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To share or not to share? The impact of mobile network sharing for consumers and operators

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To share or not to share? The impact of mobile network sharing for consumers and operators*†

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Abstract

This paper assesses the impact of mobile network sharing in Europe during the 2000-2019 period, looking at 140 mobile operators in 29 countries. We find that - consistent with economic theory - network sharing generated significant benefits for operators and consumers, including lower prices and improved network coverage and quality. This was driven by cost reductions, higher returns on investment and increased competition. These effects materialised heterogeneously, with the impact of network sharing depending on the type of sharing, the technology cycle in which it is entered into as well as the market position and size of the operators entering the agreement. This has important implications going forward as it shows that network sharing can play a vital role in the deployment of new 5G networks and that the technological and market specificity of each type of sharing agreement can significantly affect its outcomes.

Keywords: Network sharing; infrastructure sharing; mobile communications; network competition
JEL: D22; L10; L20; L96

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1 Introduction

The sharing of network infrastructure to deliver mobile services to consumers has become increasingly common, especially in Europe. The majority of network sharing agreements have been led by mobile operators as a way of reducing costs and expanding and improving networks. From an economic perspective, the impacts of such agreements are ambiguous. On the one hand, consumers may benefit from improved coverage, network quality and lower prices if cost reductions are passed through. On the other hand, the potential loss of infrastructure-based competition may result in lower service differentiation and could also reduce incentives to invest.

Despite the relevance of the topic, there is limited empirical evidence that assesses the impact of network sharing on mobile markets and consumers. This contrasts with a much larger body of literature looking at the impact of mergers and new entrants (see for example Aguzzoni et al. (2018) and Genakos et al. (2018)). In this paper, we provide new evidence on the impact of network sharing across Europe during the 2000-2019 period. During this time, network sharing not only increased but also evolved as operators entered into different types of sharing, including passive, active and roaming agreements.

The results show that network sharing has generated significant benefits for both mobile operators and consumers. Operators that entered into network sharing agreements were able to reduce prices (proxied by ARPUs) and increase network coverage and quality. This was driven by capex reductions, higher returns on investment - providing operators with both the ability and incentive to invest - and increased competition. In some cases, smaller operators benefited in terms of cost savings that allowed them to reduce prices and improve and expand their networks.

When looking at the impact of different types of sharing, we find that capex savings, profit margin improvements and price reductions were particularly associated with passive sharing. Passive sharing was also linked to increases in 3G coverage, as the majority of passive agreements in Europe were established during the phase of 3G deployments. By contrast, the positive effects of network sharing on 4G coverage and download speeds were mostly driven by active sharing, which became more prevalent when operators rolled out 4G networks after 2010. These results are robust to several identification strategies, including new Difference-in-Difference estimators that address the biases that can exist in traditional two-way fixed effects estimators.

This paper makes a number of contributions to the literature. To our knowledge, it is the first study to assess the impact of network sharing across a large number of countries over a long timescale, covering the deployment of three generations of technology. It provides empirical evidence to support the theoretical frameworks developed by studies such as Motta and Tarantino (2017), which suggested that mobile network sharing agreements should increase investment and consumer surplus under certain conditions. In this respect, it complements and builds on some of the existing studies that have demonstrated the benefits of network sharing on consumers in specific markets, (Maier-Rigaud et al., 2020). However, it then takes this further by relaxing a number of restrictive assumptions in the theoretical literature and assessing the impacts of different types of network sharing and also by assessing their impacts on competition dynamics. This is important because the results show that the impact of network sharing does depend on the type of sharing, the technology cycle in which it is entered into as well as the market position and size of the operators entering the agreement.

The study also has important implications going forward. The mobile market in Europe and globally is entering a new phase with the launch of 5G networks. These are expected to incur higher deployment costs than previous technologies, partly due to the need for more sites and spectrum. Given these comprise the largest portion of infrastructure cost, the sharing of networks is likely to take on even greater importance to deliver the high performance requirements of 5G while at the same time handling the increased traffic demand from consumers. The results from this study provide evidence that network sharing has an important role to play in enabling the competitive provision of widespread 5G networks.

The rest of this paper is structured as follows. Section 2 sets out the relevant context of network sharing in mobile markets, along with the theoretical framework that underpins this study. Section 3 presents the estimation strategy, along with a description of the data. Section 4 presents the results, and section 5 concludes.

2 Background

2.1 Network sharing in mobile communications markets

Mobile infrastructure sharing is the process by which mobile operators share elements of their infrastructure when delivering mobile services to their customers. There are many different types of network sharing agreements that are possible. Network sharing can for example involve one or several mobile technology generations and different parts of the mobile infrastructure; different geographical areas and duration over time; and are generally originated by market players but also in occasions through regulatory mandate.

For the purpose of this paper, we differentiate between two main types of network sharing: passive and active. Passive sharing involves the sharing of passive elements of the network such as towers, masts and other auxiliary infrastructure. While passive sharing can occur between two competing operators, it can also involve the presence of independent tower companies when a third party offers a site where several mobile operators can install their own equipment.

Active sharing on the other hand involves sharing active elements of the network like the radio equipment. Different types of active sharing are possible, with the two most common forms being MORAN[1], where operators share the radio access equipment but still use

[1] Multi-Operator Radio Access Network

different spectrum, and MOCN[2], where both the radio access equipment and spectrum are shared. A third and more involved form of active sharing involving the core network is also theoretically possible (GWCN[3]), although in practice it is not a common form of sharing.

National roaming can also be considered as another contractual form of sharing, because two or more operators use the infrastructure of one of the operators in certain areas or with certain technologies. It is often used by smaller operators with limited network coverage to expand their reach without significant upfront investments. A roaming agreement sets out the terms and wholesale charges that apply when the customers of one operator use the networks of the other operator. We therefore consider but differentiate national roaming from other forms of sharing in our analysis. Table 1 summarizes the characteristics of network sharing agreements.

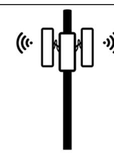
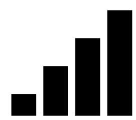
A broad range of drivers come into play when mobile operators decide to enter into a network sharing agreement. In many cases, cost savings are one of the key drivers: by sharing capital and operational expenditures, mobile operators can reduce costs and improve their financial position. There can be other critical motivations beyond cost reduction. For example, operators can often look into network sharing as a way to extend coverage into unprofitable areas. Neumann and Plückebaum (2017) discuss how for smaller players getting access to their competitors' networks can help achieve wider coverage faster. Pápai et al. (2020) discuss how incumbent mobile operators might look into network sharing to achieve a faster and more efficient roll-out of new technologies, being able to achieve better network quality (for example download speeds) and coverage.

Market structure and the extent of vertical integration in the mobile industry have evolved with each generation of mobile technology. 2G networks started off with fully integrated network operators building up their customer base, but by the time 3G networks were introduced, a degree of network sharing, primarily passive sharing and roaming, started to develop in some European countries. 4G introduced a significant increase in data capacity for consumers, and operators sought to reduce the cost of network roll-out in this generation as the primary source of revenues moved from unit-priced minutes and SMS' to monthly or top-up data packages. Market consolidation, via mergers and acquisitions, was one approach attempted by some market players to generate cost efficiencies. Another way to reduce network costs was to seek network sharing agreements in order to gain efficiencies in network construction. In the 4G era this often involved both passive and active sharing, with the objective to reduce costs, enhance coverage, and achieve a faster roll-out of 4G networks.

The roll-out of 5G networks in Europe has the potential to intensify some of the underlying drivers that saw the incidence of network sharing in Europe increase in the 4G era. It has been estimated that the number of sites required to roll-out 5G will increase by approximately 50% when compared to previous mobile network generations (GSMA, 2019), resulting in higher roll-out costs. With limited potential for incremental revenues, the need

[2]Multi-Operator Core Network
[3]Gateway Core Network

Table 1: Infrastructure sharing in mobile networks

Operators in agreement	Type of sharing	Infrastructure and service sharing	
Bilateral (1-1)	Passive		
		Masts, sites, cabinet, power, and air conditioning	
	Active	MOCN	MORAN
			
		Base station, radio access networks and spectrum	Base station, antennas and radio network controllers (RNC)
	Roaming		
		Signal service	
Multilateral (1-n)	TowerCo	Mainly passive equipment but expanding to active and services	

Notes: Active sharing also typically involves sharing backhaul networks, while passive sharing can also include backhaul network sharing (though not all).
Source: Created by the authors using icons by Michael Thompson and Wuppdidu under Creative Commons CCBY

to pool or share costs through network sharing is likely to increase. It is also possible that the nature of sharing deals also changes: since larger savings can be in theory achieved with more involved forms of sharing, it is possible that 5G brings with it an increase in the number of active sharing deals.

2.2 What are the impacts of network sharing on markets and consumers?

Given the strong growth in network sharing in mobile markets, and with its underlying drivers further strengthening in the near future, it is crucial to have a good understanding of the potential impacts of network sharing on market dynamics and consumer welfare.

Network sharing agreements can have different impacts on the degree of competition in the market, and a number of papers have discussed these theoretical effects, including Mölleryd et al. (2014), Neumann and Plückebaum (2017), Dasgupta and Williams (2017), Pápai et al. (2020). The loss of infrastructure-based competition can bring a greater risk of exchange of sensitive information at the service level which could facilitate or reduce barriers to coordinated behaviour. Network sharing can also reduce the possibility for the parties involved in the agreement to differentiate their services. This can potentially reduce the incentives to compete or to invest in improving coverage and network quality. Another concern for regulators and competition authorities can arise if the network sharing agreement creates anticompetitive effects, where one or more parties in the agreement have the incentives to restrict access to their network to downstream competitors (for example an MVNO). Finally, it has to be noted that from an operational viewpoint, sharing can also increase complexity - due to the need for technical coordination between operators - and may slow down decision making and the roll-out of new sites or upgrading to new technologies (BEREC, 2018).

Despite these challenges, European regulators have typically been favourable to network sharing deals in the vast majority of cases. This is partly because in terms of the risks to competition, regulators and competition authorities can often mitigate or eliminate such concerns by putting in safeguards and/or monitoring the agreements using ex-post competition laws and frameworks. Examples of safeguards can include: having the regulator act as arbitrator in commercial negotiations and/or disputes; having the regulator review and approve infrastructure sharing contracts and allow it access to all logs on infrastructure sharing activities, and/or; ensuring that "clean teams" separate the staff dealing with the network-sharing partners and the staff dealing with downstream customers.

More generally, regulators have often been favourable to network sharing deals because they can bring a number of positive market outcomes that are welfare enhancing for consumers. A range of industry sources estimate the potential cost reductions at between 30-65 pct, depending on the type of sharing (GSMA, 2019).

Lear et al. (2017) and BEREC (2018) discuss and summarise some of the main benefits associated with network sharing: lower costs can translate into lower consumer prices; increased network coverage in otherwise unprofitable areas, while maintaining competitive pressure; facilitating the growth of new entrants or smaller players; reducing challenges involved in duplicating infrastructure in indoor or very dense areas with limited site availability; and/or delivering positive carbon and environmental effects by reducing overall energy consumption and visual impact on landscapes. In addition to these, Pápai et al. (2020) also discuss how network sharing deals can result in a number of improvements to the quality of service experienced by consumers, including a faster roll-out of new mobile technologies, better network quality overall (from better location and radio access networks) and better coverage.

Despite the variety of potential positive and negative effects of network sharing, empirical research on these impacts remains extremely limited at the time of writing this paper. In fact, to our knowledge, no studies have to date robustly assessed the impacts of network sharing on market dynamics and consumer outcomes across a number of countries. This evidence gap is particularly significant, given the extent of network sharing deals in European mobile markets. This paper addresses this significant gap by investigating the relationship between network sharing and market outcomes. We analyse two decades of network sharing deals in Europe and assess their impacts on market dynamics and consumers. In particular, we look at the effects on cost savings and profitability, but also at the effects in terms of deployment speeds, coverage and network quality. Since these effects can potentially vary depending on the parties undertaking the sharing agreement (market leaders vs smaller players) and the type of network sharing agreement, we also specifically consider the differential impact of those as part of our assessment .

2.3 Market trends

The mobile market is characterised by frequent cycles of technology change, with new technologies introduced almost every ten years (Figure 1). At the start of the millennium, most mobile users in Europe connected using 2G technology for voice calls and messaging. With the advent of smartphones, consumers upgraded to 3G in order to use high-speed internet browsing and applications. The deployment of 4G enabled consumers to benefit from much faster speeds and new services. By the end of 2020, some European operators had also introduced 5G, although adoption was very limited.

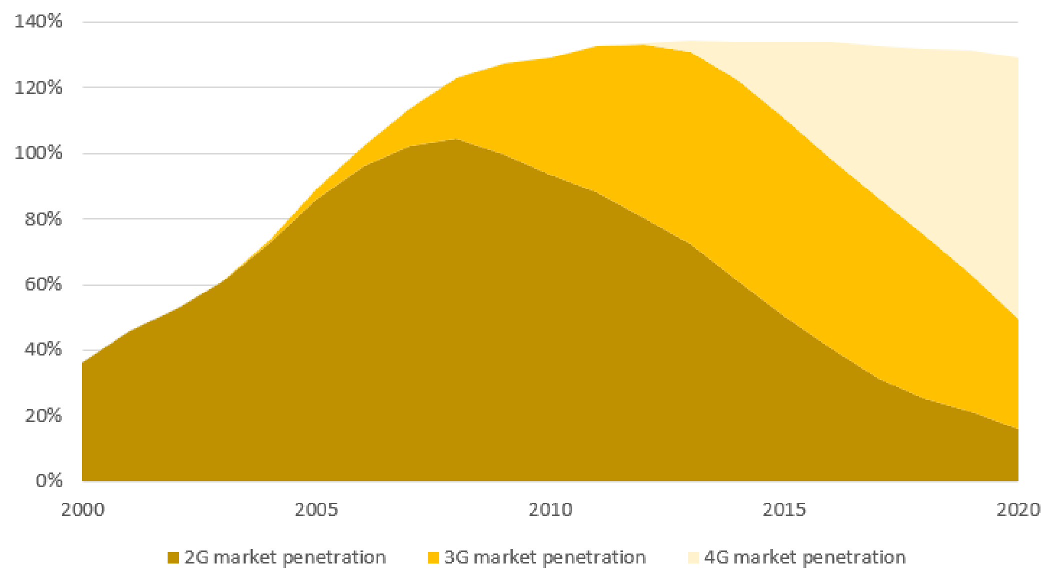
Over the same period, network sharing evolved across the continent (Figure 2). For the first ten years, network sharing mostly consisted of roaming and passive agreements. After 2010, the incidence of network sharing increased but with a different focus. In particular, passive agreements gradually subsided as active network sharing (particularly MORAN) and tower companies (TowerCos) began to emerge.

As a separate network entity, TowerCos can optimize network usage through multilateral agreements with all or most of the existing operators in the market. They can therefore allow for more efficient use of the infrastructure, in the absence of exclusivity or preferential clauses for a selection of the operators. While this study includes an assessment of TowerCos, given that a large proportion of emerged toward the end of the period and due to constraints in the data (see Section 3), the results should be interpreted with caution.

2.4 Theoretical framework

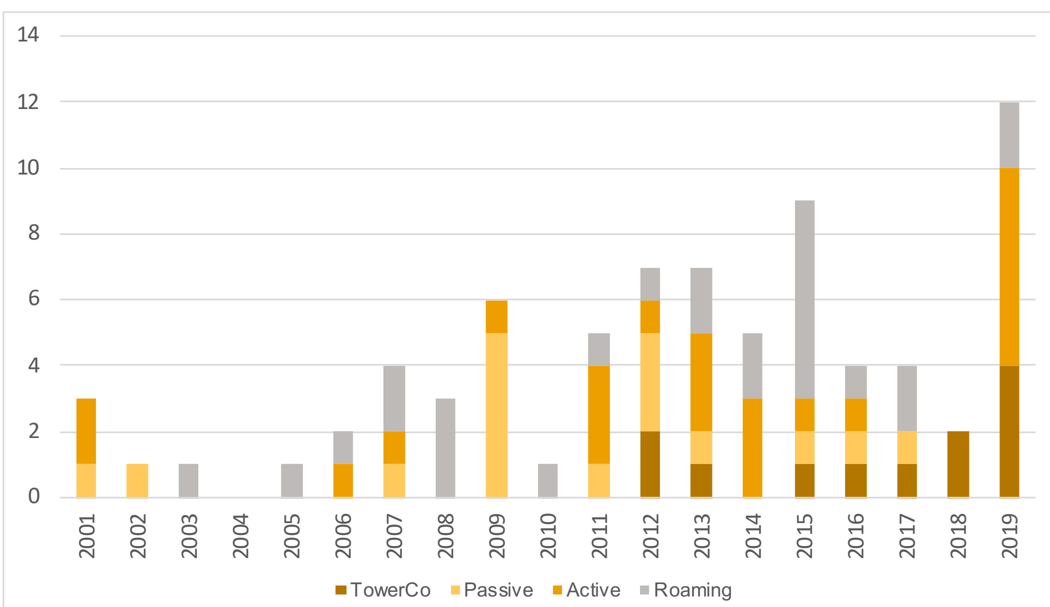
We consider the effects of network sharing deals and compare them with a counterfactual case where mobile operators do not share infrastructure. As in Motta and Tarantino (2017), we assume that two mobile operators enter a network sharing deal, operators i and k, and that this can give rise to efficiencies with the parameter $\lambda \epsilon (0, 1)$ representing the importance of these efficiency gains (G). Operators choose investment levels q_i and q_k to maximize profits

Figure 1: Mobile market penetration in Europe



Source: GSMA Intelligence. Market penetration is calculated by dividing the number of mobile connections (or SIM cards) by total population. Individuals can have multiple SIM cards, which is why total penetration exceeds 100%

Figure 2: Network sharing in Europe



Source: Coleago - Network sharing agreements database, last accessed 17 February 2020 jointly, but they still choose prices p_i and p_k non-cooperatively to maximize individual profits. With $F(x_i)$ denoting the fixed cost born by firm i to invest x_i, total costs are given by:

$$F(x_i) + F(x_k) - \lambda G(x_i, x_k) \geq 0$$

$$\text{with } \frac{\partial G(x_i,x_k)}{\partial x_i}, \frac{\partial G(x_i,x_k)}{\partial x_k} \geq 0 \text{ and } \frac{\partial G(x,x)}{\partial x_i} = \frac{\partial G(x,x)}{\partial x_k}.$$

Motta and Tarantino (2017) show that the maximization problem facing a mobile operator that enters into a network sharing agreement is $\max_{p_i} \pi_i(p_i, p_k|\lambda)$ subject to three conditions:

$$x_i = \chi(q_i|\lambda)$$

$$q_i = q_i(p_i, p_k) \text{ and}$$

$$\pi_i(p_i, p_k|\lambda) = (p_i - c(\chi(q_i|\lambda)))q_i - F(\chi(q_i|\lambda)) + \lambda/2(G(\chi(q_i|\lambda), \chi(q_k|\lambda)))$$

Under standard assumptions (symmetric firms, Bertrand competition with differentiated goods and $n \geq 2$ firms) it can be shown that the first order conditions that maximise profits for mobile operator i or k imply that the network sharing scenario will (weakly) dominate the benchmark case of no sharing for any value of $\lambda \geq 0$ in terms of consumer welfare, which is in turn a function of prices and investment. The intuition behind this result comes from the fact that the network sharing deal is assumed not to distort price choices while at the same time allowing its members to benefit from cost savings in the investment function.

In our setting, we relax some of the more restrictive assumptions in the framework by incorporating two additional factors. First, we allow mobile operators to enter different types of network sharing deals, as these can lead to different cost reductions and effects. For example, roaming agreements can be seen as an option that could deliver higher flexibility because mobile operators share all the infrastructure, both passive and active. Passive infrastructure sharing has in principle a lower cost-saving potential, but it can be relatively easier to implement, reducing transaction costs. Some forms of active sharing, for example core network sharing, have the technical potential to deliver larger savings but also involve complexities and therefore high coordination costs. Other forms of active sharing involving the RAN (which have been much more common) are easier to implement but can deliver lower efficiencies. We allow λ to take different values correspondingly: λ_1 for active sharing, λ_2 for passive sharing λ_3 for roaming agreements, with each type of sharing still bound by the same conditions of $0 < \lambda_1, \lambda_2, \lambda_3 < 1$.

Secondly, and also adding further flexibility to the theoretical framework, we allow network sharing deals to impact not only investments and prices but also competition dynamics, in the form of higher or lower market power for mobile operators i and k, and for these effects also to be different between different types of sharing. Network sharing can facilitate a faster growth of smaller players and hence increase competitive intensity. On the other hand increased homogenisation of services can reduce differentiation between mobile operators and therefore also reduce competitive intensity. This effectively implies that once competitive dynamics are considered, all effects on prices (p_i and p_k) and investments (x_i and x_k) are theoretically possible. The impacts of network sharing on consumer welfare and market dynamics are therefore a question that needs to be analysed empirically.

3 Empirical approach

3.1 DiD framework

To assess the impact of network sharing on consumer welfare, we implement a difference-in-difference (DID) model at the operator-level, thereby allowing us to empirically test the framework set out in Section 2.4. The DID model compares market outcomes between 'treated' operators that enter into a network sharing agreement, and 'non-treated operators' that do not enter into any agreement. It is formulated as follows:

$$y_{it} = \alpha_i + \beta_t + \gamma NS_{it} + \mathbf{X}_{it}\theta + \epsilon_{it} \tag{1}$$

where y_{it} is a market outcome for operator i in the quarter t. NS_{it} is the variable of interest and is defined by an indicator variable equal to one if operator i is part of a network sharing agreement during period t (or zero otherwise). Separate specifications are run for different types of agreement (active, passive and roaming).

$\mathbf{X}$ is a vector with time-varying control variables, including the proportion of a country's population living in rural areas and GDP per capita.[4] α_i denotes operator fixed effects, which capture time invariant characteristics for each operator (for example business strategy, firm structure, resources and management). β_t represents year fixed effects which account for aggregate trends over time.

The market outcomes that are considered in this study include input and output measures of investment - including capex, network coverage, download speeds (a measure of network quality) and data traffic - as well as price (proxied by ARPU). This means that the estimated coefficients for γ in equation 1 can be interpreted as the the impact of network sharing, which in turn reveal the extent of efficiency gains $\lambda_1, \lambda_2, \lambda_3$ in the theoretical framework set out in the previous section, as well as the impact of network sharing on competition. For example, if network sharing drives greater network coverage and quality and reduces prices, this provides validation that network sharing is indeed associated with a positive $\lambda > 0$ and that it may also increase the intensity of competition between operators. Alternatively, if we find that network sharing has no impact on market outcomes, this would indicate that λ is close to zero, while a negative impact would mean that network sharing reduces competitive

[4]Another relevant time-varying control that could impact some of our outcomes are spectrum holdings. For example operators with more spectrum will have more capacity to deliver faster speeds and will require less investment to deploy 3G and 4G networks. However, data was only available on spectrum holdings for all operators since 2011. We therefore ran the models for network quality and 4G coverage (which was deployed after 2010 in most countries) including spectrum holdings as a robustness check to ensure that our findings were not sensitive to its inclusion. If they are not, this gives us confidence that the results for the full period of analysis are valid.

intensity in the market.

In order to ensure a clear and consistent interpretation of results, equation 1 was modelled for each type of network sharing agreement (active, passive and roaming) against a control group of no network sharing. For example when looking at passive sharing, operators that entered into any other type of sharing (including active, roaming, tower-co and also those that underwent a merger) during the period of analysis were excluded. This ensures that the control group consists of operators that never entered into a network sharing agreement, meaning that we can interpret the results as being the impact of a passive sharing agreement relative to a benchmark of no sharing at all, which is in line with our theoretical framework. If we also included operators with other types of agreement, the interpretation would be less clear because we would be comparing a passive agreement against both 'no agreements' and active agreements.

There is also an important consideration around the timing of effects. It is unlikely that network sharing agreements would impact consumers several years after it took effect - and even if it did, any impacts would likely be confounded with other factors given the fast-moving nature of the industry. We therefore impose a time-constraint on equation 1 by implementing the regression to only include observations five years before the NSA and two years after. As a sensitivity check, we also ran it including observations in the following windows: (i) five years before and three years after; (ii) five years before and four years after; (iii) three years after, and; (iv) no restrictions on the time frame.

Given the potential heterogeneous impacts of network sharing on different operators and the implications for competition, we are also interested in understanding whether consumers are more likely to benefit from NSAs if they are with smaller or larger operators. In order to test this, we modify equation 1 to include an interaction with different types of operators based on their size.

$$y_{it} = \alpha_i + \beta_t + \sum_{n=1}^{5} \gamma_n * operator\_size_{nit} * NS_{it} + \mathbf{X}_{it}\theta + \epsilon_{it} \tag{2}$$

Where $operator\_size_{nit}$ reflects the scale of an operator's subscriber base. For this we define five categories of operators based on whether they have: (i) greater than 40% market penetration; (ii) between 30-40% market penetration; (iii) between 20-30% market penetration; (iv) between 10-20% market penetration, and; (v) less than 10% market penetration.

Another important consideration is that in our study, the treatment that applies to operators is not uniform, as operators entered into NSAs at different points in time. Recent advancements in DID have shown that in this context, the two-way fixed effect (TWFE) DID estimation outlined above can yield biased estimates (see for example Baker et al. (2021) and Goodman-Bacon (2021)). This bias may result from the variance-weighting implicit in ordinary least squares, where more weight is given to observations with higher variance in treatment. It can also result from the embedded use of past treated units as effective controls for later-treated units (as well as 'always treated' units acting as controls). This means that our sample deviates from the so-called canonical DID setup in which all the units in the treatment group receives the treatment at the same point in time.

To address this estimation challenge, we take advantage of recent methods developed in the DID literature. The starting point is the following 'event-study' specification:

$$y_{it} = \alpha_i + \beta_t + \sum_k \gamma_k * \lambda[t - NS_i = k] + \mathbf{X}_{it}\theta + \epsilon_{it} \tag{3}$$

where there are separate 'lead' and 'lag' dummy NSA variables. NS_i is the time period when the NS treatment begins for operator i and $\lambda[t - NS_i = k]$ is an indicator for being k periods from the treatment starting. The 'lag' variables allow us to distinguish potential dynamic effects, for example whether impacts occur in the short- or medium-term. If the leads are not statistically significant from zero, this gives us reassurance that any post-NSA effects are not being confounded by other unobservable factors. Or put another way, it means that changes in the relevant consumer outcome variables in the group of control operators are more likely to approximate the changes that would have occurred for the 'treated' operators if they had not entered into an NSA.

While equation 3 addresses some of the biases involved in the TWFE estimator in equation 1, it can still be contaminated by effects from other periods and treatment effects heterogeneity. We therefore implement equation 3 using the estimators developed by Borusyak et al. (2021) and Callaway and Sant'Anna (2020). These derive efficient estimators that are robust to treatment effect heterogeneity in the above settings, and they also enable different 'group-time' treatment effects to be aggregated into an overall treatment effect.

There is also a possibility that an operator's decision to enter into a network sharing agreement is endogenous to the outcomes being considered. For example, the NSA might be a direct consequence of an operator lacking network coverage or not achieving sufficient network quality. We therefore also employ an instrumental variable regression. This requires the identification of one or more indicators that impact the decision to enter a network sharing agreement but not the consumer outcomes being considered. We create an indicator that captures the incidence of network sharing across the full sample of operators in each time period. This is based on the rationale that the extent of network sharing across Europe may influence an operator's decision to engage in its own form of network sharing, but it should not have a direct impact on the operator's consumer outcomes.

Last we employ a randomization process, where we allocate the NSA treatment randomly and perform the same tests for the outcome variables of interest. We repeat this random allocation process 3,000 times for each treatment (passive, active, roaming, towerco) and compare the distribution of the implied coefficients (β) with the ones we get from our models.

3.2 Data description

The analysis in this study covers 140 operators in 29 European countries during the period 2000-2019. Data on network coverage and mobile connections - which is used to calculate market HHI as well as market penetration - are sourced from GSMA Intelligence. The network coverage data measures the proportion of the population resident in an area where 3G or 4G networks are available (i.e. coverage by population rather than by geographic area). The data is gathered from operators and regulators. Where coverage is not reported in each quarter, data is estimated by GSMA Intelligence modelling. The data on investment (CAPEX), earnings before interest, tax, depreciation and amortization (EBITDA) and mobile data traffic are also sourced from GSMA Intelligence, based on the financial reports of mobile operators. Financial and mobile traffic data are not available in every quarter, therefore the analysis is run based on when it is recorded. Network and financial data are both available for the period 2000-2019.

In terms of network quality, this study analyses download speeds. Data is sourced from Ookla®, using the Speedtest® consumer-initiated testing platform that allows mobile users to initiate a 'speed test' to measure network performance at any given time. Each time a user runs a test, they receive a measurement for download speed, upload speed and latency. The test also records the consumer's location, the network operator and the technology being used at the time of the test. Each year, Speedtest is used by 500 million unique users globally, and an average of 10 million consumer-initiated performance tests are run per day. Using these test results, Ookla calculates the average (mean) download speed metric across all users in each quarter at the operator level. Data on download speeds is available from 2011 to 2018.

With regard to the price of mobile services, there are a number of challenges in constructing a price measure that reflects consumers' payments for each operator as well as one that is consistent over time. For the period of analysis, the only pricing metric available to us at the operator or country level was average revenue per user (ARPU). We therefore carry out the empirical analysis using this metric, although it is important to note that ARPU is affected by both mobile prices and usage. Data on ARPUs are sourced from GSMA Intelligence, based on financial data reported by mobile operators during the period 2000-2019.

The data on network sharing agreements is sourced from the Coleago Mobile Network Sharing database. This contains a list of network sharing agreements in Europe since 2000, based on public announcements. Each agreement is identified based on the deal type, which can include passive, active (either MORAN or MOCN), roaming, spectrum sharing and a tower company arrangement. It also identifies the date of commencement and duration for each agreement.

With regard to tower sharing agreements, the database allowed us to identify where operators sell some (or all) of their towers to a third party entity. However, it does not identify all instances where an operator leases towers from such entities, which is one of the potential forms of network sharing that might occur in markets with independent tower companies. The results based on tower sharing agreements are therefore subject to this limitation.

Lastly, the data on GDP per capita and rural population are sourced from Eurostat.

4 Results

4.1 Main results

In this section we present the results for the baseline specifications across all network sharing types. Our baseline specification includes income and urbanization controls and limits the control group to countries which did not have any sharing agreement in place for the entire period we study (Table 2). As these markets may have specific characteristics that led them to avoid using any type of sharing, we relax the exclusion conditions and also refer to the results in Table 3 which limits the period before and after the sharing agreement to countries that did not have any type of sharing agreement in place (for five years before and three years after the sharing took place). We provide further sensitivity tests in Appendix A for regressions that incorporate country fixed effects rather than operator fixed effects (Table 10) and additional controls for spectrum assignments by operator (Table 11).

The results overall indicate strong effects from network sharing. Table 2 shows that operators entering a network sharing deal realised capex savings and improved their profit margins when compared to those operators in the baseline that did not. Furthermore, there is evidence that these cost reductions were passed through in the form of lower prices for consumers, proxied by ARPUs in our empirical analysis. When looking at the impacts of different agreement types, we found that these capex savings, profit margin improvements and price reductions materialised with particular strength in the case of passive sharing agreements.

In addition to these operator-specific effects, at the market level we also observe on average a statistically significant reduction in HHI from network sharing, highlighting that the pro-competitive effects of network sharing outweighed any potential concerns about the effects of a reduction in infrastructure based competition. This is also consistent with the price reductions observed, as well as improvements in other dimensions important for consumers such as coverage and network quality. The finding that network sharing reduced HHI and consumer prices are consistent in the alternative setting in Table 3, although the mechanisms around reduced capex and higher profits are not statistically significant in that case.

Network sharing deals also delivered positive effects by increasing network coverage for both 3G and 4G technologies. Network sharing deals resulted in average increases in population coverage of between 2-9 percentage points versus the baseline, depending on the specification and type of network sharing deal. 3G coverage improvements were generally driven by the positive effects of passive network sharing deals, whereas 4G coverage effects were mostly driven by the positive effects of active network sharing deals. Roaming agreements also had positive impacts on 3G and 4G coverage. Almost all of the results on network coverage hold in Table 3.

We also find positive effects on network quality, especially for active sharing where the results are statistically significant and hold in both Tables 2 and 3. In line with these quality improvements, we also observe improvements in data traffic per user. This is in line with expectations, as sharing antennas or spectrum can allow operators to increase network capacity, improving download speeds while reducing network congestion. Given that active sharing also increases 4G coverage, this increases the likelihood of consumers using 4G services, which typically leads to more data consumption.

The results for roaming seem to suggest a reduction in download speeds and data traffic per user (though it is worth noting that this does not hold in the alternative setting in Table 3). One potential reason for this is that roaming led to improvements in coverage in rural areas that may have been less profitable for some operators. Since speeds and data traffic are generally lower in these rural areas, this has the effect of reducing average speeds for the network. These results are further supported by looking at the results obtained by operator size, which we discuss in more detail below.

Table 2: Network sharing results with income and rural controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
Any Sharing	0.016**	0.056***	0.945	0.261***	-0.544*	0.025**	-23.167**	-100.000***
	(0.007)	(0.019)	(0.682)	(0.074)	(0.316)	(0.011)	(8.990)	(17.422)
Passive	0.039***	0.023	0.434	0.339	-1.627***	0.124***	-47.790***	-2.145
	(0.012)	(0.044)	(1.644)	(0.286)	(0.565)	(0.023)	(18.455)	(39.770)
Active	-0.012	0.053**	4.724***	0.357***	0.418	-0.006	-20.512	-54.184**
	(0.010)	(0.026)	(0.971)	(0.089)	(0.462)	(0.014)	(12.701)	(22.884)
Roaming	0.030**	0.090***	-2.870***	-0.439**	0.619	0.004	-4.857	-105.601***
	(0.014)	(0.034)	(1.070)	(0.173)	(0.658)	(0.022)	(15.595)	(27.513)

Standard errors in parentheses

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

All results include Operator and Year FEs. The testing period is limited between 5 years before the agreement and 2 years after.

Table 3: Network sharing results with alternative time windows, income and rural controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
Any Sharing	0.017**	0.031*	0.941	0.299***	-0.853***	0.036	-13.267	-49.321***
	(0.007)	(0.018)	(0.621)	(0.065)	(0.296)	(0.052)	(9.852)	(17.710)
Passive	0.049***	-0.001	-2.626*	0.573**	-2.114***	0.063	10.421	36.539
	(0.011)	(0.032)	(1.397)	(0.249)	(0.494)	(0.074)	(14.250)	(32.214)
Active	-0.008	0.046**	4.440***	0.401***	0.095	0.011	-13.709	-115.648***
	(0.009)	(0.020)	(0.921)	(0.073)	(0.388)	(0.056)	(11.801)	(26.271)
Roaming	0.024**	0.027	0.944	0.045	-0.317	0.009	20.457*	-40.307*
	(0.012)	(0.019)	(0.756)	(0.077)	(0.427)	(0.050)	(11.166)	(20.963)

Standard errors in parentheses

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

All results include Operator and Year FEs. The testing period is limited between 5 years before the agreement and 2 years after.

Mobile operators can and do have different reasons for entering into network sharing agreements, and these will typically vary according to the market position and size of each individual operator. For smaller operators and new entrants, the ultimate driver to enter into a network sharing deal tends to be focused on reaching a broader customer base or improving its offerings and quality more quickly and economically than when having to build new infrastructure. For larger, market leading operators, the motivations are often more focused on reducing unit costs for its existing customers. The eventual impacts on the competitive dynamics of the market and consumers can therefore be also heterogeneous, depending on the market position of the operators that are entering a network sharing agreement.

The results by operator size confirm that there is heterogeneity in the effects depending on the size and position of each operator entering a network sharing deal in the market (Table 4). While both smaller and larger operators tend to benefit from improved profitability, capex savings are particularly stronger and mostly observed for smaller operators. The results also show that these are passed onto consumers in the form of lower prices. Similarly, increased effects for coverage, speed, and data traffic are observed more strongly for smaller players, although there are some positive coverage effects for larger mobile operators as well. The effects on HHI are also heterogeneous when considering the size of the operator. When larger operators enter a network sharing deal, the average effect is an increase in HHI, whereas when smaller operators enter a network sharing deal, the average effect is a reduction in HHI. This is likely to reflect that mobile operators entering a network sharing deal tend to improve their position in the market.

Table 4: Network sharing results by operator size

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
40%+ X Any Sharing	0.022**	0.077*	0.056	0.112	0.134	0.059*	-9.452	357.848***
	(0.010)	(0.040)	(2.050)	(0.127)	(0.476)	(0.031)	(24.875)	(51.216)
30% - 40% X Any Sharing	0.028	0.128***	1.052	-0.536***	0.431	0.013	-5.941	-117.965***
	(0.020)	(0.039)	(1.612)	(0.148)	(0.938)	(0.029)	(19.575)	(40.243)
20% - 30% X Any Sharing	-0.023*	0.013	1.862**	0.605***	-1.257**	0.006	-23.864*	-160.003***
	(0.014)	(0.026)	(0.892)	(0.105)	(0.570)	(0.014)	(12.190)	(22.269)
10% - 20% X Any Sharing	0.025	0.093*	3.516**	0.921***	-3.795***	0.034	-52.439***	-155.193***
	(0.030)	(0.051)	(1.576)	(0.225)	(0.932)	(0.022)	(17.787)	(39.361)
0% - 10% X Any Sharing	0.121***	-0.046	-5.510***		1.611	0.113***	-10.295	-33.840
	(0.031)	(0.116)	(1.631)		(1.154)	(0.035)	(27.799)	(40.739)
Observations	2,968	1,217	1,535	749	4,026	909	838	1,558
R-squared	0.848	0.731	0.815	0.910	0.522	0.109	0.018	0.320
Number of operator_id	102	78	67	34	95	55	51	68

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2 Robustness checks

To further test the robustness of our results and address potential concerns with our main empirical strategy, we carried out the analysis employing a range of alternative specifications. First, we look into the outcomes observed across various different pre- and post-treatment periods. In Table 5 we present five different options which range from unrestricted temporal effects, 3-year post-treatment effects, 5-years pre-treatment and 2-years post-treatment (our baseline), 5-years pre-treatment and 3-years post-treatment and lastly 5-years pre-treatment and 4-years post-treatment. In these applications we mainly look for the sensitivity of the observed estimations once the temporal domain does not run indefinitely.

The results show that almost all of the findings hold to alternative periods - in particular the reduction in costs and prices and increased profitability, network coverage, speeds and traffic. The exception is that some results are not statistically significant in an unrestricted setting, though we place less weight on this because our analysis covers 20 years in total and it is very likely that the effects of network sharing will be confounded with other factors over very long periods.

Table 5: Varying windows of treatment for Any Sharing

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
Unrestricted	0.002	0.029**	1.961***	0.279***	0.177	0.012*	0.083	-60.543***
	(0.005)	(0.012)	(0.486)	(0.057)	(0.182)	(0.007)	(5.529)	(11.938)
All pre - 3 years post	0.008	0.049***	1.245*	0.158*	0.122	0.027***	-21.036**	-95.459***
	(0.007)	(0.018)	(0.647)	(0.082)	(0.300)	(0.010)	(8.178)	(16.346)
5 years pre - 2 years post	0.016**	0.056***	0.945	0.261***	-0.544*	0.025**	-23.167**	-100.000***
	(0.007)	(0.019)	(0.682)	(0.074)	(0.316)	(0.011)	(8.990)	(17.422)
5 years pre - 3 years post	0.015**	0.052***	1.500**	0.328***	-0.648**	0.027***	-21.204**	-90.007***
	(0.007)	(0.018)	(0.651)	(0.071)	(0.280)	(0.010)	(8.389)	(16.436)
5 years pre - 4 years post	0.013*	0.050***	1.607**	0.385***	-0.670**	0.029***	-20.814***	-86.472***
	(0.007)	(0.018)	(0.651)	(0.070)	(0.261)	(0.010)	(7.997)	(16.036)

Standard errors in parentheses

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

All results include Operator and Year FEs. The testing period is limited between 5 years before the agreement and 2 years after.

In Appendix A (Tables 10 and 11), we also present the results using country fixed effects as well as including control variables for spectrum holdings. All of the above results are consistent with country fixed effects, while the findings for 4G coverage and speeds are consistent when we include spectrum holdings. Given that the data for 4G coverage and speeds coincides with the period where we have spectrum data, this gives us confidence that our main results are not compromised by the absence of any controls for spectrum.

A further robustness check was to implement two DID estimators developed by Borusyak et al. (2021) and Callaway and Sant'Anna (2020) that address the biases that can arise in TWFE models. Both of these allow us to aggregate cohort or group specific effects into a single overall average treatment effect (ATT), which is comparable to our baseline approach. For clarity, we present separately the single ATT in this section and in Appendix B we present the event study results for the variables that are statistically significant post treatment and are robust across most of our approaches.

The single average treatment effect using Borusyak et al (2021) shows that most of our key findings still hold. Passive sharing still drives higher profits and price reductions as well as increased 3G coverage, while active sharing increases 4G coverage, speeds and data per user. The analysis also shows that network sharing reduces HHI, although the coefficients for capex are generally statistically insignificant. The results for roaming are positive and statistically significant for 3G coverage, though not for speeds or traffic as we found in the baseline approach. There is also a negative effect observed for passive sharing on 4G coverage and download speeds, although we did not find this in most other estimation strategies so it is not a consistent result compared to outcomes such as 3G coverage, ARPU and EBITDA.

Table 6: Borusyak et al (2021) ATT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
Any Sharing	0.011	0.065***	0.188	0.231**	-0.150	-0.007	-9.776	-98.382***
	(0.023)	(0.017)	(0.890)	(0.107)	(0.430)	(0.008)	(8.091)	(32.702)
Passive	0.047***	-0.037**	-1.571***	0.138	-2.076***	0.090***	4.631	30.625**
	(0.011)	(0.016)	(0.467)	(0.117)	(0.456)	(0.014)	(3.359)	(15.273)
Active	0.002	0.039***	3.070***	0.385***	0.100	0.013	-4.792	-110.151***
	(0.017)	(0.015)	(0.678)	(0.113)	(0.424)	(0.029)	(9.467)	(18.484)
Roaming	0.038***	0.030	0.699	0.074	-0.193	0.032	18.591***	12.162
	(0.013)	(0.026)	(1.722)	(0.061)	(0.371)	(0.025)	(4.723)	(32.344)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

When looking at the results using Callaway and Sant'Anna (2020), all of the results are consistent in terms of direction of effect. Some are statistically significant, for example the impact of passive sharing on capex and EBITDA and the impact of active sharing on 4G coverage and HHI. However, this is not the case for all the results, for example the impact of passive sharing on 3G coverage and ARPU and the impact of active sharing on speeds. This may be due to the fact this when there is wide variation in treatment timings over a long period, the estimator does not leverage the full amount of data available (as highlighted by the lack of coefficients for traffic).

Table 7: Callaway and Sant'Anna (2020) ATT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
Any Sharing	-0.001	0.076**	-0.637	-	-1.007	0.0222	-22.127	-84.737
	(0.023)	(0.039)	(3.241)	-	(0.641)	(0.0191)	(25.779)	(97.927)
Passive	0.027	0.071**	5.462***	-	-0.1404	0.17***	-55.1647**	-30.5813
	(0.055)	(0.001)	(2.1446)	-	(1.129)	(0.021)	(9.2149)	(57.4922)
Active	0.016	0.041***	0.490	-	0.325	0.020	17.347	-246.479***
	(0.025)	(0.012)	(1.655)	-	(0.595)	(0.015)	(66.873)	(70.034)
Roaming	-0.079***	0.067	2.455	-0.080***	-2.166***	0.034***	-3.370***	17.750
	(0.035)	(0.143)	(2.351)	(0.007)	(0.934)	(0.006)	(1.425)	(109.087)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In Appendix B, we also look into the dynamic effects of network sharing using the event study results of Borusyak et al (2021). This serves two purposes. First, we want to understand whether the effects actually materialise in the years after the network sharing took place and were not anticipated in previous years. Confirmation that this was the case provides additional reassurances that the effects observed were actually driven by the network sharing deal and not any confounding factors or existing trends for operators entering the network sharing deal. Secondly, we also want to understand the dynamic nature of the effects and whether the effects are temporary or sustained over time.

The results from the event studies provide further evidence of the robustness of our main set of estimates. For passive sharing, the results for 3G coverage and EBITDA are persistently significant after the agreement and are not anticipated, with hardly any statistically significant effects before the date of the network sharing deal. We find similar results when looking at the impact of active sharing on 4G coverage, download speeds and HHI. This confirms the effects discussed in our main results in relation to 3G and 4G coverage, consumer prices, profit margins and HHI.

Finally, since there is a possibility that an operator's decision to enter into a network sharing agreement is endogenous to the outcomes being considered, we carried out the instrumental variable regression discussed in Section 3. Table 8 shows that the results for active sharing are generally robust to the findings obtained in the baseline, while most of the results for passive sharing are consistent but not statistically significant. However, diagnostics such as the F-statistic suggest that network sharing in other countries may not be a strong instrument for the presence of a network sharing deal, therefore these results should be treated with some caution.

Table 8: Instrumental variable results for all types of sharing

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	3G coverage (%)	4G coverage (%)	Speed DL (MBps)	log of traffic (GBs)	ARPU (Euros)	EBITDA	CAPEX normalized	HHI
Any Sharing	1.654*	2.428**	103.141**	7.528	-8.331	-0.040	-160.434	-503.393
	(0.900)	(1.234)	(45.611)	(5.986)	(11.671)	(0.150)	(134.503)	(348.329)
F-statistic	3.379	3.868	5.113	1.582	0.510	0.0714	1.423	2.088
Passive	3.444	2.544*	123.850*	36.477	-31.034	-0.394	-149.147	-1,149.228
	(2.424)	(1.474)	(63.672)	(44.003)	(21.618)	(0.357)	(205.840)	(859.184)
F-statistic	2.018	2.980	3.783	0.687	2.061	1.217	0.525	1.789
Active	1.145***	1.622***	88.112***	6.625*	-5.610	-0.021	-194.597	-646.914*
	(0.385)	(0.477)	(32.601)	(3.648)	(7.785)	(0.166)	(161.574)	(357.164)
F-statistic	8.858	11.55	7.305	3.298	0.519	0.0156	1.451	3.281
Roaming	1.849**	6.757	172.381*	9.336	12.482	-0.343	145.409	-693.508
	(0.926)	(6.575)	(91.939)	(6.356)	(17.070)	(0.447)	(247.284)	(609.921)
F-statistic	3.990	1.056	3.515	2.157	0.535	0.588	0.346	1.293

Standard errors in parentheses

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

Notes: Passive sharing instrumented with the share of passive agreements across all operators, Active sharing instrumented with the share of active agreements across all operators and Roaming sharing instrumented with the share of roaming agreements across all operators. All results are within a period between 5 years before the agreement and 2 years after, excluding all other sharing agreements during that time

Lastly, we test for the causality of the treatment by randomizing network sharing agreements and plotting the density plots of the β for each type of sharing to compare the magnitude of the effects. These are presented in Appendix C. Again, most of the results are generally consistent with those obtained in our main specification, with significant differences from the randomly allocated β for passive sharing on 3G coverage, EBITDA and capex (though not ARPU) and of active sharing on 4G coverage, download speeds and HHI.

4.3 Towerco results

With regard to tower sharing agreements, we present the results from the empirical analysis separately in this section. This is because we do not have access to data on the number of deals between mobile operators and Towerco companies, which is the data we would need to carry out the same analysis for towercos in line with other forms of network sharing.

Instead, our towerco dataset only identifies when operators sell some (or all) of their towers to a third party entity. This makes it difficult to interpret the findings, as the metric provides an indication for when tower companies increased their prevalence in a country, but does not allow us to identify where and when an individual operator leases towers from such entities. The results in this section are therefore presented for transparency but are indicative only and need to be read carefully and with significant caution.

Table 9 shows the results of our baseline specification for Towercos on each of the market, as well as the results when restricting the control group to countries without sharing to five years before and three years after sharing took place. The only results that are consistent and statistically significant are that Towerco agreements reduced ARPUs and 3G coverage. When looking at the estimators developed by Borusyak et al (2021) and Callaway and Sant'Anna (2020), these results hold, and they also suggest that Towerco agreements reduced capex and HHI, as well as increasing speeds. This suggests that Towercos may have had a similar impact to passive sharing in terms of reducing costs and lowering prices for consumers, and possibly enhancing speeds.

The negative coefficient on 3G coverage is likely to reflect the timing of these agreements. In Europe, all the Towercos in our data have been established since 2012 and the majority since 2015 (see Figure 2), when 3G networks had been mostly rolled out. Therefore, any effect of Towercos is likely to be based on a limited sample of operators that were still rolling out 3G in this period, or otherwise they may reflect more recent developments in the market where operators that lease towers are beginning the process of shutting down their 3G networks to focus network resources on 4G and 5G. However, given the overall limitations with this metric, we do not place significant weight on these findings. Further research is therefore needed before reliable conclusions can be drawn on the effects of towercos.

Table 9: Toweco results with income and rural controls

VARIABLES	(1) 3G coverage (%)	(2) 4G coverage (%)	(3) Speed DL (MBps)	(4) log of traffic (GBs)	(5) ARPU (Euros)	(6) EBITDA	(7) CAPEX normalized	(8) HHI
Baseline with income and rural controls								
TowerCo	-0.069***	-0.046	1.088	0.076	-3.371***	0.032	13.467	-25.752
	(0.020)	(0.031)	(1.166)	(0.168)	(0.815)	(0.020)	(13.974)	(28.764)
Baseline with alternative time windows								
TowerCo	-0.041***	0.031*	1.075	-0.080	-2.701***	0.023	7.190	-31.652*
	(0.013)	(0.019)	(0.662)	(0.086)	(0.440)	(0.038)	(8.109)	(17.834)
Borusyak et al. (2021)								
Towerco	-0.016**	-0.112***	1.109**	-0.038	-3.331***	-0.001	-13.474***	-117.854***
	(0.007)	(0.012)	(0.532)	(0.054)	(0.598)	(0.014)	(4.733)	(28.932)
Callaway and Sant'Anna (2020)								
Towerco	-0.012	-0.044***	2.043**	0.368**	-1.079***	0.034***	-14.761***	-117.122
	(0.002)	(0.001)	(1.032)	(0.001)	(0.543)	(0.001)	(0.001)	(116.373)
IV results								
TowerCo	0.571	1.159	47.578***	3.967	-4.744	-0.248	-51.414	-415.674
	(0.490)	(0.742)	(16.201)	(2.970)	(12.542)	(0.229)	(104.000)	(279.290)
F-statistic	1.358	2.440	8.624	1.784	0.143	1.178	0.244	2.215

Standard errors in parentheses

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

Notes: TowerCos instrumented the share of TowerCo agreements across all operators. All results are within a period between 5 years before the agreement and 2 years after, excluding all other sharing agreements during that time.

5 Concluding remarks

This paper provides new evidence on the impacts of network sharing on both mobile operators and consumers, offering empirical validation of theoretical models that suggest network sharing can increase competition and consumer welfare. The results show that European operators that entered into network sharing agreements were able to reduce prices (proxied by ARPUs) and increase network coverage and quality. This was driven by capex reductions, higher returns on investment - providing operators with both the ability and incentive to invest - and increased competition. Smaller operators tended to benefit the most in terms of cost savings that allowed them to reduce prices and improve and expand their networks.

When looking at the impact of different types of sharing, we find that capex savings, profit margin improvements, 3G coverage improvements and price reductions were particularly associated with passive sharing. Meanwhile, the positive effects of network sharing on 4G coverage and download speeds were mostly driven by active sharing, which became more prevalent when operators rolled out 4G networks after 2010. These results are robust to several identification strategies, including new Difference-in-Difference estimators that address the biases that can exist in traditional two-way fixed effects estimators.

The study also has important implications for the 5G era, as operators are expected to incur higher deployment costs than previous technologies, partly due to the need for more sites and spectrum. Given these comprise the largest portion of infrastructure cost, the sharing of networks is likely to take on even more importance to deliver the high performance requirements of 5G while at the same time handling the increased traffic demand from consumers. The results from this study provide compelling evidence that network sharing has an important role to play in enabling the competitive provision of widespread 5G networks.

In light of this, there are two particular policy considerations that arise from this study. First, the experience from the 3G and 4G era shows that network sharing is a viable option to extend coverage and competition simultaneously, while reducing the costs involved in infrastructure duplication. This should be considered by regulators and competition authorities that are reviewing new and deeper forms of infrastructure sharing during the 5G era. Second, it is important to note that almost all infrastructure sharing in Europe has thus far been voluntary and commercially led, with a wide range of network sharing agreements that have continually evolved over time. This suggests that sharing on this basis, provides measurable benefits that do not deter investment incentives.

Nevertheless, although this study has addressed a number of evidence gaps around the economic impacts of mobile network sharing, there remain a number of areas requiring further research. First, the impact of TowerCos requires further exploration, especially given their increasing incidence in recent years. This will require more detailed data on the nature and usage of TowerCos by operators in each market, as well as new data to assess the impact of very recent agreements. Second, the impact of network sharing on consumer prices would benefit from better and more comprehensive data on mobile pricing, as this study relied on ARPU inputs which deviate from actual prices per normalized unit (voice or data). Last, the scope of this study has been limited to assessing network sharing as a 'binary' treatment at the country-level. In practice, the incidence and intensity of network sharing can vary significantly within countries depending on geography and the specifics of each agreement. If more granular data can be gathered at a sub-national level, this would enable a more detailed understanding of the impacts of network sharing.

Appendices

Appendix A: Sensitivities to baseline approach

Table 10: Network sharing results with country FEs, income and rural controls

VARIABLES	(1) 3G coverage (%)	(2) 4G coverage (%)	(3) Speed DL (MBps)	(4) log of traffic (GBs)	(5) ARPU (Euros)	(6) EBITDA	(7) CAPEX normalized	(8) HHI
Any Sharing	0.015**	0.069***	0.570	0.354***	-0.581*	0.027**	-23.404***	-89.327***
	(0.007)	(0.019)	(0.641)	(0.091)	(0.315)	(0.011)	(8.687)	(15.164)
Passive	0.037***	0.039	0.272	0.354	-1.613***	0.124***	-20.787	-43.171
	(0.012)	(0.044)	(1.517)	(0.297)	(0.565)	(0.023)	(17.281)	(31.809)
Active	-0.009	0.065**	3.915***	0.428***	0.396	-0.003	-11.278	-60.329***
	(0.010)	(0.026)	(0.901)	(0.105)	(0.460)	(0.014)	(11.886)	(20.027)
Roaming	0.027*	0.094***	-2.703***	-0.258	0.444	0.007	-31.757**	-90.128***
	(0.014)	(0.034)	(1.001)	(0.178)	(0.653)	(0.022)	(13.907)	(23.420)
TowerCo	-0.069***	-0.035	1.031	0.079	-3.349***	0.032	13.234	-29.734
	(0.020)	(0.031)	(1.168)	(0.176)	(0.817)	(0.020)	(13.890)	(29.122)

Standard errors in parentheses

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

All results include Operator and Year FEs. The testing period is limited between 5 years before the agreement and 2 years after.

Table 11: Network sharing results with spectrum, income and rural controls

VARIABLES	(1) 3G coverage (%)	(2) 4G coverage (%)	(3) Speed DL (MBps)	(4) log of traffic (GBs)	(5) ARPU (Euros)	(6) EBITDA	(7) CAPEX normalized	(8) HHI
Any Sharing	0.007	0.070***	0.872	-0.009	-0.256	0.027**	-23.740***	-102.251***
	(0.008)	(0.019)	(0.677)	(0.059)	(0.277)	(0.011)	(9.027)	(17.249)
Passive	0.028	0.063	0.719	0.324*	0.260	0.118***	-47.477**	7.369
	(0.024)	(0.045)	(1.636)	(0.180)	(0.663)	(0.023)	(18.490)	(39.387)
Active	-0.010	0.075***	4.692***	0.033	-0.579	-0.003	-21.494*	-55.531**
	(0.011)	(0.027)	(0.967)	(0.075)	(0.378)	(0.014)	(12.770)	(22.676)
Roaming	0.025*	0.079**	-3.057***	-0.454***	1.275***	0.006	-5.251	-111.910***
	(0.013)	(0.034)	(1.061)	(0.113)	(0.437)	(0.022)	(15.632)	(27.162)
TowerCo	-0.012	-0.078*	1.217	0.069	-3.086***	0.030	13.548	-21.884
	(0.017)	(0.044)	(1.159)	(0.107)	(0.462)	(0.020)	(13.984)	(28.506)

Standard errors in parentheses

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

All results include Operator and Year FEs. The testing period is limited between 5 years before the agreement and 2 years after.

Appendix B: Event study figures

Any sharing - 4G

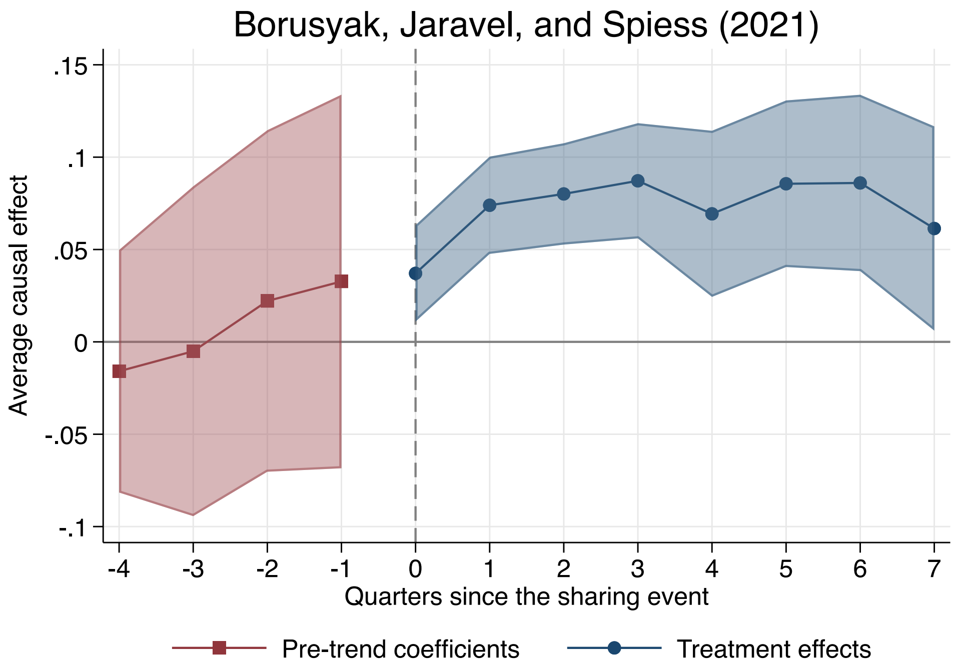


Figure 3: Any sharing 4G

Any sharing - Traffic

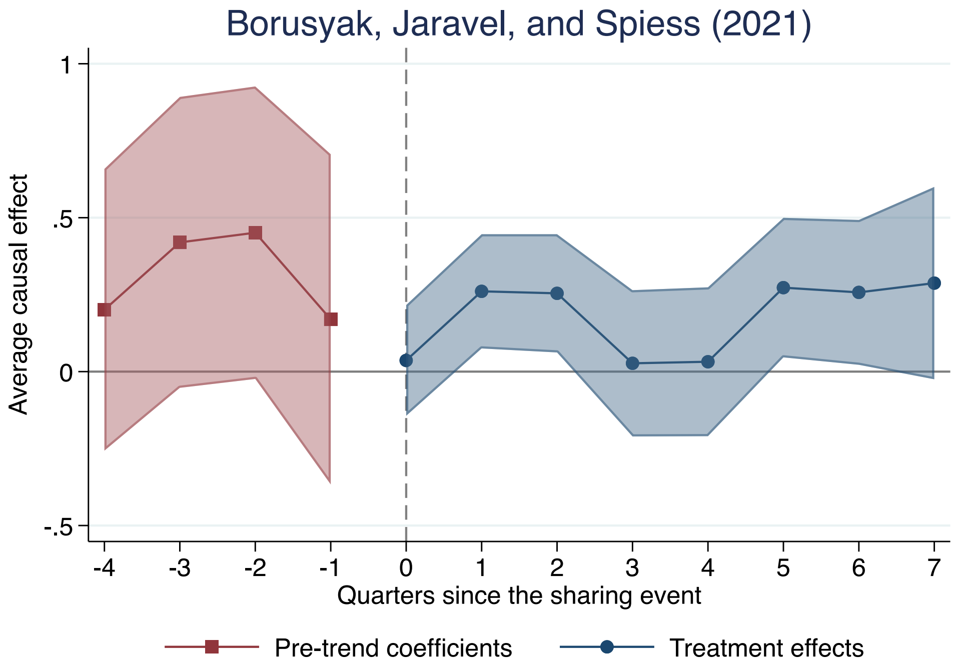


Figure 4: Any sharing Traffic

Any sharing - HHI

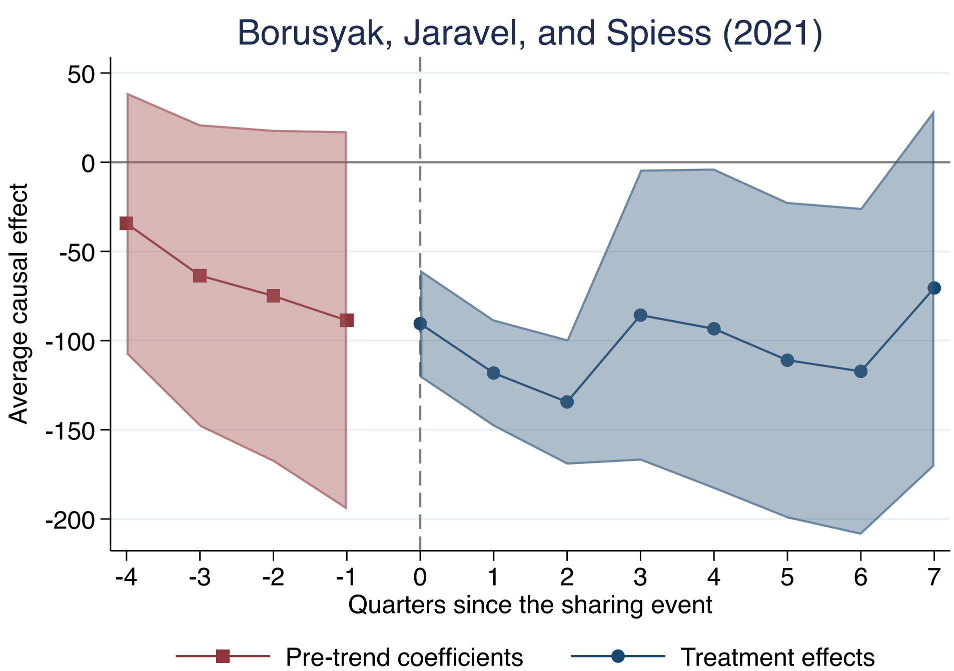


Figure 5: Any sharing HHI

Passive - 3G

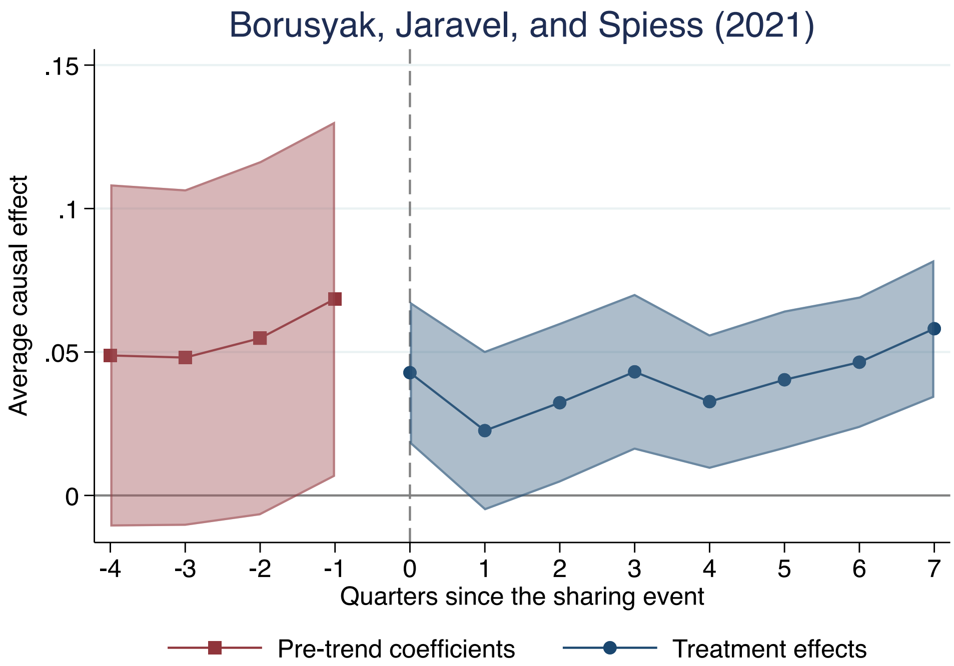


Figure 6: Passive 3G

Passive - EBITDA

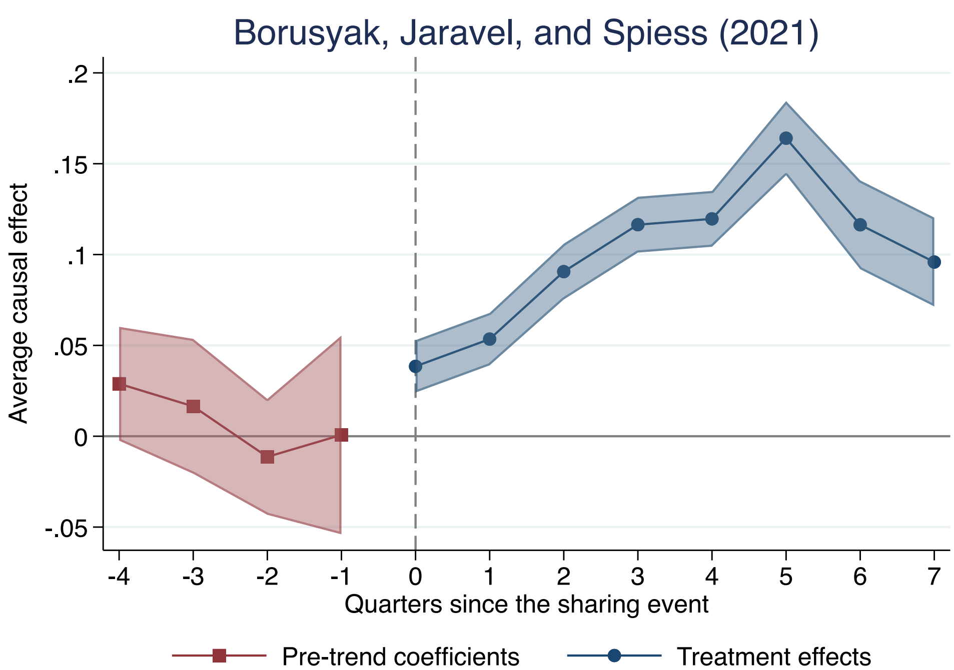


Figure 7: Passive EBITDA

Passive - CAPEX

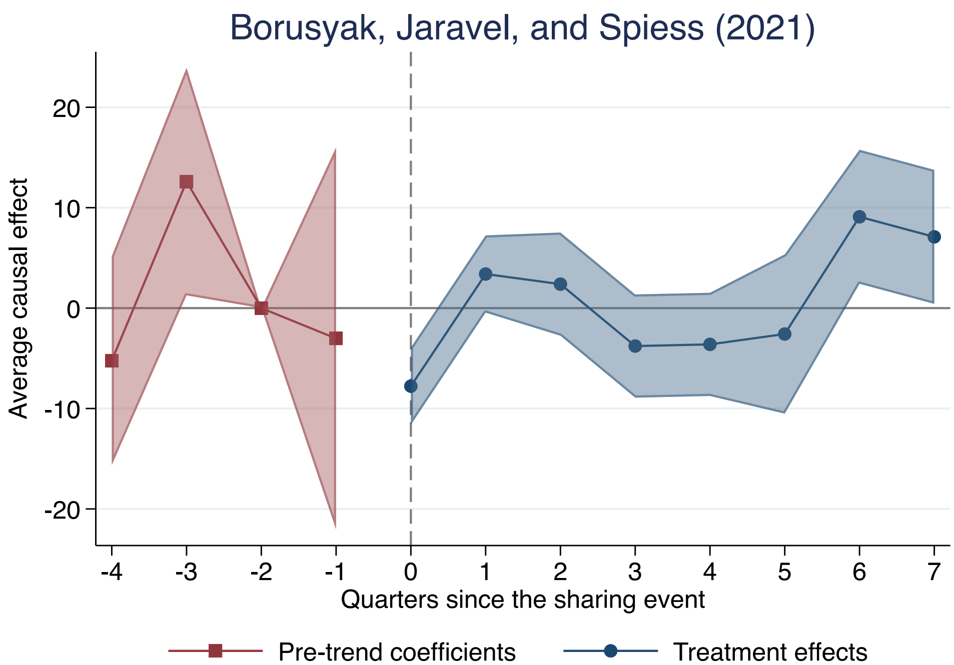


Figure 8: Passive CAPEX

Active - 4G

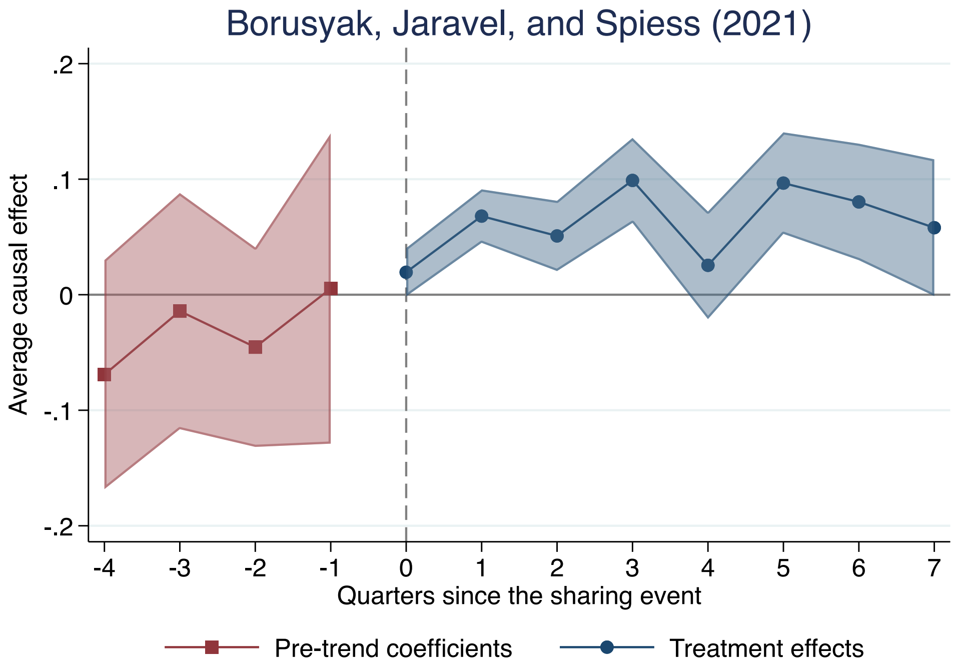


Figure 9: Active 4G

Active - Speed

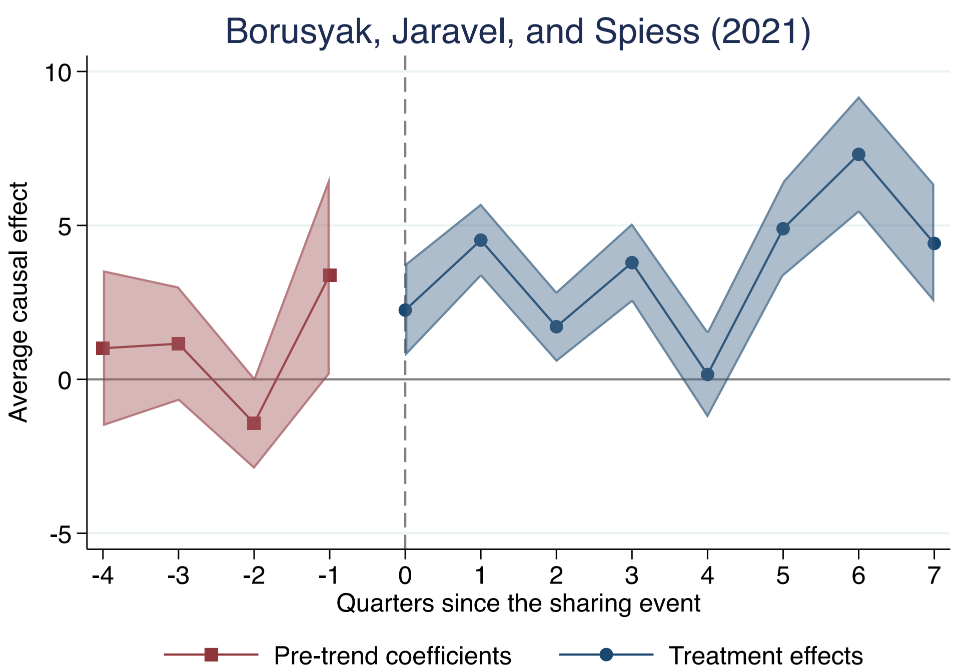


Figure 10: Active Speed

Active - HHI

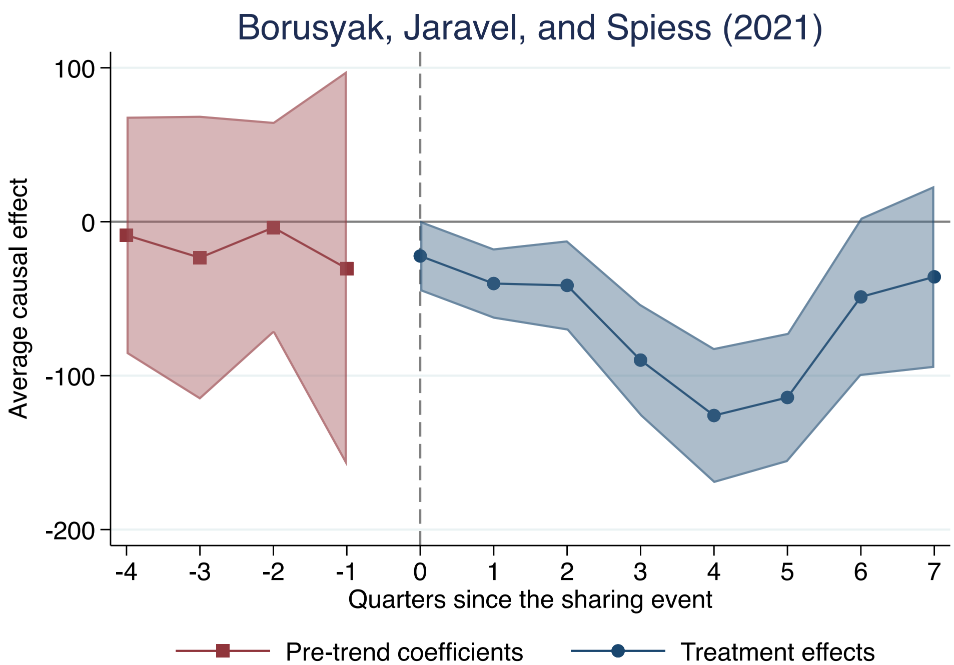
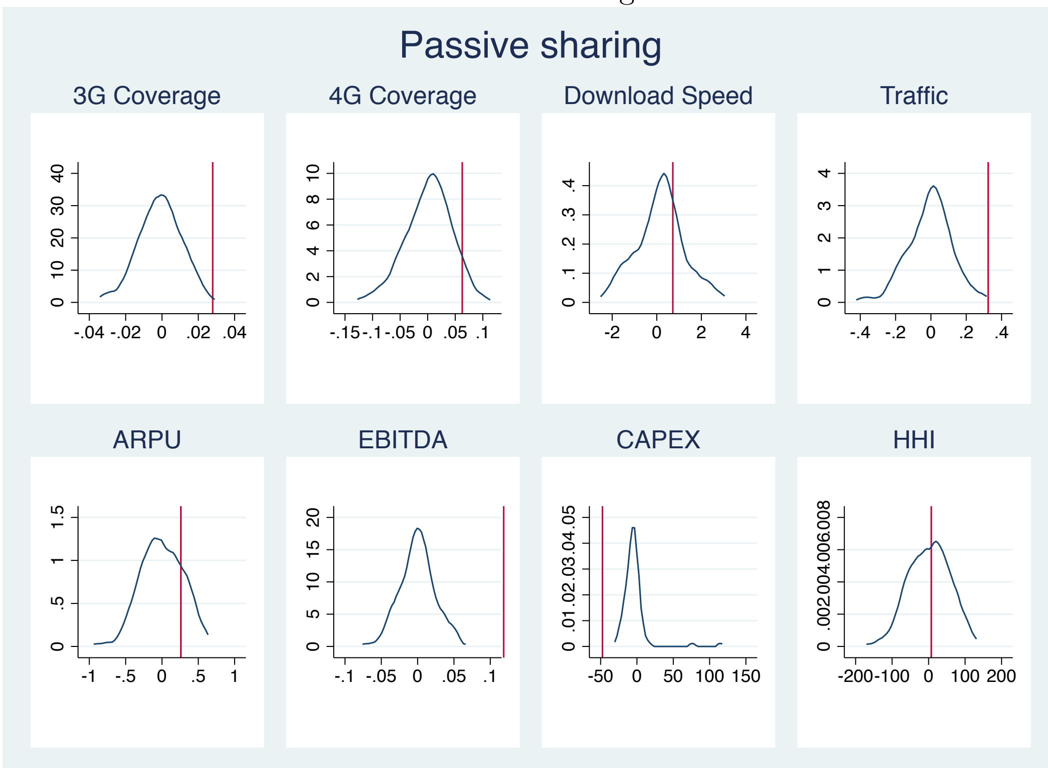


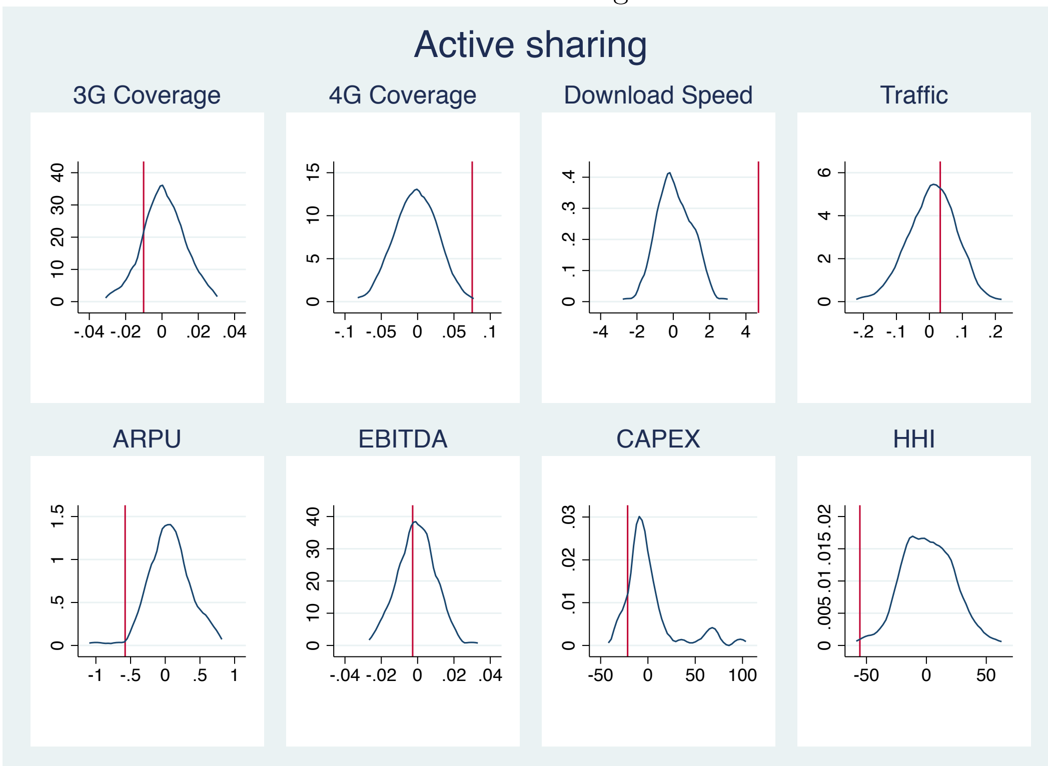
Figure 11: Active HHI

Appendix C: Randomization of the treatment effect

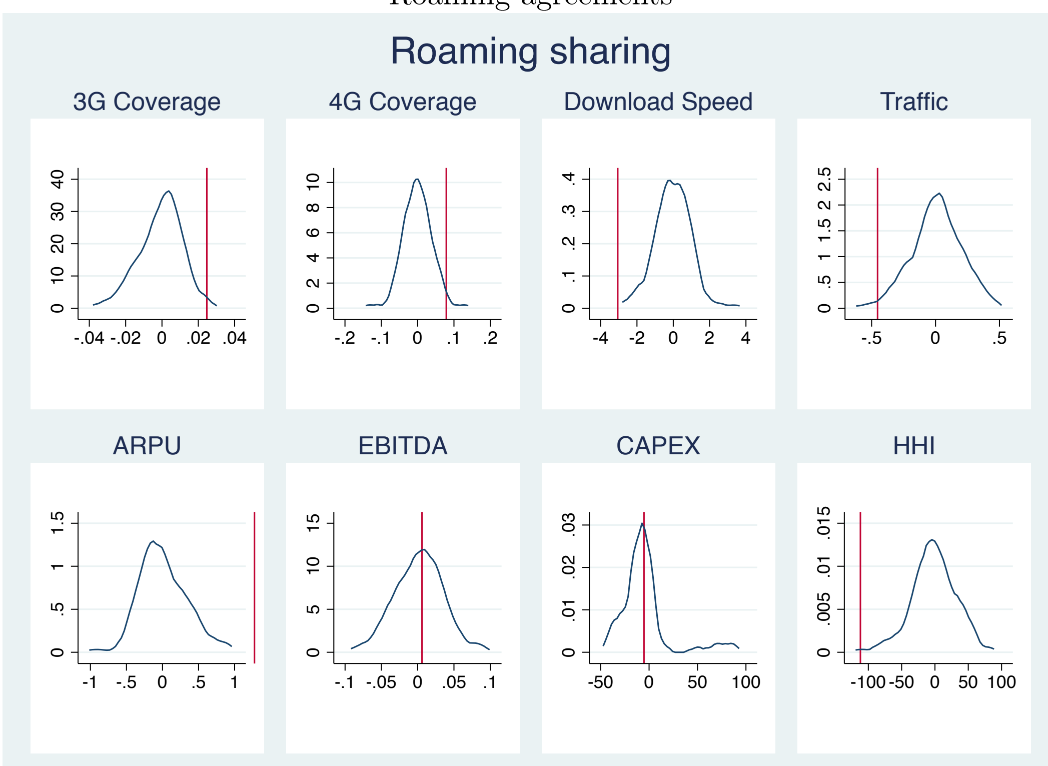
Passive sharing



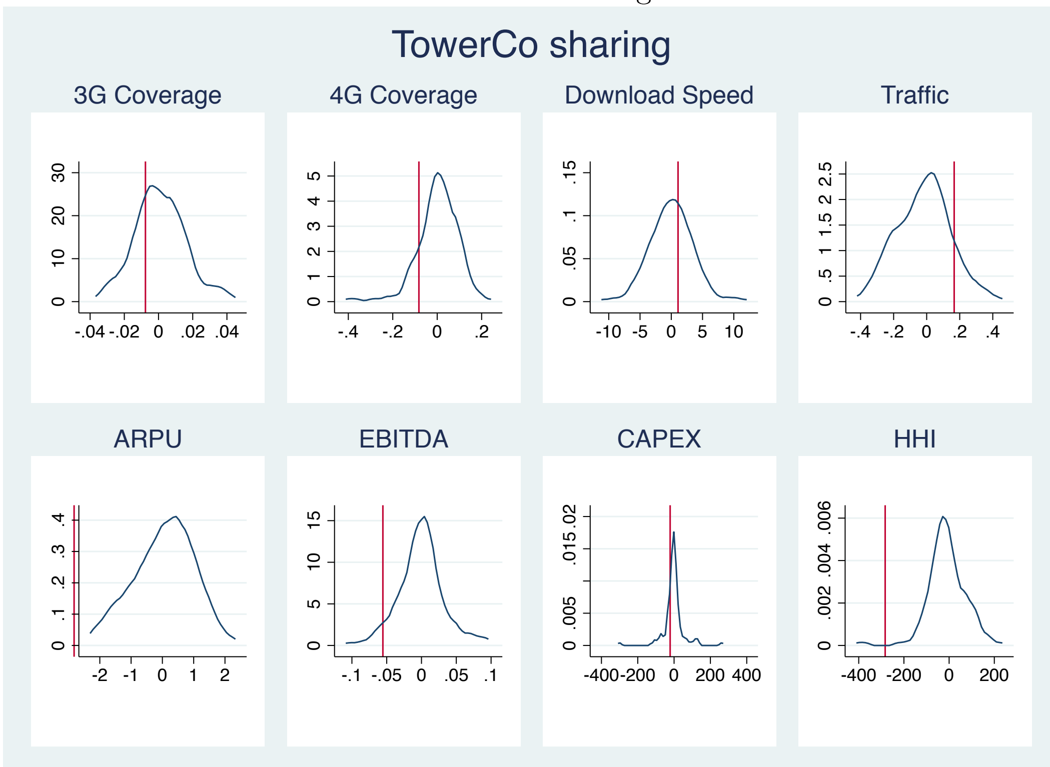
Active sharing



Roaming agreements



TowerCo sharing



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