle and the bottom panels show the estimates from extensions, where we allow the regulation to have different effects across operators according to their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

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 countries with the top 3 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.

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 wholesale. Figure 2 plots the distribution of the estimated effects, transformed in percentage terms. Heterogeneity appears to be larger for retail than wholesale. For example, retail volume increased by 193% on average for voice and 485% for data across operators, with standard deviations almost twice as large.

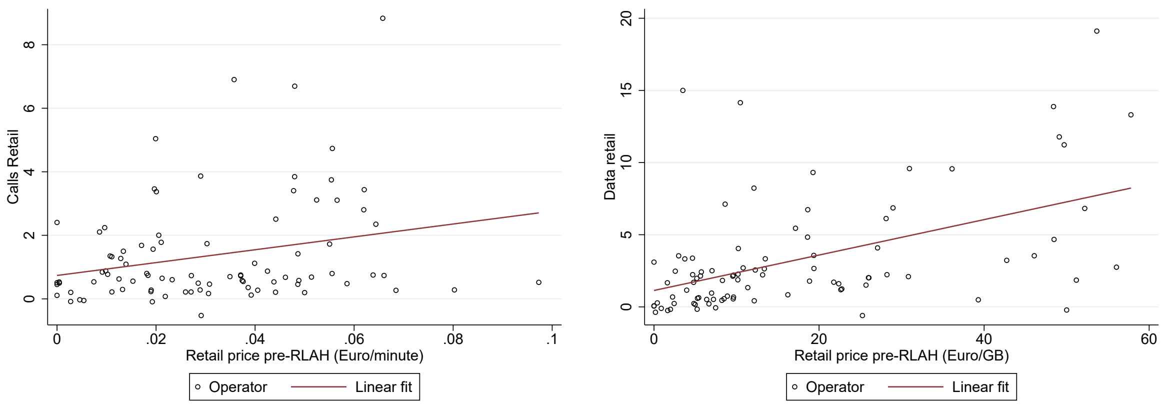
Figure 2: Operators' treatment effects



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 the 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. As discussed in section 3, we can use our estimated retail volume effects to approximate the resulting change in consumer surplus with (2), with lower and upper bounds based on (3).[28] We make use of our flexible model with operator-level effects β_i^k. We aggregate over operators per country, and convert to annual terms.[29]

[28]The approximate change is obtained with linear demand, the lower bound with very convex demand, and the upper bound with very concave demand.

[29]More specifically, the change in consumer surplus (2) contains Δq_{out} as given by (8). We calculate this for the first quarter of 2017 and convert to the year 2017 using the time fixed effects of that year.

Table 3: Consumer surplus by region

	Voice			Data		
	Lower bound	CS change	Upper bound	Lower bound	CS change	Upper bound
South	27.0	51.4	75.9	80.9	434.7	788.4
North	24.4	32.1	39.8	94.3	176.8	259.2
West	155.3	191.3	227.4	386.7	711.8	1037.0
Central-East	50.5	102.7	154.9	67.1	285.1	503.2
EEA	257.1	377.5	498.0	629.0	1608.4	2587.8

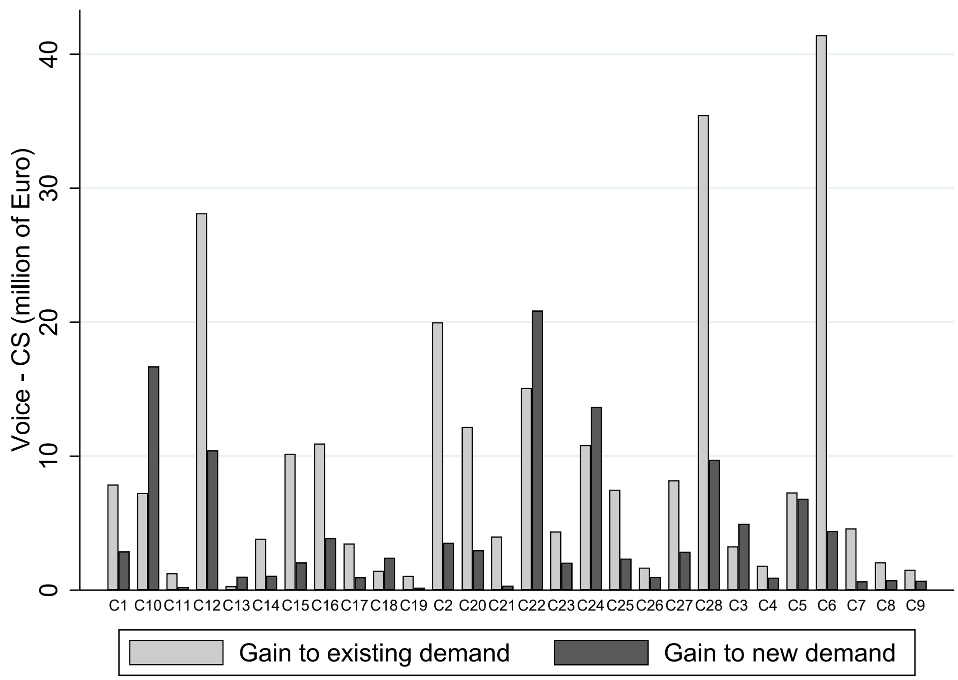
Note: The "Lower bound" is defined as the gain to the infra-marginal consumers, i.e. existing consumption; "CS change" is a linear approximation of the consumer surplus including gains from increased demand, i.e. including new consumption; the "Upper bound" is computed as the sum of the gain to the infra-marginal consumers and the maximum gain from increased demand. Note that the difference between "CS change" and "Lower bound" approximates the gains due to new consumption. European countries have been grouped in four regions according to the classification in Table 2. All figures are in millions of Euro.

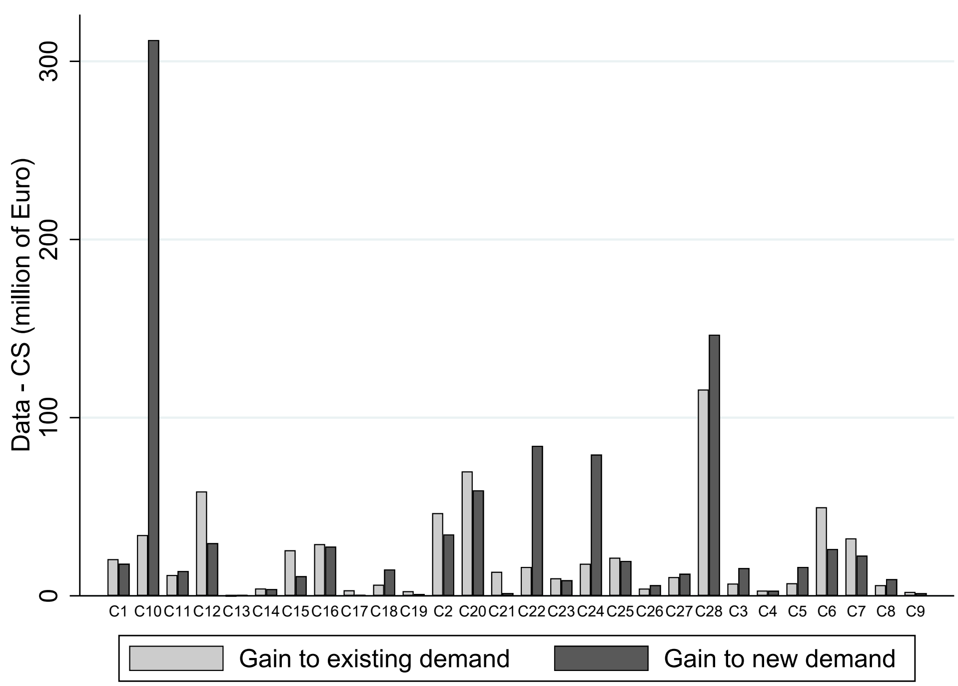
Table 4 summarizes the results aggregating over four geographic areas in the EEA. Overall, the RLAH regulation raised consumer surplus by a 377.5 million Euro for voice services, and by 1.608 billion Euro for data services. This adds up to a total annual increase in consumer surplus of almost 2 billion Euro. Note that the bounds are wider for data services, because the estimated increase in retail volume was especially high for data, as documented in Section 5. The total gains from the regulation amount to 886.1 million Euro from existing consumption, and even up to 1.1 billion Euro from new consumption (the latter largely due to new data consumption).[30] Looking at the different regions, we can see that countries in the West region mainly gain from zero surcharges on their existing consumption (e.g. for data, 386.7 million Euro gains from existing consumption versus 711.8-386.7= 325.1 million Euro from new consumption). In contrast, countries in the other regions benefit far more from new consumption. For example, in the South region the gains from existing consumption are only 80.9 million Euro, compared with approximate gains from new consumption of 434.7-80.9=353.8 million Euro.

Figure 4 provides a more disaggregated overview by country. The light shaded bars are the gains from existing consumption (lower bounds) and dark shaded bars the gains from new consumption (i.e. the approximate CS change minus the lower bounds). This confirms that for some countries the gains are mainly due to existing consumption (e.g. C12, C2, C6), while for other countries the gains mainly stem from newly generated demand (e.g. C10, C22, C24).

[30]The gains from existing consumption are simply the sum of the lower bounds for voice and data. The gains from new consumption are the difference between the approximate CS change and the lower bound, again summed over voice and data.

Figure 4: Consumer surplus by countries





Note: The gains from existing demand refer to the "Lower bound". The gains from new consumption are calculated as the difference between "CS change" and "Lower bound". All figures are in millions of Euro. To ensure confidentiality, country numbering does not respect country alphabetical ordering.

Figure 4 also stresses that there is a lot of heterogeneity in the consumer surplus gains across countries. Figure 5 and Figure 6 further explore two sources of this heterogeneity. Figure 5 relates the countries' total consumer surplus gains to their population. This shows that larger countries typically achieve larger consumer surplus gains, but also that the gains are not proportional to their population size.[31] 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

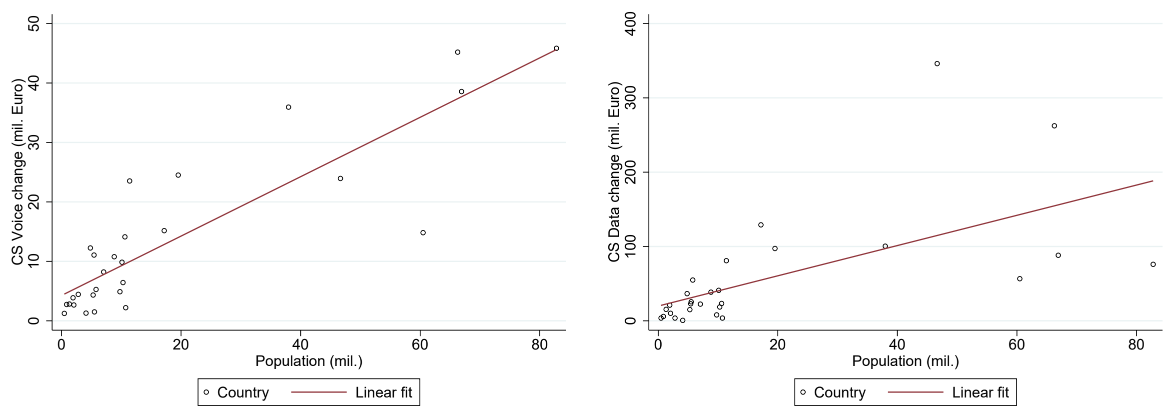


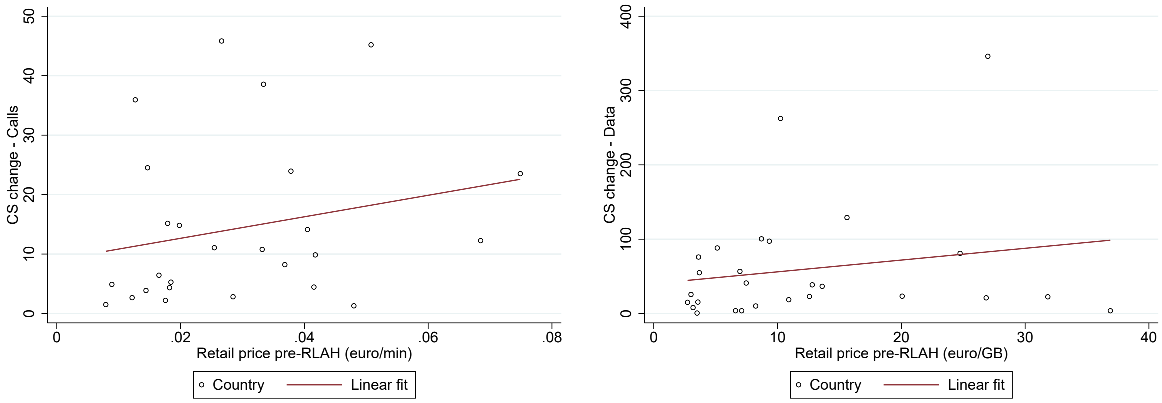
Figure 6 relates the total consumer surplus gains to the retail roaming price before the regulation.[32] This shows that consumer surplus gains indeed tend to be larger in countries that were more constrained, i.e. those with high retail roaming prices before the regulation. Nevertheless, the relationship is weaker than that between the consumer surplus gains and population size in 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.

[31] 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.

[32] 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 (6), which is the sum of the change in consumer surplus (2), retail profits (4) and wholesale profits (5). 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 presents our main findings. As already shown in the bottom row of our previous Table 4, the total gains to consumers in the EEA amounts to almost 2.0 billion Euro annually, of which 1.6 billion Euro stems from data and 380 million Euro stems from voice services. About 890 million Euro or 45% of these gains go to existing consumers, who no longer need to pay an extra price for international roaming. The remaining part (1.1 billion Euro) stems from newly generated demand. The consumer surplus gains from new demand are comparatively much stronger for data than for voice, because we had estimated a larger impact of the regulation on data.

Table 4: Total welfare effects

	Voice	**Data**	**Total**
Consumer Surplus	377.5	1608	1986
Gain to existing consumers	257.1	629.0	886.1
Estimated gain to new consumers	120.4	979.4	1100
Retail Profit (outbound)	-503.7	-857.1	-1361
Loss at given retail volume	-257.1	-629.0	-886.1
Extra loss from higher retail vol.	-298.2	-486.8	-785.0
Gain from reduced wholesale price	31.64	253.6	285.2
Wholesale Profit (inbound)	172.6	135.7	308.2
Wholesale revenues change	167.3	110.1	277.4
Loss from higher wholesale vol.	-30.75	-132.9	-163.7
Gain from reduced wholesale cost	35.98	158.5	194.5
Total Profit	-331.1	-721.4	-1053
Total Welfare	46.43	887.0	933.4

Note: Calculations are based on the operator-level effects $\hat{\beta}_i^k$ and the economic framework provided in Section 4. All figures are in millions of Euro.

The annual 2.0 billion Euro gains to consumers come at the expense of the operators' profits. Outbound *retail profits* drop by almost 1.4 billion Euro. This stems from losses on both existing consumers (886.1 million Euro) and new consumers (785 million Euro), who can roam for free while the operator still pays a wholesale price to the foreign operator. These two sources of retail loss are insufficiently compensated by the retail profit gain from the reduced wholesale prices after the regulation (285.2 million Euro). Inbound *wholesale profits* increase by nearly 310 million Euro. This is insufficient to compensate for the drop in outbound retail profit, so the total profit drop of the operators amounts to an annual 1.053 billion Euro.

The impact of the regulation on total welfare is positive and mainly stems from data services. The total welfare gain is an annual 933.4 million Euro, or about 80% of roaming revenues before the regulation. To interpret the magnitude of the welfare increase, it is useful to go back to our stylized representation of the welfare gains in 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 prices 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 prices. Our findings imply that the reduction in market power far outweighs the new distortion from excessive consumption when roaming surcharges become free. 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.

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. The baskets are defined according to the methodology of OECD (2017) on the basis of the price data collected by Teligen.[33] The data cover a total of 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,

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

medium and low voice volume users. As in Genakos et al. (2018), prices refer to hypothetical bills for the most advantageous choice of a consumer given her volume usage.

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:

$$\ln P_{jct} = \beta_j \times (EEA \times Post)_{ct} + \phi_{jc} + \psi_{jt} + \varepsilon_{jct}, \tag{9}$$

where $(EEA \times Post)_{ct}$ is a dummy variable equal to one for countries in the treatment group (EEA country) 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 outbound 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.[34]

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). The average prices are higher for the high consumption baskets. 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 waterbed effect).

[34]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.

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 (9). 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 not significantly different from zero. The right column of Table 6 allows for additional heterogenous effects for outbound countries. This confirms the findings of the left column: the main effects are still statistically insignificant, and there is also no significant extra effect for outbound countries.

To summarize, these findings indicate that the regulation did not imply statistically significant waterbed effects on the domestic market, in line with our 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 the mobile operators, i.e. about 4% of domestic revenues as discussed above. As a result, any adjustments in price strategies would be small.

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

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. 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 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 increase in total consumer surplus in the EEA by an annual 2 billion Euro, of which half 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 far outweigh the profit losses from the regulation. As a result, total welfare increases considerably, by almost 1 billion Euro annually or about 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, the net welfare effects are large because the zero price caps eliminate market power from double marginalization or insufficient network capacity, and 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 do not find 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: different consumer gains across EEA countries, and overall consumer gains coming 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.

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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 $w^1_{in,c} = \exp(\beta^k_i) w^0_{in,c}$.

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

[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.

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 investment, 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] The 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

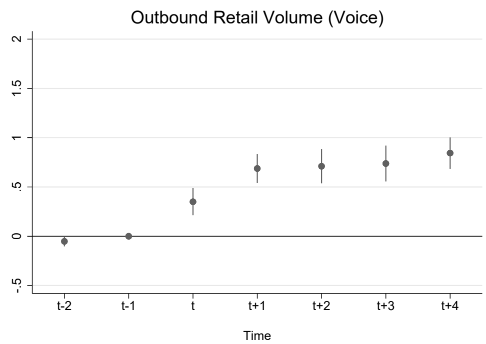
Table A.2: Before and after regulation comparison

	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

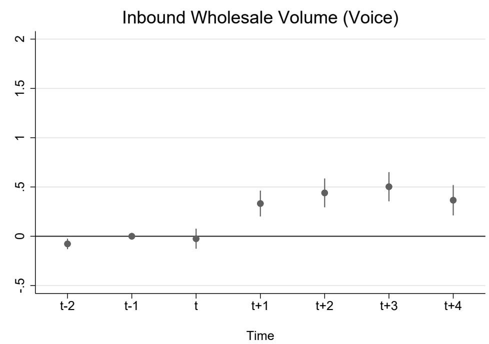
Note: Clustered robust standard errors in parentheses. Clusters defined at country and operators' level.
*** p<0.01, ** p<0.05, * p<0.1

A.2.2 Results from event study

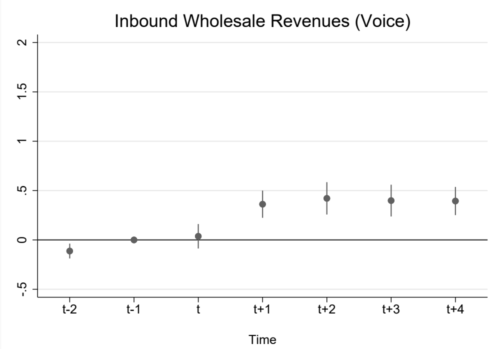
Figure A.1: Event study analysis



(a)

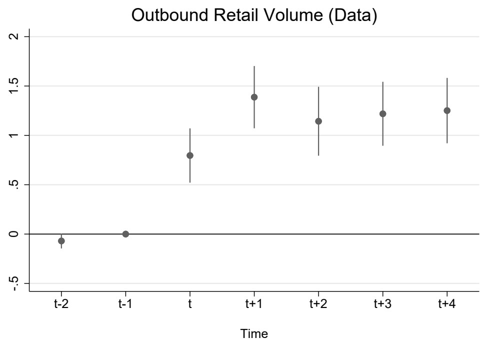


(b)

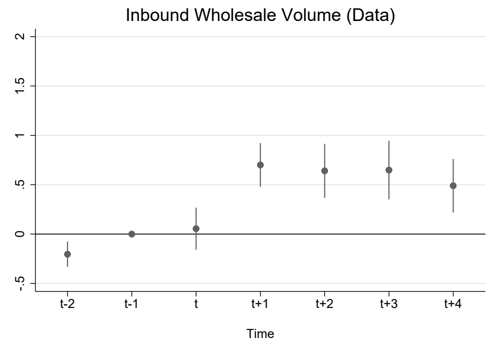


(c)

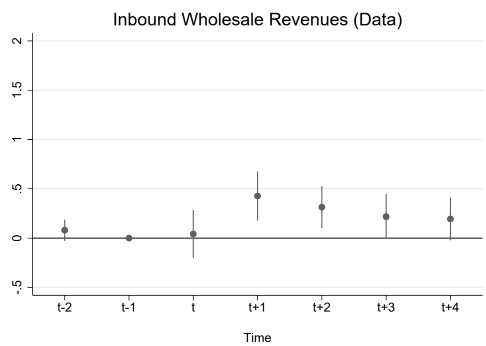
Figure A.2: Event study analysis



(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	377.5	1608	1986
Retail Profit (outbound)	-480.0	-830.8	-1311
Loss at given retail volume	-257.1	-629.0	-886.1
Extra loss from higher retail vol.	-322.3	-474.9	-797.2
Gain from reduced wholesale price	81.06	269.3	350.3
Total Profit	-307.4	-695.1	-1002
Total Welfare	70.12	913.3	983.5
b. MVNOs' whol. outbound price = whol. cap			
Consumer Surplus	377.5	1608	1986
Retail Profit (outbound)	-501.7	-846.2	-1348
Loss at given retail volume	-257.1	-629.0	-886.1
Extra loss from higher retail vol.	-297.3	-489.1	-786.5
Gain from reduced wholesale price	32.68	266.8	299.5
Total Profit	-329.2	-710.5	-1040
Total Welfare	48.36	897.9	946.3

Note: Authors calculations