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Conference Paper The impact of RAN sharing

23rd Biennial Conference of the International Telecommunications Society (ITS): "Digital societies and industrial transformations: Policies, markets, and technologies in a post-Covid world", Online Conference / Gothenburg, Sweden, 21st-23rd June, 2021

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Ivaldi, Marc; Aimene, Louise; Jeanjean, Francois; Liang, Julienne (2021) : The impact of RAN sharing, 23rd Biennial Conference of the International Telecommunications Society (ITS): "Digital societies and industrial transformations: Policies, markets, and technologies in a post-Covid world", Online Conference / Gothenburg, Sweden, 21st-23rd June, 2021, International Telecommunications Society (ITS), Calgary

This Version is available at: https://hdl.handle.net/10419/238031

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The impact of RAN sharing *

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Abstract

In this paper, we formulate and estimate a structural model of demand to analyse the equilibrium effect of the RAN sharing by using cross-country panel data in 28 EU countries in years 2010-2020. Based on model estimates, our simulation analysis in Spain firstly provides a quantitative assessment of the impact of RAN sharing on mobile operators. We find that prices decrease for mobile operators involved in RAN sharing agreement due to cost reductions. In a competitive environment where operators compete, MNOs not involved in RAN sharing also lower their prices in a Nash equilibrium. We further evaluate the consumer welfare consequence of the presence of RAN sharing, and find that the RAN sharing enhanced the consumer surplus by generating lower prices for all mobile operators.

Key Words: Mobile telecommunications; network sharing; competition; consumer welfare

JEL Classification: L40, L96, L11

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1 Introduction

The fast evolution of new technologies in the telecommunications requires significant and repeated investments in infrastructures. Their deployment in rural areas, less profitable, makes their duplication difficult, which could harm competition. This context leads to an increase of Infrastructure sharing or co-investment agreements. These agreements may concern passive (Base station, black fiber....) or active infrastructure (Optical Network termination (ONT), Optical Radio access Network (RAN),...) or both. They aim to reduce both variable costs (OPEX) and investment costs (CAPEX) which is an obvious advantage. However, these agreements may also have drawback. Some are worried about a possible harm to competition, investment and consumers, especially when the agreement is extended to dense urban areas and involves the leaders of the market. For example, in the case of Czech republic, Margrethe Vestager, the European Commissioner in charge of competition policy expressed concern that the recent network sharing agreement would reduce competition and thereby harms innovation EC (2019). This paper highlights the trade-off between cost saving and increased market power of operators involved in the RAN sharing agreement. It first investigates, with a theoretical model, the impact of a RAN sharing agreement on prices, subscriptions, profits and consumer surplus. We find that, provided there is no eviction, RAN sharing agreement decreases prices of all operators, even those that are not involved in the agreement. Indeed, the impact of cost saving on prices outweighs the impact of market power on the margins. We find that subscriptions, as well as profit margins increase for MNOs involved, decrease for the others and increase at the market level. We find that RAN sharing agreement increases consumer surplus and welfare.

Those results do not depend on the density of the area, neither on the rank of the MNOs involved. The only restriction for the validity of the results is that there mustn't be an eviction of a MNO non involved in the agreement.

Furthermore, we find that RAN sharing agreement tends to increase the total amount of investment of the industry unless MNOs involved in the agreement are much less efficient than the others. Those findings are tested with a structural model of demand using a cross-country panel data of 28 European countries between 2010 and 2020. Using the estimations of the structural model, we investigate the Spanish RAN sharing agreement. The empirical results are consistent with the theoretical predictions, (excepted for investment as the structural model does not address this issue.)

The remainder of this paper is organized as follows. Section 2 discusses the relevant literature. Section 3 presents theoretical model for analysis of investment incentives in presence of RAN sharing. Section 4 describes the data used in our study. Section 5 introduces our structural model of demand and our estimation strategy. Section 6 presents our estimation results. Section 7 presents the analysis of impact of RAN sharing on mobile operators involved or not involved in RAN sharing by counterfactual simulation. Section 8 compares the welfare in presence and in absence of RAN sharing. Section 9 concludes.

2 Literature review

Our paper relates to two main streams of the economic literature. On the one hand, we relate to a stream of research analysing the effects of competition among operators on the economic welfare. On the other hand, we relate to the broader field of research on the link between competition and investment.

In the first stream, the paper most closely related to our work is Cojoc *et al.* (2020). The authors use a structural model to estimate the effects of network sharing agreements in the Czech Republic. The results of their model indicate that network sharing agreements under study generated cost savings for the sharing parties, which were passed-on to consumers in the form of lower prices and higher average download speed. Our paper draws heavily on their methodology. Bourreau *et al.* (2018) analyse a specific case of network sharing by comparing the outcomes of different regulatory regimes that may be imposed on a dominant telecommunication operator and particularly the outcomes of a full co-investment regime. In case of co-investment, the network deployed and the deployment costs are shared by the financing partners. This paper concludes that in terms of total investment and social welfare, the regulatory regime encouraging network sharing agreements dominates both pure access obligation and access plus co-investment obligations, especially when demand is uncertain. Previously Nitsche & Wiethaus (2011) had

analysed how different types of access regulation to next generation networks affect investments and consumer welfare. Their simulations had shown that risk-sharing creates most consumer welfare and benefits consumers as it combines relatively high ex-ante investment incentives with strong ex-post competitive intensity. However, Krämer & Vogelsang (2017) find results opposite to the previous ones. With the use of a laboratory experiment, they investigate the impact of co-investments on competition in regulated network industries. Their main finding is that co-investment (i.e. cooperation at the infrastructure level) facilitates tacit collusion (i.e. cooperation at the retail level) significantly, which questions the positive evaluation of co-investments with respect to consumers' surplus in the theoretical literature. Our paper, by showing that network sharing enhances consumer surplus by generating lower prices, has results in line with those of Cojoc *et al.* (2020), Bourreau *et al.* (2018) and Nitsche & Wiethaus (2011) but opposite to those of Krämer & Vogelsang (2017).

The second stream of literature we relate to examines the relationship between competition and investment. Motta & Tarantino (2017) show that without efficiency gains, mergers reduce total industry investment and consumer surplus. However, if it entails sufficient efficiency gains they might increase investments so much as to outweigh the usual detrimental effect of the merger on prices. Consequently, the authors show that to the extent that the same efficiency gains can be achieved by a Network-Sharing Agreement, "such an agreement is likely to be superior to the merger from the welfare point of view".

3 Theoretical model for analysis of investment incentives in presence of RAN sharing

3.1 Setting of the model

In this section, we use an oligopoly model with substitutability. we assume n operators compete in price. We denote q_i , the number of subscribers of operator i, p_i the price of subscribing to operator i and c_i the marginal cost of a subscription for operator i. We assume that m operators $(2 \le m \le n)$ are involved in the agreement and thus n - m operators do not. We assume that RAN sharing agreement reduces marginal costs by $\lambda > 0$ for all the partners, and only for all the operators involved in the agreement. In the following, we assume that the m first operators are involved in the agreement and the n-m others are not. If $i \leq m$ operator i is involved and if i > m, operator i is not.

We assume that utility of consumers, U follows the utility of Singh & Vives (1984)

$$U = \sum_{i=1}^{n} a_i q_i - \frac{1}{2(1+\gamma)} \sum_{i=1}^{n} \left(q_i^2 + \gamma \sum_{j \neq i} q_i q_j \right) - \sum_{i=1}^{n} p_i q_i \tag{1}$$

where a_i is the net consumer surplus for subscribing to operator i and γ is the coefficient of substitutability. This utility function leads to the following expression of price:

$$p_i = a_i - \frac{1}{1+\gamma} \left(q_i + \gamma \sum_{j \neq i} q_j \right)$$
(2)

3.2 Results of basic model

Profit is written: $\pi_i = (p_i - c_i)q_i$

The first order condition leads to the following number of subscriptions to operator i:

$$q_{i} = A(\gamma, n)(a_{i} - c_{i}) - B(\gamma, n) \sum_{j \neq i} (a_{j} - c_{j})$$
(3)
with $A(\gamma, n) = \frac{(1+\gamma)(1+(n-2)\gamma)(2+3(n-2)\gamma+(n^{2}-5n+5)\gamma^{2})}{(1-\gamma)(1+(n-1)\gamma)(4+6(n-2)\gamma+(2n^{2}-9n+9)\gamma^{2})}$
and $B(\gamma, n) = \frac{(1+\gamma)(1+(n-2)\gamma)(\gamma+(n-2)\gamma^{2})}{(1-\gamma)(1+(n-1)\gamma)(4+6(n-2)\gamma+(2n^{2}-9n+9)\gamma^{2})}$

the RAN sharing agreement reduces marginal costs of involved operators. If operator i is involved, its marginal cost writes: $c_i = c_{i0} - \lambda$, if i is not, its marginal cost is unchanged: $c_i = c_{i0}$, where c_{i0} is the marginal cost of operator i in absence of RAN sharing. We denote q_{i0} and p_{i0} respectively, the number of subscribers and the price of subscription of operator i in absence of RAN sharing agreement.

In a first time, we assume that the number of operators, n, is not impacted by the RAN sharing agreement. In other words, we assume that the RAN sharing agreement does not result in foreclosure. All operators make a positive profit.

Proposition 1. The RAN sharing agreement increases the number of subscription for operators involved, decreases the number of subscriptions for the others and increases the subscriptions of the industry.

Proof.:

In the following, for simplification, we denote $A(\gamma, n) = A$ and $B(\gamma, n) = B$. The increase in subscriptions to operator *i* due to RAN sharing is $q_i - q_{i0}$ and depends on whether *i* is involved in the agreement or not. Using equation (3), we can write:

 $q_i - q_{i0} = A\lambda - B\lambda(m-1)$, if *i* is involved and

 $q_i - q_{i0} = -Bm\lambda$ otherwise.

 $\forall \gamma \in [0, 1] \text{ and } n \geq 2, A\lambda - B\lambda(m-1) \text{ is positive and } -Bm\lambda \text{ is negative which means that}$ the RAN sharing agreement increases the number of subscriptions for involved operators and decreases it for the others.

At the industry level, the number of subscribers is given by $Q = \sum_{i=1}^{n} q_i$ and $Q_0 = \sum_{i=1}^{n} q_{i0}$ in absence of RAN sharing agreement. We know that there are *m* operators involved and n - moperators not involved, as a result, the number of subscriptions induced by the RAN sharing agreement is given by: $Q - Q_0 = (A - B(n-1)) m\lambda$. It turns out that $A \ge B(n-1)$, therefore, the number of subscription increases at the industry level.

Proposition 2. The RAN sharing agreement decreases prices for all operators, whether or not they are involved. The decrease in price is higher for involved operators.

Proof.:

Using equation (2), the impact of the RAN sharing agreement on price can be written:

$$p_i - p_{i0} = -\frac{1}{1+\gamma} \left(q_i - q_{i0} + \gamma \sum_{j \neq i} (q_j - q_{j0}) \right)$$

The result depends on whether i is involved or not.

$$p_i - p_{i0} = -\frac{\left[(A+B)(1+\gamma(m-1)) - Bm(1+\gamma(n-1))\right]\lambda}{1+\gamma}$$
 if *i* is involved and
$$p_i - p_{i0} = -\frac{\left[\gamma Am - Bm(1+\gamma(n-2))\right]\lambda}{1+\gamma}$$
 if *i* is not involved.

 $\forall \gamma \in [0,1]$ and n > 2, These two expressions are negative and therefore prices decrease for all operators, whether or not they are involved.

The difference between the drop in price for involved and not involved operators is written:

$$\Delta p(notinvolved) - \Delta p(involved) = \frac{\lambda(A+B)(1-\gamma)}{1+\gamma} > 0$$

which means that the drop in price is higher if the operator is involved.

Proposition 3. The RAN sharing agreement increases the price-cost margin of involved operators and decreases the price-cost margin of the others. The average price-cost margin increases.

Proof.:

For involved operators, the impact of the RAN sharing agreement on margin is given by:

 $p_i - c_i - (p_{i0} - c_{i0}) = p_i - p_{i0} + \lambda$

We can check that this expression is positive, thus the RAN sharing agreement increases margin of involved operators.

For the others, the impact of the RAN sharing agreement is $p_i - c_i - (p_{i0} - c_{i0}) = p_i - p_{i0}$ From proposition (2), we know this expression is negative. As a result, RAN sharing decreases margin of not involved operators.

The change in average price-cost margin is given by:

$$\Delta pcm = \frac{m(\Delta p(involved) + \lambda) + (n - m)\Delta p(notinvolved)}{n}$$
 which can be rewritten:
$$\Delta pcm = \frac{m(1 + \gamma - (1 + \gamma(n - 1))(A - B(n - 1)))\lambda}{n(1 + \gamma)}$$

This expression is positive, thus the RAN sharing agreement increases the average margin.

Proposition 4. RAN sharing increases Consumer Surplus as well as Welfare.

Proof.:

From proposition (2), we know that the RAN sharing agreement decreases prices for all operators, therefore, utility of subscribers who stay with the same operator increases. The RAN

sharing agreement churns some subscribers from non involved operators to involved one. Those subscribers increase their utility even more. Furthermore, from proposition (1), we know that the RAN sharing agreement increases the total number of subscribers. These new subscribers that enter the market have a positive utility to subscribe thanks to the RAN sharing agreement, as a result, the RAN sharing agreement increases consumer surplus. From proposition (3), the RAN sharing agreement increases the average margin and from proposition (1), the RAN sharing agreement increases the number of subscription, therefore, RAN sharing increases total profit and hence, welfare.

3.3 Extension with investment stage

In this subsection, we extend the model with a two stages game. In the first stage, operators choose the amount of their investment and in the second stage, they compete in price "à la Bertrand" as in the previous subsection. We assume that operators invest to decrease their marginal costs. Without investment, we assume that marginal cost of firm *i* is c_{0i} . Investment decreases marginal cost by x_i and marginal cost with investment is $c_i = c_{0i} - x_i$. We assume that the cost of investment of firm *i*, F_i is quadratic according to x_i . $F_i = x_i^2/2\tau$ where τ is a constant parameter. In such case, profit of operator *i* is written: $\pi_i = (p - c_{i0} + x_i)q_i - F_i$.

This involves two first order conditions. One for the investment stage and the other for competition stage.

$$\frac{\partial \pi_i}{\partial p_i} = q_i(p_i, p_{-i}) + \frac{\partial q_i(p_i, p_{-i})}{\partial p_i}(p_i - c_i(x_i)) = 0$$
(4)

$$\frac{\partial \pi_i}{\partial x_i} = -c'_i(x_i)q_i(p_i, p_{-i}) - F'(x_i) = 0$$
(5)

In such case, the decrease in marginal cost of firm *i* depends on the number of subscriptions of firm *i* following: $x_i = \tau q_i$ and the amount of investment is $F_i = \tau q_i^2/2$. the number of subscriptions of operator *i* is:

$$q_i = A(\gamma, n, \tau)(a_i - c_{0i}) - B(\gamma, n, \tau) \sum_{j \neq i} (a_j - c_{0j})$$
(6)

with

$$\begin{aligned} A(\gamma, n, \tau) &= \frac{(1+\gamma)(1+(n-2)\gamma)((2-\tau-\gamma(2+\tau-n))(1+(n-2)\gamma)-(n-1)\gamma^2)}{((2-\tau-\gamma(1+\tau-n))(1+(n-2)\gamma)-(n-1)\gamma^2)((2-\tau-\gamma(1+\tau))(1+(n-2)\gamma)-(n-1)\gamma^2)} \\ B(\gamma, n, \tau) &= \frac{(1+\gamma)(1+(n-2)\gamma)(1+(n-2)\gamma)-(n-1)\gamma^2)((2-\tau-\gamma(1+\tau))(1+(n-2)\gamma)-(n-1)\gamma^2)}{((2-\tau-\gamma(1+\tau-n))(1+(n-2)\gamma)-(n-1)\gamma^2)((2-\tau-\gamma(1+\tau))(1+(n-2)\gamma)-(n-1)\gamma^2)} \end{aligned}$$

Notice that when $\tau = 0$ we find again equation (3)

In the following, we assume that operators involved in the agreement invest together. They invest an amount of $F = x^2/2\tau$ and decrease their marginal costs by x. in such case, the equation (5) is slightly different and becomes:

$$\frac{\partial \pi}{\partial x} = -\sum_{i=1}^{m} c'_i(x) q_i(p_i, p_{-i}) - F'(x) = 0$$
(7)

which yields $x = \tau \sum_{i=1}^{m} q_i$ and $F = \tau (\sum_{i=1}^{m} q_i)^2/2$. The amount of investment per involved operator is $F_i = \tau (\sum_{i=1}^{m} q_i)^2/2m$ which is higher than the amount of investment of involved operators in absence of RAN sharing agreement.

Proposition 5. the RAN sharing agreement tends to increase the total amount of investment of the industry unless involved operators are much less efficient than the others.

Proof. :

The amount of investment of the industry in presence of RAN sharing agreement is written:

$$I_R = \frac{\tau}{2} \left((\sum_{i=1}^m q_i)^2 + \sum_{i=m+1}^n q_i^2 \right)$$

In absence of RAN sharing agreement, investment of the industry is:

$$I_0 = \frac{\tau}{2} \sum_{i=1}^n q_{i0}^2$$

If the market is symmetrical in absence of RAN sharing agreement, then involved operators are as efficient as outsiders. In such case, the difference $I_R - I_0$ is positive.

Indeed,
$$I_R - I_0 = \frac{\tau}{2} \left((\sum_{i=1}^m q_i)^2 - \sum_{i=1}^m q_{i0}^2 + \sum_{i=m+1}^n (q_i^2 - q_{i0}^2) \right)$$

Thus $I_R - I_0 > \frac{\tau}{2} \left(\sum_{i=1}^m (q_i^2 - q_{i0}^2) + \sum_{i=m+1}^n (q_i^2 - q_{i0}^2) \right)$
 $I_R - I_0 > \frac{\tau}{2} \left(\sum_{i=1}^m (q_i - q_{i0})(q_i + q_{i0}) + \sum_{i=m+1}^n (q_i - q_{i0})(q_i + q_{i0}) \right)$

From proposition (1), we know that the number of subscribers increases for involved operators and decreases for the others. Moreover, the q_{i0} are the same for all operators when market is symmetrical, therefore, $q_i - q_{i0}$ is higher for involved operators where $i \leq m$ than for the others where i > m. As a result,

$$I_R - I_0 > \frac{\tau}{2} \left(\sum_{i=1}^m (q_i - q_{i0}) + \sum_{i=m+1}^n (q_i - q_{i0}) \right)$$

Furthermore, we know that the PAN sharing

Furthermore, we know that the RAN sharing agreement increases the total number of subscribers of the industry, as a result $\sum_{i=1}^{n} q_i > \sum_{i=1}^{n} q_{i0}$

and therefore, $I_R - I_0 > \sum_{i=1}^{m} (q_i - q_{i0}) > 0$

If the market is symmetrical, the RAN sharing agreement increases the investment of the industry. If the market is not symmetrical and if involved operators are more efficient than the others in absence of RAN sharing agreement, i.e $a_i - c_{i0}$ are higher for involved operators than for the others, then we still have $q_i - q_{i0}$ higher for involved operators than for the others, and therefore, in that case, the RAN sharing agreement also increases the investment of the industry. If involved operators are far less efficient than the others, it is possible that the RAN sharing agreement decreases investment of the industry.

4 Data

This section introduces the datasets used in our empirical analysis. Our analysis draws on two datasets at operator level for 28 European countries¹. Our data is an unbalanced panel over 43 quarters from 2010Q1 to 2020Q3 operator-level observations. In total, there are 3400 observations for 28 European countries and 88 MNOs. The first dataset comes from Strategy

¹28 European countries: Austria Belgium Bulgaria Croatia Czechia Denmark Estonia Finland France Germany Greece Hungary Ireland Italy Latvia Lithuania Netherlands Norway Poland Portugal Romania Slovakia Slovenia Spain Sweden Switzerland UK Ukraine

Analytics, comprising ARPU, OPEX per user and MNO's market share. The market share is the total number of active subscribers to mobile services per operator. It approximates the probability that an individual chooses a mobile offer from a MNO. The measure for the price paid by consumers is the average revenue per user (ARPU), which equals total services revenue divided by the total number of subscribers. The measure for OPEX (Operational Expenditure) is calculated as the total mobile revenues minus EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization).

The second dataset, from GSMA intelligence, includes mobile network nation-wide population coverage for 3G and 4G technologies for each MNO. The coverage data is sourced directly from operators and regulators whenever they report 3G/4G coverage metrics (e.g. in financial statements, investor presentations and regulatory filings). As the metric is generally reported based on coverage by population rather than by area, we use the former.

Table 1: Summary statistics								
Variable	Obs	Mean	Std. Dev.	Min	Max	Source		
market share	3400	31%	13%	0%	81%	Strategy Analytics		
ARPU (USD)	3400	18.0	9.0	1.0	59.8	Strategy Analytics		
coverage3G (population)	3400	88%	20%	0%	100%	GSMA		
coverage4G (population)	3400	60%	41%	0%	100%	GSMA		
OPEX per user	3400	16.3	10.1	0.5	91.4	Strategy Analytics		

These two datasets complement each other and provide an unprecedented opportunity to estimate a structural model of consumer demand in the European mobile market. Table 1 reports the descriptive statistics for the variables used in the estimation. These variables refer to the determinants of consumers' indirect utility of a MNO, namely the price and MNOs' network coverage for 3G and 4G technologies. 3G coverage is higher than 4G since the latter is deployed several years after 3G. The other main variable used in the empirical model is the market share which approximates the probability of a consumer to choose a specific MNO among all possible MNOs. The mean value of 31% indicates that the number of MNO is about 3 or 4 operators in European countries². The variable OPEX per user is used as instrumental variable to overcome the endogeneity of the variable price. Based on the estimated demand function, we then estimate the mobile operator's marginal cost functions.

5 Structural model

In this section, we formulate a general equilibrium model of the mobile market. On the demand side, consumers face a discrete choice of mobile operators' offer. On the supply side, mobile operators compete by simultaneously and independently setting their mobile network coverage (3G/4G) and price to maximize their own profit.

5.1 Consumer's behavior: Discrete choice for mobile operator

We start with the consumer's demand for mobile operator. It is assumed that there are t = 1, ..., T observable markets consisting of $i = 1, ..., I_t$ consumers, facing j=1,...,J alternative MNOs in each country³. For each market, aggregated data are observed on MNO demand, prices (ARPU) and MNO's characteristics. Motivated by the fact that most individuals have subscribed to a mobile offer provided by a MNO in our sample, we use a nested logit model which groups consumers' choice into nests and creates a hierarchical structure. Individual *i*'s indirect utility from subscribing MNO *j* at time *t*, u_{ijt} , is determined by the price and the observed mobile networks coverage. The demand model is described by the following nested logit:

$$u_{ijt} = \beta Coverage_{jt} - \alpha p_{jt} + \xi_j + \xi_{jt} + (1 - \sigma)\epsilon_{ijt} + \zeta_{igt}$$

$$\tag{8}$$

where $\beta Coverage_{jt} - \alpha p_{jt} + \xi_{jt}$ is the mean net value for choosing MNO j at time t that

 $^{^2\}mathrm{An}$ average market share of 25% corresponds to 4 MNOs in a country, 33.3% to 3 MNOs. Therefore, 31% corresponds to 3-4 MNOs in European countries with 25%;31%;33.3%.

³The number of market in our study is the number of countries multiplied by the number of quarters. Markets are assumed to be independent and can be geographic (country), time series, or longitudinal

is common to all consumers. u_{ijt} depends on the coverage of networks coverage of operator j, price of MNO j, a vector ξ_j with MNO-specific valuation and a vector ξ_{jt} of unobserved characteristics. The term $(1 - \sigma)\epsilon_{ijt} + \zeta_{igt}$ corresponds to the unobserved random errors and reflect consumers heterogeneity. ϵ_{ijt} is an individual-specific valuation for MNO j. The random variable ϵ_{ijt} is i.i.d. The nesting parameter σ measures the degree of preference correlation within a nest and generally $0 \le \sigma < 1$. If $\sigma = 1$, consumers perceive all operators of the same nest as perfect substitutes. If $\sigma = 0$, the model is equivalent to a simple logit model.

As shown in Berry (1994), by assuming that consumers choose the MNO with the highest utility, and using the expression for the mean utility in equation (8), the choice probabilities at aggregate level, can be equated to the market share. The demand model can be estimated by the following nested-logit regression of market share on MNO's networks coverage, prices and log-share term related to the nesting structure:

$$ln\left(\frac{s_{jt}}{s_{0t}}\right) = \mu_0 + \beta Coverage_{jt} - \alpha p_{jt} + \sigma ln(s_{j|gt}) + \xi_j + \xi_{jt}$$
(9)

where s_{jt} is market share of operator j at time t, defined as the ratio of number of subscribers of operator j to the total market size⁴. Coverage_{jt} is a vector of coverage of mobile networks of technology 3G and 4G. s_{0t} corresponds to outside option (MVNOs' subscribers and others). $s_{j|gt}$ is within-nest market share of operator j at time t in nest g. p_{jt} is the price of operator jat time t, measured by ARPU (Average Revenue Per User). As above-mentioned, the nesting parameter σ should be such as $0 \le \sigma < 1$. p_{jt} and $s_{j|gt}$ are endogenous, instrumented by OPEX per user and BLP type instruments (Berry et al. (1995)) such as mean OPEX of competitors and/or mean ARPU of competitors. We consider that OPEX can hardly have a direct impact on market shares, except via prices.

From the demand estimation, the own- and cross-price elasticities can be calculated with following expressions. The elasticity of demand for MNO j with respect to the price of MNO jis expressed as

 $^{^{4}}$ The total market size is defined as the population * subscription penetration by country * 140%

$$\eta_{jj,t} = -\frac{\hat{\alpha}}{1-\hat{\sigma}} p_{jt} (1-\hat{\sigma}s_{j|gt} - (1-\hat{\sigma})s_{jt})$$
(10)

This elasticity first shows the intensity of competition within the mobile market of each country. $\eta_{jj,t}$ indicates also how the preference correlations are reflected in aggregate substitution patterns. Mobile offers in the same nest have a higher cross-price elasticity.

The cross-price elasticity of demand for MNO j with respect to a change in price of MNO i is expressed as

$$\eta_{ji,t} = \frac{\hat{\alpha}}{1-\hat{\sigma}} p_{it} (1-\hat{\sigma}s_{i|gt} - (1-\hat{\sigma})s_{it})$$

$$\tag{11}$$

5.2 Mobile operators' behavior, marginal costs analysis

On the supply side, operators could compete by simultaneously and independently setting their mobile networks coverage (3G/4G) and price to maximize their own profit. As explained in Cojoc *et al.* (2020), since the market is assumed to be in equilibrium in each quarter, the prices in the dataset are assumed to correspond to a MNO's profit maximizing prices. At the profitmaximizing price, prices and own-price demand elasticities $\eta_{jj,t}$ are related to marginal costs c_{jt} via the Lerner index.

$$\frac{p_{jt} - c_{jt}}{c_{jt}} = \left|\frac{1}{\eta_{jj,t}}\right| \tag{12}$$

By introducing equation (10) into equation (12), MNO's marginal costs can be recovered after the estimation of demand:

$$c_{jt} = p_{jt} - \frac{1 - \hat{\sigma}}{\hat{\alpha}(1 - \hat{\sigma}s_{j|gt} - (1 - \hat{\sigma})s_{jt})}$$
(13)

We assumed that the marginal costs are reduced by $20\%^5$ for MNOs involved in RAN sharing agreements. To evaluate the effects of RAN sharing agreements observed in one of the European countries, we compare prices and consumer surplus (CS) in presence of RAN sharing to the environment in absence of RAN sharing. In our model, this is achieved by comparing the

 $^{^5 \}rm Wireless$ Federation's work with numerous operators highlights that: (1) A 20-35% saving in network OPEX,(2) A 20-50% saving in CAPEX

prices/MS/CS in two Nash equilibrium, i.e. the first Nash equilibrium in presence of RAN sharing and the second Nash equilibrium in absence of RAN sharing.

6 Main empirical results

	We	report the	main	results	of t	the nested	logit	regression	of	equation	(9)	in	Table	6.
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VARIABLES	lsj			
α	0.087^{***}			
	(0.006)			
σ	0.538^{***}			
	(0.088)			
coverage4Gpop	0.486^{***}			
	(0.162)			
cov3G4G	0.520***			
	(0.159)			
Population	0.105***			
	(0.014)			
MNO fixed effect	\checkmark			
quarter fixed effect	\checkmark			
Observations	3400			
Number of countries	28			
Number of MNO	88			
R-square d	0.521			
First-Stage F-statistic	58.89			
Robust standard errors in parentheses				

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Most parameters of Table 6 are precisely estimated, and the signs of parameter estimates are expected. The price coefficient $(-\hat{\alpha})$ is negative and significant that are consistent with economic theory. The coefficient for 4G coverage and for the coverage gap between technology 3G and 4G are both positive and significant⁶. The ratio of coefficient of 4G coverage to price coefficient (α) gives the consumers' willingness to pay for a full population 4G coverage, around 6 USD. The value of σ , between 0 and 1, shows that the nested structure is consistent. We control for MNO and time fixed effect by introducing MNO and quarter dummies.

⁶Mobile network coverage for 3G is generally higher than for 4G. We use the difference in coverage between 3G and 4G in the regression when this difference is positive.

To overcome the endogeneity of price and within-nest market share, we use three instruments: MNO's OPEX per user, average competitors' OPEX per user and average competitors' ARPU. All instruments lag the endogenous variables by one quarter. The first stage F-statistics, largely higher than the threshold of 10, indicates that the instruments are strong enough in terms of statistics. Since there are three instruments for two endogenous variables, one can conduct the Hansen-Sargan test of over identification, testing the null hypothesis that the instruments are exogenous. The p-value associated with this test is 0.813, implying that the null hypothesis cannot be rejected.

7 Analysis of impact of RAN sharing on mobile operators involved or not involved in RAN sharing by counterfactual simulation

There is an ongoing debate on how to encourage mobile operators to develop RAN sharing, in which the two main issues are the impact on firms' competition and consumer welfare respectively. We use the structural model to conduct some counterfactual simulations to contribute to this debate. First, the prices of the current situation are predicted by using the structural model. The latter predictions are compared to observed prices. The comparison between observed and predicted values indicates the goodness of our regression model. Second, we assess the change in prices in presence and in absence of RAN sharing.

As explained in subsection 5.2, we compare two Nash equilibrium in presence and in absence of RAN sharing by solving a system of simultaneous equations (Ivaldi & Verboven (2005)).

Firstly, demand having a nested logit structure, the system of equations to solve for the current situation for a given MNO j at time t is given by

$$c_{jt} - p_{jt} + \frac{1 - \hat{\sigma}}{\hat{\alpha}(1 - \hat{\sigma}s_{j|gt} - (1 - \hat{\sigma})s_{jt})} = 0$$
(14)

$$s_{j|gt} - \frac{exp(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}p_{jt}}{1 - \hat{\sigma}})}{\sum_{j}^{K} exp(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}p_{jt}}{1 - \hat{\sigma}})} = 0$$
(15)

$$s_{jt} - s_{j|gt} \frac{\left(\sum_{j}^{K} exp\left(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}p_{jt}}{1 - \hat{\sigma}}\right)\right)^{(1 - \hat{\sigma})}}{1 + \left(\sum_{j}^{K} exp\left(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}p_{jt}}{1 - \hat{\sigma}}\right)\right)^{(1 - \hat{\sigma})}} = 0$$
(16)

where $\hat{\delta}_{jt} = ln(\frac{s_{jt}}{s_{0t}}) - \hat{\sigma}ln(s_{j|gt}) - \hat{\beta}Coverage + \hat{\alpha}p_{jt}$ denoting the fixed level of consumer valuation for MNO j and K the total number of MNOs in the market. The marginal costs c_{jt} are calculated from equation (13) after the estimation of Table 6. c_{jt} are then introduced in above system of equations. The numerical resolution of simultaneous equations (14), (15) and (16) gives predicted value for prices p_{jt} , market share s_{jt} and within-nest market share $s_{j|gt}$. We can measure the goodness of our structural model by comparing observed and predicted values of p_{jt} , s_{jt} and $s_{j|gt}$.

By assuming the marginal costs could be increased by 20% in absence of RAN sharing compared to the situation in presence of RAN sharing (the RAN sharing agreement is only authorized for less dense areas in Spain for Vodafone Spain and Orange Spain), counterfactual market shares and prices are derived by solving following system of simultaneous equations

$$\tilde{c}_{jt} - \tilde{p}_{jt} + \frac{1 - \hat{\sigma}}{\hat{\alpha}(1 - \hat{\sigma}\tilde{s}_{j|gt} - (1 - \hat{\sigma})\tilde{s}_{jt})} = 0$$
(17)

$$\tilde{s}_{j|gt} - \frac{exp(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}\tilde{p}_{jt}}{1 - \hat{\sigma}})}{\sum_{j}^{K} exp(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}\tilde{p}_{jt}}{1 - \hat{\sigma}})} = 0$$
(18)

$$\tilde{s}_{jt} - \tilde{s}_{j|gt} \frac{\left(\sum_{j}^{K} exp\left(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}\tilde{p}_{jt}}{1 - \hat{\sigma}}\right)\right)^{(1-\hat{\sigma})}}{1 + \left(\sum_{j}^{K} exp\left(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage - \hat{\alpha}\tilde{p}_{jt}}{1 - \hat{\sigma}}\right)\right)^{(1-\hat{\sigma})}} = 0$$
(19)

The numerical resolution of simultaneous equations (17), (18) and (19) gives counterfactual values for prices p_{jt} , market share s_{jt} and within-nest market share $s_{j|gt}$. We can show prices change in Spain at 2020Q3 in presence and in absence of RAN sharing in Figure 1.



Figure 1: Comparison of prices in Spain at 2020Q3; observed, predicted and simulated values

Notes: Top bars of each MNO correspond to observed ARPU in 2020Q3 for four Spanish MNOs (MasMovil, Movistar, Orange Spain and Vodafone Spain). Middle bars correspond to predicted ARPU by the nested logit regression of Table (6) and in presence of RAN sharing between Vodafone Spain and Orange Spain. Bottom bars correspond to simulated ARPU by assuming an increase of marginal costs of 20% in absence of RAN sharing for Vodafone Spain and Orange Spain.

As shown in Figure 1, the ARPU values predicted (middle bars) by the nested logit regression of Table (6) for all four Spanish MNOs are quite close to the observed ARPU values (top bars). The very similar values between observed and predicted ARPU values indicate the goodnessof-fit for our empirical model. Bottom bars show the simulated ARPU by assuming an increase of marginal costs of 20% in absence of RAN sharing for Vodafone Spain and Orange Spain. By comparing the middle bars and the bottom bars, we can observe that the prices (ARPU) for Vodafone Spain and Orange Spain would be higher in absence of RAN sharing, which is the consequence of higher marginal costs.

8 Welfare comparison: in presence and in absence of RAN sharing

In this section, we investigate the impact of the RAN sharing on Spanish consumers at 2020Q3 by analysing the change in consumer surplus in presence and in absence of RAN sharing.

To calculate the consumer surplus in presence of RAN sharing, we use predicted prices and market shares by solving equations (14), (15) and (16). Total consumer surplus aggregates the net consumer valuation by using following expression

$$CS_{kt} = \frac{N_{kt}(1-s_{0t})}{\hat{\alpha}} ln(1 + (\Sigma_j^K exp(\frac{\hat{\delta}_{jt} + \hat{\beta}Coverage_{jt} - \hat{\alpha}p_{jt}}{1-\hat{\sigma}}))^{1-\hat{\sigma}}) \quad (20)$$

K the total number of mobile operators in the country and $\tilde{\delta} = ln(\frac{s_{jt}}{s_{0t}}) - \hat{\sigma}ln(s_{j|gt}) + \hat{\alpha}p_{jt} - \hat{\beta}Coverage_{jt}$, corresponds to the fixed level of consumer valuation for a MNO in presence of RAN sharing.

To calculate the consumer surplus in absence of RAN sharing, we firstly assume that an increase of marginal costs of 20% for Vodafone Spain and Orange Spain. Then, we use simulated prices and market shares \tilde{p}_{jt} , \tilde{s}_{jt} and $\tilde{s}_{j|gt}$ by solving equations (17), (18) and (19). Total consumer surplus aggregates the net consumer valuation by using following expression

$$\tilde{CS}_{kt} = \frac{N_{kt}(1-\tilde{s}_{0t})}{\hat{\alpha}} ln(1+(\Sigma_j^K exp(\frac{\tilde{\delta}_{jt}+\hat{\beta}Coverage_{jt}-\hat{\alpha}\tilde{p}_{jt}}{1-\hat{\sigma}}))^{1-\hat{\sigma}}) \quad (21)$$

where $\tilde{\delta} = ln(\frac{\tilde{s}_{jt}}{\tilde{s}_{0t}}) - \hat{\sigma}ln(\tilde{s}_{j|gt}) + \hat{\alpha}\tilde{p}_{jt} - \hat{\beta}Coverage_{jt}$, corresponds to the fixed level of consumer valuation for a MNO in absence of RAN sharing.

The difference between the two consumer surplus values, i.e. between equation (20) and equation (21), indicates the impact of the RAN sharing on consumer welfare.



Figure 2: Comparison of consumer surplus change in Spain at September 2020: in presence and in absence of RAN sharing

<u>Notes</u>: Left bar corresponds to consumer surplus (million USD) in 2020Q3 for Spanish market in presence of RAN sharing between Vodafone Spain and Orange Spain. Right bar corresponds to consumer surplus in 2020Q3 for Spanish market in absence of RAN sharing between Vodafone Spain and Orange Spain by assuming an increase of marginal costs of 20% in absence of RAN sharing for Vodafone Spain and Orange Spain.

As shown in Figure 2, the gain in consumer surplus, linked to the RAN sharing between Vodafone Spain and Orange Spain, would be higher than 50 million USD per month for Spanish mobile market.

9 Conclusion and policy implications

In this paper, we formulate and estimate a structural model of demand to analyse the equilibrium effect of the RAN sharing by using cross-country panel data in 28 EU countries in years 2010-2020. Based on model estimates, our simulation analysis in Spain firstly provides a quantitative assessment of the impact of RAN sharing on mobile operators. We find that prices decrease for mobile operators involved in RAN sharing due to cost reductions. In a competitive environment where operators compete in price, MNOs not involved in RAN sharing also lower their prices

in a Nash equilibrium. We further evaluate the consumer welfare consequence of the presence of RAN sharing, and find that the RAN sharing enhanced the consumer surplus by generating lower prices for all mobile operators.

A next step should be to further investigate the supply model by including the sharing status and the number of RAN sharing sites over time. Additional counterfactual simulations could be performed for European countries other than Spain.

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A Appendix

Proof that $\forall \gamma \in [0, 1]$ and $n \ge 2, A - B(n - 1) \ge 0$

$$A - B(n-1) = \frac{(1+\gamma)(1+(n-2)\gamma)(2+(2n-5)\gamma+(3-2n)\gamma^2)}{(1-\gamma)(1+(n-1)\gamma)(4+6(n-2)\gamma+(2n^2-9n+9)\gamma^2)}$$

The denominator is positive and the term $(1 + \gamma)(1 + (n - 2)\gamma)$ is also positive, the sign of A - B(n - 1) is thus the sign of $2 + (2n - 5)\gamma + (3 - 2n)\gamma^2$

For n = 2 this term becomes $2 - \gamma - gamma^2$ which is positive and this term increases with n, therefore, this term is positive if $n \ge 2$.

Proof that
$$\forall \gamma \in [0,1]$$
 and $n \ge 2, A - B(m-1) \ge 0$
As $m \le n, A - B(m-1) \ge A - B(n-1) \ge 0$ and therefore $A - B(m-1)$ is positive.

proof that $p_i - p_{i0}$ is negative for all operators involved or not.

We know that $n \ge m$, therefore we can write:

$$(A+B)(1+\gamma(m-1)) - Bm(1+\gamma(n-1)) \ge (A-B(m-1))(1+\gamma(m-1))$$

and since A - B(m-1) is positive, $(A+B)(1+\gamma(m-1)) - Bm(1+\gamma(n-1)) \ge 0$ and therefore: $p_i - p_{i0} = -\frac{[(A+B)(1+\gamma(m-1)) - Bm(1+\gamma(n-1))]\lambda}{1+\gamma} \le 0$ if operator i is involved. The sign of $\gamma A - B(1+\gamma(n-2))$ is the sign of $1 + (n-2)\gamma + (1-n)\gamma^2$ this expression is

positive if n = 2 and increasing in n therefore:

 $p_i - p_{i0} = -\frac{[\gamma Am - Bm(1 + \gamma(n-2))]\lambda}{1 + \gamma} \le 0 \text{ if operator } i \text{ is not involved.}$

Proof that $(p_i - p_{i0}) + \lambda$ is positive for involved operators. If i is involved, $p_i - p_{i0} + \lambda = -\frac{[(A+B)(1+\gamma(m-1)) - Bm(1+\gamma(n-1)) + (1+\gamma)]\lambda}{1+\gamma}$ and since $m \le n$, $p_i - p_{i0} + \lambda \ge \frac{(B(n-1) - A)(1 + (n-1)\gamma) + (1+\gamma)}{1+\gamma}$ and the sign of $(B(n-1) - A)(1 + (n-1)\gamma) + (1+\gamma)$ is the sign of $2 + (2n-1)\gamma + (6n-11)\gamma^2 + (6-4n)\gamma^3$ which is positive if $n \ge 2$

proof that Δpcm is positive $(B(n-1) - A)(1 + (n-1)\gamma) + (1 + \gamma)$ is positive, therefore Δpcm is positive.