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Market structure and performance in mobile markets. The example of Europe

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Market structure and performance in mobile markets.

The example of Europe *

June 7, 2023

Abstract

In this paper, we address the issue of the appropriate market structure in European mobile markets by presenting empirical evidence on the effect of the number of MNO on investment. Using a structural entry model based on a country-level dataset of 28 European countries, we find that, in average three player markets invest more at country level and offer more data traffic per subscriber than four or more player markets.

Key Words: *Mobile telecommunications; competition; investment; market structure; consumer welfare*

JEL Classification: D43, L11, L96

*Any opinions expressed here are those of the authors and not those of Orange. All errors are our own.

1 Introduction

The impact of market structure on performance in terms of investment, consumer surplus, welfare and quality (coverage, speed, latency), has been a debated issue since the inception of mobile markets. The number of Mobile Network Operators (MNO) in most of country is currently comprised between 3 and 5, and often between 3 and 4. Do three-player markets provide better market outcomes (investment, download/upload speed, coverage) than four-player markets as claimed by the report GSMA (2020) and Abate *et al.* (2020) or market concentration reduces incentives to invest and quality as claimed by Ofcom (2020).

This paper confirms that although there is no magic number of MNO that best suits in all cases, three player markets provide in average better outcomes than four or more player markets.

Using a 28 European countries data panel, comprising 106 Mobile Network operators (MNO), from 2010 to 2020, we find that three-player markets invest more per subscriber than others. We also find they provide a higher data traffic growth (although a lower voice traffic growth). These results may be explained by the inverted U relationship between competition and incentives to invest. The number of MNOs increases the competitive pressure and three player markets appear in average, closer to the top of the inverted-U curve than four or more player markets. The difference between voice and data traffic is consistent with Aimene *et al.* (2021). The rate of technical progress tends to shift the top of the inverted-U curve to lower degrees of competition. As data experiences a higher rate of technical progress than voice, the top of the curve should be achieved with less MNOs for data than for voice. Indeed, the top of the curve is often exceeded with three MNOs for data but not for voice. The weight of the data being preponderant and always increasing, it turns out that consumer surplus is, on average, higher with three players than with more.

The remainder of this paper is organized as follows. Section 2 presents a literature review, section 3 presents the data set and outlines some characteristics of the mobile markets. Section 4 presents the empirical framework, the econometric models and the estimation strategy. Section 5 provides the results for investment, section 6 provides a robustness check, section 7 extends these results to data traffic and section 8 concludes.

2 Literature review

The relationship between market structure, investment, quality and performances in wireless markets involves at least two streams of economic literature. The first stream we present in this paper does not concern specifically mobile industry but deals more generally on the relationship between market structure or competition on innovation and investment. The second is the empirical literature on the relationship between market structure and its consequences specifically on the mobile industry. According to Schumpeter (1942), innovations are more likely to be made by large firms that have financial means and can expect sufficient returns. In this view, competition tends to reduce incentives to invest. On the contrary, Arrow (1962) points out that innovation is more likely to emerge when competition is fierce because firms can expect more profits from their innovation which allows them to escape competition by providing them with temporary monopoly power. Aghion *et al.* (2005) highlight that both effects coexist simultaneously. They are called respectively "Schumpeterian effect" and "escape competition effect". The authors show that for a low degree of competition, the "escape competition effect" dominates and an increase in competition pressure increases the incentives to invest in innovation, while for a large degree of competition, the "Schumpeterian effect" dominates and an increase in competition pressure reduces the incentives to innovate. The combination on those two effects lead to an inverted-U relationship between competition and innovation. The theoretical framework is detailed in Aghion *et al.* (2014). An inverted U relationship assumes that there is a level of competition that maximizes investment in innovation. Jeanjean (2021) shows that this level of competition that maximizes investment decreases with the potential technical progress. Hounghonon & Jeanjean (2016), estimated that investment in the wireless industry is maximized for a degree of competition that corresponds to a gross margin rate of around 38%.

Another way to deal with relationship between market structure and investment is the study of the impact of mergers on investment. Motta & Tarantino (2021) studied cost reducing innovation and found that absent spillover or efficiency gains, mergers lower investment. However, Bourreau *et al.* (2018) show that this result is not general and is valid only with certain classes of model (Models with hedonic prices, CES, quality adjusted prices) but not in all cases. as a

result, Jullien & Lefouili (2018) conclude that the overall impact of a merger on innovation may be either positive or negative.

The second stream of literature presented here refers to empirical literature on the impact of market structure or mergers on investment and market outcomes in mobile industry. Two reports economics (2015) and consult (2015) in 2015 have investigated the relationship between concentration and investment in wireless markets. They found no significant evidence of a link between concentration (Herfindahl index or number of MNOs) and investment. Hounghonon & Jeanjean (2016) highlighted this inverted-U relationship between competition (measured by the Lerner index) and investment (log of Capex). Genakos *et al.* (2018) found a positive impact on operator investment and no significant impact on industry investment in most (but not all) specifications. Interestingly, the authors noted an increase in the impact and a higher significance when the panel is restricted to the most recent years (2006-2014) suggesting that the impact could be increasing over time. This could explain the lack of significant results in the oldest reports. Jeanjean & Hounghonon (2017) with a more recent panel (2006-2015) found a negative impact of the number of MNOs on operator investment and a positive impact on industry investment in the short run but eventually a negative one in the long run. The authors also highlighted the positive impact of asymmetry among operators on investment. Finally, a GSMA report GSMA (2020) also found a positive relationship between the lerner index and investment at the operator level as well as between the lerner index and quality (download speed, coverage). Aimene *et al.* (2021) found that recent 4-3 mergers in Europe tended to increase the price per voice minute and decrease the price per gigabyte of data. They explain this difference by the higher rate of technical progress for data than for voice, which means that data optimizes investment in more concentrated markets than voice. As the weight of data in revenues continues to increase, market concentration tends to increasingly benefit investments. Finally, the Ofcom report mentioned above Ofcom (2020), finds a negative impact of concentration on investment and quality. However, those results should be considered with caution as some control variables used, like technological cycle or spectrum holding may be endogenous.

3 Data

This section presents the datasets used in our empirical analysis and provides some summary statistical observations that illustrate the differences in investment and traffic growth based on the number of MNOs.

3.1 Dataset description

Our analysis draws on country-level datasets for 28 European countries¹. Our data is an unbalanced panel over 47 quarters from 2010Q1 to 2021Q3. In total, 1316 observations have been collected from 28 European countries.

Table 1: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	source
nbMNO	1316	3.55	0.60	3	5	Analysis Mason
HHI	1316	3398	453	2327	4907	Analysys Mason
CAPEX (M€)	1308	211.75	291.95	2.913	2666.59	WCIS
GDPpcap_ppp (k€/cap)	1232	34.68	15.54	2.14	94.84	World bank
country area (km ²)	1316	190832	173862	20273	603628	World bank
population (Million)	1316	20.04	22.74	1.29	80.69	World bank
subscribers (Million)	1308	25.77	29.57	1.58	118.70	Analysys Mason
connections (Million)	1316	27.47	31.48	1.61	148.39	WCIS
MVNO share	1316	.063	.070	0	0.30	Analysis Mason
4G launch	1316	0.807	0.394	0	1	GSMA
5G launch	1316	0.124	0.330	0	1	GSMA
opex (M€)	1029	822.31	1071.14	39.28	4349.19	WCIS
Data traffic (TByte)	1316	170.41	349.46	0.3	3454.5	Analysys Mason
Voice traffic (minute)	1316	1.17 e+10	1.32 e+10	7.61 e+8	5.99 e+10	Analysys MASON
Data revenue (M€)	1316	537.04	737.86	10.77	3211.89	Analysys Mason

Table 1 reports the descriptive statistics for the variables used in the estimation. The number of MNOs, the Herfindhal Index, the number of subscribers, the MVNO share of subscriptions, the data traffic, the voice traffic and the data revenues are derived from Analysis Mason’s ”Telecom Market Matrix”. WCIS provides the quarterly capex and opex and the number of connections

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

which is different from the number of subscribers². The GDP(PPP) per capita, the population and the country area come from the World Bank. The GDP per capita is calculated by dividing the country-level GDP(PPP) by the population³. The GSMA provides the date of 4G and 5G launch in each country. The presence of 4G and 5G are 1 if the technology is launched by at least one operator in the country and 0 otherwise.

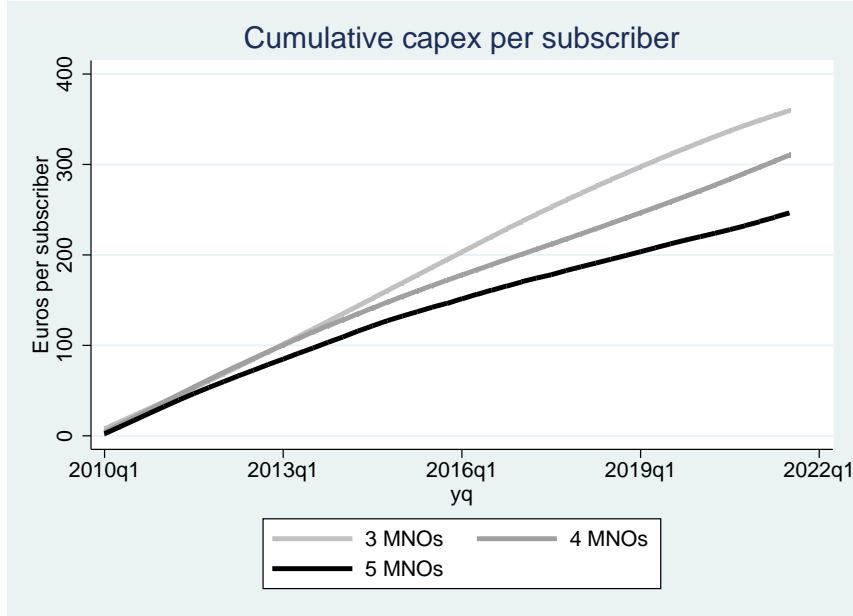
3.2 Observations

The average capex per subscriber in Table 1 is 8.44 €/month/sub. However, this figure hides significant differences based on the number of MNOs. Average Capex per subscriber is 8.86 €/month/sub with 3 MNOs, 8.06 €/month/sub with 4 MNOs and 7.63€/month/sub with 5 MNOs. This shows a decrease in the investment per user according to the number of MNOs in the market. Moreover, if we consider the cumulative investment, the gap increases over time. Moreover, if we consider the cumulative investment, the gap increases over time. The figure below (Figure.1) shows the evolution in average cumulative investment over time based on the number of MNOs.

²The definition from WCIS is: These refer to the total number of active cellular subscriptions used through a handset, a portable device (dongles, tablets, personal hotspots such as MiFi, and other PC-centric devices such as notebooks), or a cellular-capable IoT device. Omdia tracks active subscriptions which corresponds to the total number of active connections in regular use on a network. This may differ from registered subscriptions sometimes reported by operators.

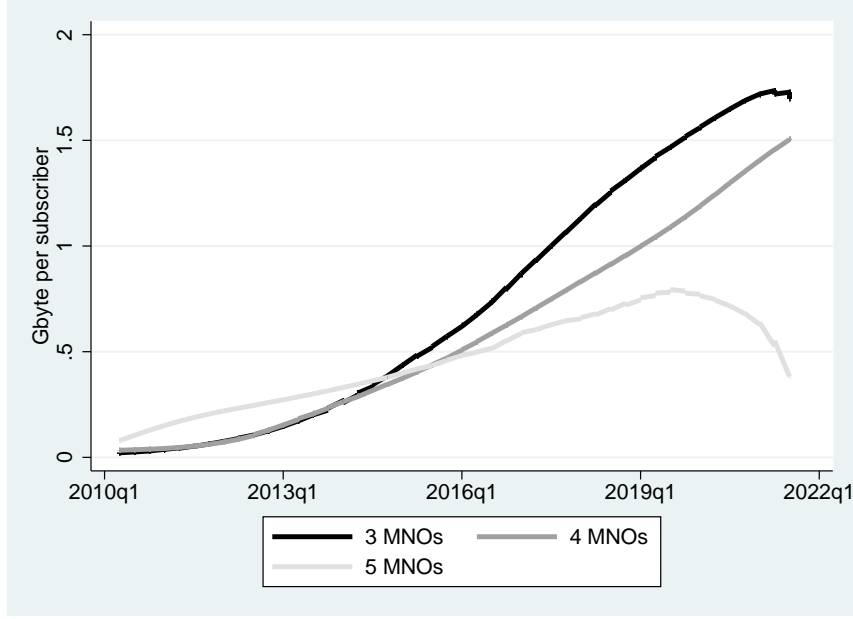
³GDP comparisons using PPP are arguably more useful than those using nominal GDP when assessing a nation's domestic market because PPP takes into account the relative cost of local goods, services and inflation rates of the country, rather than using international market exchange rates, which may distort the real differences in per capita income.

Figure 1: Cumulative Investment (Lowess smoothing)



Such differences in investment paths should translate into differences in traffic growth. Indeed, we observe that average data traffic growth decreases with the number of MNOs (Figure.2). This is not necessarily the case for voice traffic. The reason of the difference between voice and data is due to the difference in the technological advance which is higher for data than for voice. As mentioned by Hounghonon & Jeanjean (2016), there is an inverted U relationship between competition and investment in wireless markets and as explained in Aimene *et al.* (2021) technical progress increases competitive pressure, as a result the number of MNOs that maximizes investment is lower for data than for voice. Given the ever-increasing dominance of data revenue over voice revenue, the market is currently data driven and therefore the number of MNOs that maximize investment for data is most likely the one that also maximizes investment for the entire market. We provide in the appendices, the corresponding graph for voice traffic and also for data traffic considering voice digitized as data which turns out to be very similar to the graph with only data traffic as the share of voice in data transmission is low and ever decreasing.

Figure 2: Data traffic growth per quarter (Lowess smoothing)



These observations suggest that, on average, 3 players markets invest more than 4 or more players markets and that this translates into lower prices ⁴ and more dynamic traffic growth. However, is the impact of the number of MNO on investment causal, or is it possible that it is due to something else? The following of the paper shows that the relation is indeed causal.

4 Structural model

This paper primarily aims to examine the extent to which the investment is causally affected by the number of mobile operator in an European country. To estimate the effect of the number of mobile operator on investment, we borrowed the model used by Manuszak & Moul (2008) and specify the following reduced form econometric model:

$$CAPEX_{it} = \lambda X_{it} + g(N_{it}; \gamma) + u_{it} \quad (1)$$

where $CAPEX_{it}$ is the investment in quarter t in country i , X_{it} a vector of country-level

⁴price of Gbyte. The price of Gbyte $p_u = \text{Revenue}/\text{datatraffic}$. Since revenues are roughly steady an increase in traffic corresponds to a decrease in Gbyte price

socio-demographic characteristics, including the GDP and population density. The function $g(N_{it}; \gamma)$ captures the effect of the number of mobile operators with N_{it} characterizing the market structure and γ reflecting the incremental effects of additional mobile operator. u_{it} reflects unobserved factors that impact CAPEX.

In this simple regression however, we face the issue of a potential correlation between N_{it} and u_{it} . Indeed, contrary to one of the necessary conditions for correct inference, market structures are not randomly assigned. Instead, mobile operators base their entry decision on demand and cost factors as well as the anticipated entry and investment behavior of their competitors. All mobile operators have more incentives to invest in countries. The unobserved factors impact both CAPEX and market structure which may yield inconsistent estimation of the relationship between those two variables by inconsistent estimates of γ and λ . We could have solved this issue by using an instrumental variable, but a good instrument remains difficult to find in this case. Then we use an alternative model that describes observed mobile operator entry. We use this latter to generate correction term for the regression of the investment to account for potential correlation between the error term and N_{it} .

Following Bresnahan & Reiss (1991), we introduce a latent profit function as

$$\Pi_{it}(Z_{it}, N_{it}, e_{it}; \theta) = \Pi_{it}(Z_{it}, N_{it}; \theta) + e_{it} \quad (2)$$

where Z_{it} is a vector of country-level characteristics that impact profitability in country i at time t , e_{it} are unobserved factors, and θ are unknown parameters of profit function Π_{it} . According to Manuszak & Moul (2008), the latent profit function Π_{it} should be interpreted as the reduced form of the expected present discounted value of profits resulting from competition between firms, once all entered in the market. We assume that profits are decreasing in N_{it} . In a Nash equilibrium, mobile operators enter the market until no additional operators would be profitable. The market structure is characterized by the following restrictions on latent profits:

$$N_{it} = 0 \Leftrightarrow \Pi_i(Z_i, N_{it} = \mathbf{1}; \theta) + e_i < 0$$

$$N_{it} = 1 \Leftrightarrow \Pi_i(Z_i, N_{it} = \mathbf{1}; \theta) + e_i > 0, \Pi_i(Z_i, N_{it} = \mathbf{2}; \theta) + e_i < 0$$

$$N_{it} = 2 \Leftrightarrow \Pi_i(Z_i, N_{it} = \mathbf{2}; \theta) + e_i > 0$$

Following Bresnahan & Reiss (1991), we can estimate the parameter θ by maximum likelihood. Moreover, we impose distributional restrictions on the two error terms, by assuming that, conditional on X_i and Z_i

$$\begin{pmatrix} u_i \\ e_i \end{pmatrix} \sim N \left(\begin{pmatrix} \mu \\ \Sigma \end{pmatrix} \right) \quad (3)$$

with

$$\mu = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (4)$$

and

$$\Sigma = \begin{pmatrix} \sigma_u^2 & \sigma_{ue} \\ \sigma_{ue} & 1 \end{pmatrix} \quad (5)$$

From the distribution assumptions, it follows that

$$E[CAPEX_{it}|X_{it}, Z_{it}, N_{it}] = \lambda X_{it} + g(N_{it}; \gamma) + \sigma_{ue} h(N_{it}, Z_{it}; \theta) \quad (6)$$

where

$$h(N, Z_{it}; \theta) = \begin{cases} \frac{\phi[\pi(N, Z_{it}; \theta)] - \phi[\pi(N+1, Z_{it}; \theta)]}{\Phi[\pi(N, Z_{it}; \theta)] - \Phi[\pi(N+1, Z_{it}; \theta)]} & \text{for } 0 < N < N^{max} \\ \frac{\phi[\pi(N^{max}, Z_{it}; \theta)]}{\Phi[\pi(N^{max}, Z_{it}; \theta)]} & \text{for } N = N^{max} \end{cases} \quad (7)$$

with $\phi(\cdot)$ and $\Phi(\cdot)$ representing the pdf and cdf of the standard normal distribution. The term $\sigma_{ue}h(N_{it}, Z_{it}; \theta)$ reflects the potential correlation between u_{it} and N_{it} by including the possibility that $E[u_{it}|N_{it}]$ is not equal to zero.

The model is an ordered probit where the outcome variable describes the number of mobile operators present in a country with the latent profit function

$$\Pi_i(Z_i, N_{MNO}, e_i; \theta) = \beta Z_i + \Delta_1 * I(N_{MNO} = 3) + \Delta_2 * I(N_{MNO} = 4) + \nu_t + \varepsilon_i \quad (8)$$

Δ_1 measures the impact of the entry of a third mobile operator. Δ_2 presents the incremental impact of adding one or more mobile operators. $I(\cdot)$ is an indicator equal to one if the expression in parentheses is true. Time fixed effects are controlled by the quarter indicators (ν_t).

The functional form for quarterly CAPEX can be expressed as:

$$CAPEX_i = \lambda X_i + \gamma_1 I(N_{MNO} = 3) + \gamma_2 I(N_{MNO} = 4) + \sigma_{ue}h(N_{MNO}, Z_i; \hat{\theta}) + \varepsilon_i \quad (9)$$

where γ_1 measures the impact of 3 MNO market on CAPEX. γ_2 measures the impact of the additional mobile operator entry. $h(N_{MNO}, Z_i; \hat{\theta})$ is the correction term computed using the first stage maximum likelihood estimates of $\theta = \{\beta, \Delta_1, \Delta_2\}$.

We introduce country fixed effects into equation (9) to account for time-invariant factors. We use two exogenous variables used only in the first stage. The first exogenous variable is the area of the country and the second is the launch of 4G technology which is 0 before the launch and 1 after.

5 Main empirical results

We report the main results of the entry model. First the ordered probit then the regression of Investment. The table below, table (2) provides the ordered probit. The explanatory variables are progressively included. We find that the sign of country area is negative. This is not

surprising because the larger the country, the more expensive the coverage. A potential new entrant may be discouraged by the size of the country, especially if there are high coverage requirements. As expected, the sign of 4G launch is positive because The arrival of 4G tends to improve profitability and promote market entry. Both variables are significant. These variables are used as exogenous variable in the capex regression, both must be significant to be considered as a valid instrument. The country area is fixed for each country and obviously does not depend on the number of MNOs nor unknown variable. The presence of 4G technology mainly depends on the technological advance of equipment manufacturer rather than country or market specific features. Both are thus good candidates as exogenous variable for the entry model.

GDP per capita is negative and significant in all specifications. This means population wealth is associated with a lower number of MNO, probably because the number of MNO tends to reduce ARPU. As expected, the density of population is positive but not significant in all specifications, indeed, density of population tends to reduce cost per capita and thus increases the number of MNOs. The number of subscribers tends to decrease the number of MNOs, indeed, for a given population, the number of subscribers represents the penetration rate of the service. This penetration rate reduces market growth prospects and therefore weighs negatively on the number of MNOs. The presence of 5G affects positively but not significantly the number of MNOs. New generations of technology increase the quality of the service which increases demand and tends to impact positively the number of MNOs. The non-significance of 5G is probably due to the still low rate of its deployment in the time of this study. The marketshare of MVNO as well as opex per subscriber are positively and significantly related to the number of MNOs. This is probably due to the positive correlation between GDP per capita and the number of MNOs.

Table 2:

VARIABLES	nbMNO (1)	nbMNO (2)	nbMNO (3)	nbMNO (4)	nbMNO (5)
countryarea	-22.426*** (3.350)	-20.962*** (3.485)	-21.070*** (3.488)	-20.153*** (3.775)	-11.312* (5.834)
GDPpcap_ppp	-0.2703 (0.0319)	-0.3196*** (0.0341)	-0.3160*** (0.0341)	-0.3163*** (0.0342)	-0.3147*** (0.0367)
4G launch	1.976*** (0.269)	1.928*** (0.268)	1.912*** (0.267)	1.918*** (0.267)	1.626*** (0.283)
5G launch		0.0766 (0.3210)	0.0348 (0.3282)	0.0543 (0.3339)	0.1115 (0.4712)
popdensity		0.0982*** (0.0369)	0.0863** (0.0374)	0.0934** (0.0378)	0.0596 (0.0497)
MVNOshare			3.578 (2.702)	3.283 (2.780)	12.322*** (3.442)
connections				-0.0076 (0.0159)	-0.0977*** (0.0202)
opexpsub					0.0503** (0.0220)
country fixed effect	✓	✓	✓	✓	✓
quarter fixed effect	✓	✓	✓	✓	✓
Observations	1232	1232	1232	1232	982
Log pseudolikelihood	-333.78	-329.51	-328.73	-328.65	-269.83
Pseudo R-square	0.6885	0.6925	0.6932	0.6933	0.6945
Robust standard errors in parentheses					
*** p<0.01, ** p<0.05, * p<0.1					

Now, we provide the results for the capex per subscriber using on the one hand, the area of the country and in the other hand, the presence of 4G technology as exogenous variable.

First, the table below, table (3) provides the corresponding result for the Capex per subscriber, the area of the country as exogenous variable used only in the first stage is not reported in the regression.

Table 3:

VARIABLES	capexpsub (1)	capexpsub (2)	capexpsub (3)	capexpsub (4)	capexpsub (5)
nbMNO					
4	-0.0730 (0.7909)	-0.8134 (0.7884)	-0.8637 (0.7841)	-0.9866 (0.7675)	-1.3558* (0.6960)
5	-2.8493 (1.7351)	-3.9624** (1.8246)	-4.0406*** (1.7695)	-4.2333** (1.7176)	-4.7220*** (1.4576)
hasard	0.2100 (0.4373)	0.6096 (0.4457)	0.6391 (0.4410)	0.6944 (0.4374)	0.8224* (0.4285)
GDPpcap_ppp	0.0255 (0.0381)	-0.0220 (0.0395)	-0.0242 (0.0397)	-0.0338 (0.0398)	-0.0248 (0.0430)
4G launch	-0.6250 (0.5994)	-0.4833 (0.6065)	-0.4752 (0.6045)	-0.5480 (0.6034)	-0.4524 (0.5027)
5G launch		0.6912 (0.4476)	0.6878 (0.4435)	0.9510** (0.4448)	0.1849 (0.4409)
popdensity		0.1015** (0.0509)	0.1017** (0.0513)	0.1479*** (0.0549)	0.1945*** (0.0658)
MVNOshare			0.4499 (5.6765)	-1.1480 (5.4943)	-3.2452 (5.6058)
connections				-0.1301*** (0.0378)	-0.1117** (0.0482)
opexpsub					0.0522* (0.0275)
country fixed effect	✓	✓	✓	✓	✓
quarter fixed effect	✓	✓	✓	✓	✓
Observations	1224	1224	1224	1224	982
R-square	0.6656	0.6675	0.6675	0.6709	0.7888
Robust standard errors in parentheses					
*** p<0.01, ** p<0.05, * p<0.1					

Then the table below, table (4) provides the corresponding result for the Capex per subscriber, the presence of 4G technology as exogenous variable used only in the first stage is not reported in the regression.

Table 4:

VARIABLES	capexpsub (1)	capexpsub (2)	capexpsub (3)	capexpsub (4)	capexpsub (5)
nbMNO					
4	-0.6114 (0.7172)	-1.1947* (0.6904)	-1.2350* (0.7001)	-1.4114** (0.6890)	-1.6302** (0.6625)
5	-4.1396** (1.5263)	-4.9372*** (1.5622)	-4.9840*** (1.5466)	-5.3148*** (1.5033)	-5.4441*** (1.3385)
hasard	0.5242 (0.4060)	0.8391** (0.3992)	0.8613** (0.4030)	0.9488** (0.4006)	0.9926** (0.4152)
countryarea	-15.251*** (3.503)	-13.264*** (3.862)	-13.370*** (3.908)	-1.251 (5.582)	4.478 (6.699)
GDPpcap_ppp	0.0062 (0.0416)	-0.0360 (0.0415)	-0.0550 (0.0425)	-0.0535 (0.0427)	-0.0345 (0.0471)
5G launch		0.7086 (0.4427)	0.7040 (0.4385)	0.9680** (0.4406)	0.2057 (0.4411)
popdensity		0.1010** (0.0510)	0.1011** (0.0683)	0.1127 (0.0552)	0.1932*** (0.0656)
MVNOshare			0.5648 (5.7130)	-1.0080 (5.5282)	-3.2816 (5.5946)
connections				-0.1293*** (0.0377)	-0.1126** (0.0489)
opexpsub					0.0537** (0.0272)
country fixed effect	✓	✓	✓	✓	✓
quarter fixed effect	✓	✓	✓	✓	✓
Observations	1224	1224	1224	1224	982
R-square	0.6652	0.6673	0.6673	0.6707	0.7884

Robust standard errors in parentheses

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

We find that in both tables, using the area of the country or the presence of 4G technology as exogenous variable, that the number of MNOs decreases the capex per subscriber. Four players markets invest less by subscriber than 3 players markets (between 1.27€ (table 3) and 1.56€ (table 4) per quarter according to specification (5)) and five players markets even less (more than 5€ per quarter in both cases according to specification (5)). In table (3) estimates for 4 and 5 MNOs are negative in all specifications and significant for 5 MNOs in all specifications except the first and significant for 4 MNOs in specification (5). In table (4) estimates for 4 and 5 MNOs are negative and significant in all specifications except the first for 4 MNOs. The variable hazard, that represents $h(N, Z_{it}; \theta)$ and corrects for errors in ordered probit is significant in specification (5) in table (3) and in all specifications except the first in table (4). That means the correction is efficient. GDP per capita is not significant. The density of the population is positive and significant. Indeed, the density of the population tends to decrease the cost of investment per subscriber, as a result, the higher the density, the higher the investment per subscriber. The number of subscribers, as expected, is negative and significant thanks to economies of scale. The

presence of 4G technology does not seem to significantly modify the investment per subscriber, while the presence of 5G tends to increase it, though weakly significant. The share of MVNO has not a significant impact.

6 Robustness check

We now present, as robustness check, an instrumental variable regression of capex per subscribers using the Herfindahl index rather than the number of subscribers.

Herfindahl index is closely linked to the number of MNOs, however it is a continuous variable unlike the number of MNOs which is a discrete variable. The table below table(5) provides OLS and 2SLS estimates of investment per subscriber. Specifications (1) and (2) are OLS regressions. Specification (1) estimates the impact of HHI on the capex per subscriber and specification (2) estimates the quadratic impact of HHI on capex per subscriber with both the HHI and the squared HHI in the regression. Specification (3) is a 2SLS regression using the presence of 4G technology as instrument. Specification (4) is a 2SLS regression that estimates the quadratic impact of HHI on capex per subscriber. To do this, two instruments are required, we use the presence of 4G technology and the size of the market as instruments. (the area of the country that does not vary over time cannot be used as instrument). The size of the market is defined by the population multiplied by the average penetration rate (subscribers/population) for the 28 countries in each quarter. With this definition, the size of the market in a country is not influenced by the capex per subscriber in this country. The presence of 4G and the size of the market have an impact on investment, however, they are not influenced by investment nor by a missing variable.

Market's concentration measured by the herfindahl index HHI increases significantly the investment per subscriber in all the specifications. The order of magnitude is near 0.01 € per quarter and per subscriber for one point of HHI, column (3). HHI are ranged between 2000 and 5000. To compare with the results of the entry model, one additional MNO decreases the HHI by some few hundred which corresponds to some few euros per quarter and per subscriber. This is consistent with the result of the entry model where, according to table (4), one additional MNO

decreases investment by about 1.5 € per quarter and per subscriber between 3 and 4 MNOs and decreases investment by 3.8 € per quarter and per subscriber (5.3€-1.5€) between 4 and 5 MNOs. Columns 2 and 4 show an inverted U relationship between capex per subscriber and HHI where the maximum lies around 4399 in column (2) and 4107 in column (5). The results for HHI maximum are both significant even if the result for squared HHI is not significant in column (2) (but almost). The result of the column (4) is more consistant as capex may have an impact on HHI and thus requires instrumental variables. HHI=4107 corresponds more to 3 MNO than four or five MNOs. This is consistant with the GSMA report GSMA (2020). The confidence interval can be calculated with the standard error assuming the number of MNOs are normally distributed in function of the HHI. For the column (4), the 95% confidence interval is $HHI \in [3561; 4651]$. 52% of 3 MNOs observations are in the confidence interval versus 11% of 4 MNOs and 9% of 5 MNOs. 47% of 3 MNOs observations are below the confidence interval versus 88% of 4 MNOs and 91% of 5 MNOs.

Furthermore, the average HHI for 3-player markets, 3674 is in the confidence interval, while the average HHI for 4-player or 5 player markets, respectively 3126 and 3051 are both below the confidence interval. Three-player markets are therefore on average closer to the top of the inverted-U curve reached for an HHI of 4107. It is therefore not surprising that an increase in the number of MNOs leading to a decrease in the HHI also leads to a decrease in investments.

Table 5:

VARIABLES	capexpsub (1) OLS	capexpsub (2) OLS	capexpsub (3) IV	capexpsub (4) IV
HHI	0.0015* (0.0008)	0.0080* (0.0047)	0.0093* (0.0048)	0.0969* (0.0545)
HHI ²		-9.13 e-07 (6.43 e-07)		-1.18 e-05* (7.07 e-06)
popdensity	0.1476*** (0.0554)	0.1496*** (0.0555)	0.1796*** (0.0566)	0.2165*** (0.0793)
GDPpcap-ppp	-0.0192 (0.0333)	-0.0225 (0.0334)	-0.1574 (0.1015)	-0.2489* (0.1464)
4G launch	-0.8771 (0.5438)	-0.9010* (0.5414)	Instrument	Instrument
5G launch	0.9067** (0.4498)	0.9260** (0.4533)	0.6908 (0.5206)	0.8631 (0.7072)
MVNOshare	-4.795 (5.799)	-5.313 (5.802)	-19.317** (9.558)	-31.094** (14.150)
market size	-0.1374** (0.0644)	-0.1913** (0.0655)	-0.978** (0.0809)	Instrument
country fixed effect	✓	✓	✓	✓
quarter fixed effect	✓	✓	✓	✓
HHI Maximum		4399*** (684)		4107*** (278)
Observations	1224	1224	1224	1224
R-square	0.6685	0.6692	0.0090	-0.3288
Number of countries	28	28	28	28
First-stage F-statistic			26.391	7.485
F statistic 10% critical value			16.38	7.03

Robust standard errors in parentheses

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

7 Consequences on data traffic

Growth of data traffic is spurred by investment, therefore, the countries that invest more have also higher data traffic. The impact of market structure on investment should also be reflected on data traffic.

In this part, we show that the exponential data traffic growth is driven by investment and then, using the same framework as previous sections, we show that data traffic tends to decrease with the number of firms.

First, we test the hypothesis that the exponential growth of data traffic is driven by investment and follows the relation:

$$T_t = T_{t-1} e^{\alpha \text{Cape}x_t} \quad (10)$$

where T_t is the data traffic at time t .

Taking into account the volatility of the investments and the delays which can vary in time between the investment and its realization in the traffic, we will not test this equation directly but rather test the cumulative effect of the investments at time t on the traffic, following:

$$T_t = T_0 e^{(\alpha \sum Capex_i)} \quad (11)$$

this equation can be rewritten: $\ln T_t = \ln T_0 + \alpha \sum (Capex_t)$

The equation we estimate is:

$$\ln T_{it} = \ln T_{i0} + \alpha_i \sum (Capex_{it}) + \epsilon_{it} \quad (12)$$

Using ordinary least square, we estimate the coefficient α for each country and if the hypothesis is valid, the coefficient of $\ln T_0$ should not be significantly different from 1.

The table below (Table 6) provides the results of the estimation:

Table 6:

VARIABLES $\ln T_t$	coef.	Robust Std.Err	95%	conf. Interval
$\ln T_0$	0.994859***	0.0094985	0.9762248	1.013493
α				
Austria	0.0010226***	0.0000171	0.0009891	0.0010562
Belgium	0.00091***	0.0000146	0.0008813	0.0009386
Bulgaria	0.0035829***	0.0000391	0.0035063	0.0036595
Croatia	0.0048911***	0.0000753	0.0047434	0.0050388
Czechia	0.0015909***	0.0000292	0.0015337	0.0016482
Denmark	0.0017665***	0.0000297	0.0017083	0.0018247
Estonia	0.012922***	0.0001807	0.0125675	0.0132766
Finland	0.0015391***	0.0000379	0.0014648	0.0016134
France	0.0001321***	1.61e-06	0.000129	0.0001353
Germany	0.0001268***	1.17e-06	0.0001245	0.0001291
Greece	0.0010611***	0.0000328	0.0009968	0.0011254
Hungary	0.0013435***	0.0000186	0.001307	0.0013799
Ireland	0.0014413***	8.08e-06	0.0014255	0.0014572
Italy	0.0001399***	1.79e-06	0.0001364	0.0001434
Latvia	0.0208768***	0.0003823	0.0201269	0.0216267
Lithuania	0.0118619***	0.0001534	0.0115609	0.0121629
Netherlands	0.0005545***	3.04e-06	0.0005485	0.0005605
Norway	0.0008969***	0.0000184	0.0008608	0.0009331
Poland	0.000831***	0.000018	0.0007956	0.0008664
Portugal	0.000423***	0.0000135	0.0003965	0.0004494
Portugal	0.000423***	0.0000135	0.0003965	0.0004494
Romania	0.0012916***	0.0000156	0.001261	0.0013222
Slovakia	0.001517***	7.46e-06	0.0015024	0.0015316
Slovenia	0.0038629***	0.0000828	0.0037006	0.0040253
Spain	0.0002013***	2.20e-06	0.000197	0.0002057
Sweden	0.0007695***	0.0000152	0.0007397	0.0007993
Switzerland	0.000543***	9.50e-06	0.0005244	0.0005617
UK	0.0001403***	2.47e-06	0.0001355	0.0001451
Ukraine	0.0010009***	0.0000261	0.0009496	0.0010521
Observations		1316		
R-square		0.9941		

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

The coefficient of $\ln T_0$ is not significantly different from unity and the coefficient α is very significant for all countries, which lends support the hypothesis of an exponential growth in data traffic driven by the investment.

This means that the number of MNOs should reduce the data traffic per subscriber since it reduces investment per subscriber. We reuse the model of the previous section to test the impact of the number of MNOs on data traffic per subscriber and on average megabyte prices. The average megabyte price is obtained by dividing the revenues of data by the data traffic. The table below shows that the number of MNOs actually reduces data traffic. The two first columns presents the results for data traffic and the two last, the results for data prices. The data price is calculated by dividing the data revenues by the data traffic. The first and the third columns use the country area as exogenous variable and the second and the fourth columns, the

presence of 4G technology.

Table 7:

VARIABLES	lnadatatrafficpsub (1)	lnadatatrafficpsub (2)	lnpudata (3)	lnpudata (4)
nbMNO				
4	-0.6681*** (0.0793)	-0.5688*** (0.0782)	0.6615*** (0.0806)	0.5859*** (0.0745)
5	-0.9416*** (0.1357)	-0.6801*** (0.1166)	0.9987*** (0.1389)	0.7999*** (0.1174)
countryarea		1.4079** (0.6377)		-4.2079*** (0.6108)
hasard	0.3886*** (0.0459)	0.3095*** (0.0398)	-0.3317*** (0.0415)	-0.2848*** (0.0380)
GDPpcap_ppp	-0.0098*** (0.0035)	-0.0063* (0.0034)	0.0126*** (0.0038)	0.0099*** (0.0036)
4G launch	0.1638*** (0.0454)		-0.1246*** (0.0420)	
5G launch	0.0838 (0.0656)	0.0763 (0.0670)	-0.1492** (0.0639)	-0.1435** (0.0644)
popdensity	0.0233*** (0.0062)	0.0238*** (0.0064)	-0.0239*** (0.0058)	-0.0242*** (0.0059)
MVNOshare	2.177*** (0.548)	2.191*** (0.557)	-3.461*** (0.538)	-3.471*** (0.546)
connections	-0.0399*** (0.0036)	-0.0328*** (0.0036)	0.0164*** (0.0034)	0.0162*** (0.0034)
opexpsub	0.0270*** (0.0031)	0.0265*** (0.0030)	-0.0114*** (0.0032)	-0.0110*** (0.0031)
country fixed effect	✓	✓	✓	✓
quarter fixed effect	✓	✓	✓	✓
Observations	982	982	982	982
R-square	0.9731	0.9727	0.9681	0.9678
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

As expected, the number of MNOs tends to reduce the average price of megabyte and thus, to increase the data traffic consumed per subscriber. The number of MNOs spurs investment which accelerates deployment of next-generation equipment and therefore drives lower data costs and boosts data consumption.

8 Conclusion and policy implications

We address the issue of the appropriate market structure in European mobile markets by presenting empirical evidence on the effect of the number of MNO on investment. Although there is no magic number of MNO that is appropriate in all cases, this paper demonstrates that three player markets in Europe, provide in average higher investment per subscriber than four (or more) player markets. More MNOs put more pressure on operators to invest in order to

differentiate themselves from competitors, but this results in a lower return on investment if all competitors invest. These two diametrically opposed effects appear to be balanced around 3 MNOs. In market consolidation in European mobile markets, particularly 4 to 3 mergers, should be encouraged by competition authorities because it leads to more investment and, therefore, a faster growth of data traffic and lower Gbyte prices for consumers. European markets are among the world's least concentrated, making it difficult for them to grow and invest as much as they would like. This excessive fragmentation of wireless markets is likely to delay Europe from realizing its digital ambitions.

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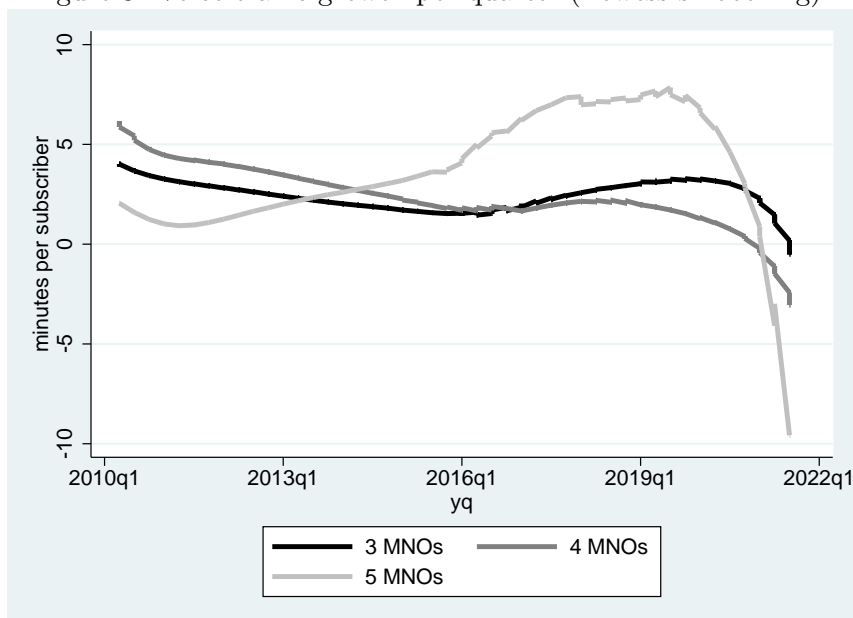
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Appendix

Graph for voice traffic growth

Figure 3: Voice traffic growth per quarter (Lowess smoothing)

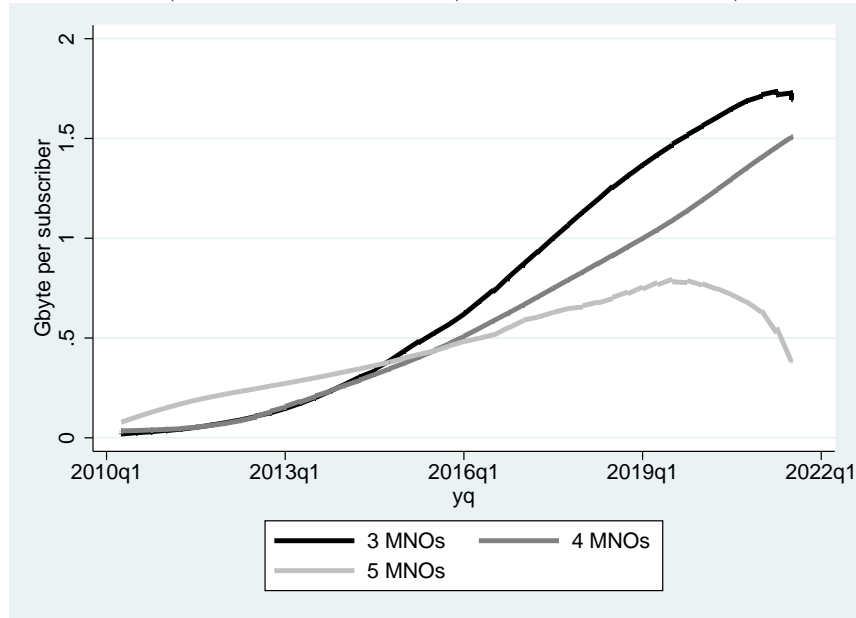


Voice traffic increases at a relatively slow pace. However, the differences between the number of firms from this graph does not allow to provide clear conclusions.

Graph for total traffic considering voice digitized as data⁵.

⁵We convert voice traffic to data traffic considering one minute of voice call requires 0.18 Mbytes

Figure 4: Total traffic (digitized voice + data) growth per quarter (Lowess smoothing)



This graph is very similar to figure 2. Indeed, voice traffic increases at a low pace while data traffic increases exponentially. As a result, the share of voice traffic in the total traffic decreases sharply over time from an average of 33 % in the early 2010 to less than 0.5% in the end of 2021.

Impact of the number of MNOs on voice traffic and total traffic (Digitized voice + data)

Table 8:

VARIABLES	voicetrafficpsub (1)	voicetrafficpsub (2)	Intotaltrafficpsub (3)	Intotaltrafficpsub (4)
nbMNO				
4	61.130*** (13.474)	53.056*** (11.343)	-0.5899*** (0.0777)	-0.5153*** (0.0745)
5	162.757*** (27.651)	141.515*** (21.511)	-0.8340*** (0.1292)	-0.6379*** (0.1127)
countryarea		750.490*** (105.877)		1.0991* (0.5937)
hasard	-21.235*** (8.053)	-16.229** (6.533)	0.3144*** (0.0398)	0.2682*** (0.0378)
GDPpcap_ppp	4.909*** (0.796)	4.623*** (0.735)	-0.0048 (0.0034)	-0.0021 (0.0033)
4G launch	-13.309** (6.746)		0.1228*** (0.0446)	
5G launch	31.883*** (9.999)	32.494*** (11.339)	0.0898 (0.0635)	0.0842 (0.0646)
popdensity	-1.724** (0.844)	-1.763** (0.841)	0.0167*** (0.0056)	0.0171*** (0.0056)
MVNOshare	-449.657*** (96.938)	-450.729*** (96.206)	1.8844** (0.5266)	1.8943*** (0.5338)
connections	-0.582 (0.549)	-0.607 (0.544)	-0.0293*** (0.0033)	-0.0290*** (0.0034)
opexpsub	2.561*** (0.547)	2.604*** (0.559)	0.0251*** (0.0030)	0.0247*** (0.0030)
country fixed effect	✓	✓	✓	✓
quarter fixed effect	✓	✓	✓	✓
Observations	982	982	982	982
R-square	0.8914	0.8908	0.9725	0.9722

Robust standard errors in parentheses

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

The number of MNOs seems to increase the voice traffic, as mentioned in the introduction. The number of MNOs, clearly decreases total traffic (data traffic + voice traffic (digitized)).