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Three Private Firms and an Independent Regulator are Sufficient for Rapid Mobile Network Penetration

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CCP Working Paper 11-1

Abstract:
The speed of market penetration (i.e. diffusion) is an important summary measure of how well the market works for potential consumers of a new product. This paper identifies the structural features associated with rapid diffusion of mobile telephony. We use a sample of thirty countries over the sixteen years in which average penetration rose from 2% to 97% of the population (earlier studies observed only the initial years of diffusion during which there was typically only one or two networks). We find a non-monotonic effect of market structure, with three firms maximising consumer uptake. Privatization and independent regulation are also important positive factors. Further results show that the market structure effect works only partially through the level of prices.

February 2011

***JEL Classification Codes*: L13, L51, L96**

Keywords: competition; market structure; privatization; independent regulator; mobile network; diffusion

ISSN 1745-9648

Acknowledgements:
We thank, Stephen Davies, Jon Stern, Paul Stoneman and Catherine Waddams for comments and discussions. Earlier versions of this paper were presented at the conferences of EARIE, the Competition Law and Economics European Network (CLEEN) New Researchers Workshop, and CRESSE 2010. Financial support of the Economic and Social Research Council is gratefully acknowledged

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1. Introduction

In the context of a growing market with consumer network externalities, the speed of a new product's market penetration (i.e. diffusion) is an important summary measure of how well the market is performing for potential consumers. Delays in uptake can result in large welfare losses.[1] When the market is regulated, it is particularly important to understand how the various potential regulatory levers (e.g. price, number of firms, public ownership) affect the diffusion process. As penetration approaches saturation, usage becomes the more important indicator of market performance, but in this paper we focus on the central period of diffusion in which average market penetration across the more developed economies rose from less than 2% to nearly 97% over 16 years.

Like any other product, the demand for mobile phone services is influenced by a range of marketing and technical factors that constitute the overall product 'offer'. This offer includes price level, price structure (e.g. cost of sending relative to receiving a call), reach (geographic coverage) and reliability. Individual elements of the product offer are difficult to observe and measure on a consistent basis either internationally or over time. Furthermore, the optimal balance in the offer can be sensitive to national idiosyncrasies. In fact, one of the theoretical virtues of a competitive market is that it creates incentives for firms to respond to these idiosyncrasies and to provide the most attractive offer to consumers. This leads us to focus on the structural characteristics of the market that drive competition. The aim of this paper is to identify those structural features that are associated with the competitive environment which maximises the rate of diffusion of mobile telephony through the population.

Mobile network penetration has been expanding rapidly in recent years, though there are signs it is reaching maturity in the advanced countries. We employ a panel of 29 OECD countries and China over the period 1991-2006. We include China because of its scale and economic growth at the time, but we also test for robustness using the OECD-only sample.[2] This period covers the core of the penetration phase in each market.[3]

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[1] See Hausman (1997).

[2] The Chinese mobile network market has grown fast but it is not immediately clear whether this is a distinct phenomenon or if it is following a similar pattern to OECD countries conditional on its market structure. As the market with the highest number of mobile phone subscribers and the largest market potential, China also provides a robustness check on our core relationship between structure and diffusion.

[3] In contrast, fixed-line markets have stagnated with a national average fixed-line penetration in our sample growing slowly to just under 51% in 2000 then shrinking (see Table 1 below).

We focus on three structural features: the number of firms; ownership (i.e. privatization); and the existence of an independent industry regulator. Earlier work on telecom market penetration (including fixed line) focused on demographic and technology factors, privatization, first new entry and the early part of the diffusion process.[4] The latter two limitations appear to be important because, by using data that more completely covers the core diffusion years for the countries in our sample and distinguishing between different numbers of firms, we find a non-monotonic effect of market structure.[5] Thus, while previous work has typically found that opening the market beyond monopoly is beneficial, it provides little guidance for important competition policy issues such as the number of operators to be licensed or merger regulation. The previous empirical literature also has little to say about regulatory institutions. Our main contributions are to distinguish the fine-grained effects of each extra entrant and of an independent regulator, and to estimate our model over the core years of the diffusion process.[6] Having identified the key structural features associated with rapid diffusion, we go on to ask whether the effect of a more competitive structure works mainly through the average price level as distinct from non-price-level elements in the offer.

The remainder of this paper is structured as follows. In the next section, we review some related literature on competition, ownership and regulation in telecoms markets. Section 3 sets out the econometric methodology and Section 4 describes the data. Section 5 presents and discusses the empirical results. Section 6 concludes.

2. Competition and regulation in mobile telecommunications

We identify three structural dimensions to telecommunications competition: the number of networks; private (versus state) ownership; and the existence and independence of an industry regulator.

A number of studies of mainly fixed line telecom markets have found that 'competition' is associated with higher penetration, productive efficiency, lower service price and better service

[4] For work on fixed line penetration, see for example: Ros (1999, 2003); Wallsten (2001, 2004); Fink et al. (2001); McNary (2001); Li and Xu (2002, 2004); Gasmi et al. (2006). The effect of competition has been tested using either a binary dummy variable (e.g., Ros, 1999, 2003; Fink et al., 2001) or indirect proxies of competition from other telecom segments (e.g., Li and Xu, 2002, 2004; Wallsten, 2001, 2004). Work on mobile penetration has investigated the early stages of diffusion and focused on technological constraints, technology 'generations', industry standards, and entry regulation (e.g. Gruber and Verboven, 2001a and 2001b, whose data covers the period 1984-97). Our work is most closely related to the latter.

[5] The number of mobile networks is largely regulated due to spectrum scarcity but we later investigate possible endogeneity.

[6] More broadly, there appears to be little econometric research on the relationship between industrial organization and the uptake of consumer goods in other markets.

quality. However, these early studies are unable to address questions relating to the extent of oligopolistic competition. Importantly, only the early part of the diffusion process was observable in the data and there was very little experience of other than monopoly and duopoly market structures. They mainly use either a binary competition variable[7] or indirect proxies from other telecom segments.[8] Gruber and Verboven (2001a, 2001b) include a duopoly dummy variable which they find to be statistically significant but quantitatively small. Liikanen et al. (2004) include two market structure variables: the number of firms and a 3-firm Herfindahl index. Both are entered linearly and neither is statistically significant. The most recent observation in these papers is 1998 which, as shown in the next section, is still early in the diffusion process.

Our empirical model allows for non-monotonicity in the relationship between market structure and diffusion. Given the existence of switching costs between network operators, including pecuniary network externalities that can be created by the price structure in mobile telephony (e.g. on-net calls may be charged at a discount to off-net), there are incentives to compete *for* the market. This may result in a relatively small number of firms being sufficient for strong competition. Indeed, it is possible that if there are 'too many' operators, they may have a reduced incentive to invest in their network to achieve the highest quality. Consequently, we need to allow for possible non-monotonicity in the relationship between the number of firms and consumer uptake.

It would be important to take account of the endogeneity of market structure if there was free entry and exit. In particular, as the market grows, we normally expect that more firms may enter profitably without sacrificing substantial economies of scale. However, the entry of mobile networks is tightly controlled by licensing, and the number of licences is chosen by the government or regulator.[9] Nevertheless, we test for a relationship between the number of networks and market size as a check on the exogeneity of market structure because the regulator may be influenced by market size in determining the number of licences. Anticipating our results, we find no evidence that market structure is other than exogenous.

The received evidence on ownership is that the success or failure of privatization is highly dependent on political and economic environments in general and the post-privatization

[7] E.g. Ros (1999, 2003), Fink et al (2001). Boylaud and Nicoletti (2000) do measure competition by a continuous variable: the market share of new entrants.

[8] See, e.g. Li and Xu (2002, 2004); Wallsten (2001, 2004).

[9] See, for example, Gruber and Verboven (2001a or 2001b). Mergers are also regulated though they may be more likely to be approved if the market is perceived as sufficiently competitive. Mergers were not a substantial issue in the period and countries in our sample.

regulatory framework in particular.[10] A survey by Megginson and Netter (2001) suggests that, on balance, deregulation and liberalization in the wider telecom sector are associated with significant improvements in performance and efficiency, but the impact of privatization alone is less clear. This general finding is supported by fixed-line telecom studies that have tried to identify the characteristics of regulatory institutions which determine the quality of regulatory governance.[11] They find consistently that the existence of a strong and independent regulator is a key institutional element that tends to be associated with higher levels of certain performance measures (including fixed-line penetration). Beyond the general regulatory functions (e.g. preventing anticompetitive behaviour), the existence of an independent regulator signals the credibility of a government's commitment to private investments and the government's propensity to undertake effective pro-competition policies.[12] Following the literature, we define an 'independent regulator' as one which is separated from industrial operators and other governmental bodies, backed by legislation rather than executive decree and able to make decisions independently.

The regulatory relationship is different if firms are publicly owned because there is more likely to be a legislative or heavy lobbying response to regulatory decisions that are seen to harm public enterprises. This suggests we should test for a regulatory effect that depends on ownership.

The effectiveness of an independent regulator also depends on market structure. With a monopoly provider, it is particularly difficult for the regulator to overcome its fundamental asymmetric information problem. With two or more providers, a wider range of regulatory techniques becomes possible (e.g. yardstick competition). Thus, although regulation may become less necessary as the number of providers increases, it may also become more effective – at least up to the point that it is no longer necessary.

3. Econometric specification

Mobile network penetration is encouraged by consumer adoption externalities and constrained by market saturation. The balance of these two effects means that it follows a classic

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[10] See Levy and Spiller (1994, 1996); Ramamurti (2000); Villalonga (2000); Yarrow (1986); North (1990).

[11] See, for example, Stern and Holder (1999); Gutierrez and Berg (2000); Gual and Trillas (2003); Gutierrez (2003a, 2003b); Cubbin and Stern (2006); Gasmi et al. (2006); Parker and Kirkpatrick (2005). Exceptionally, Maiorano and Stern (2007) use data from low and middle-income countries over a 15-year period of 1990-2004 to investigate the relationship between regulatory institutions and performance in the mobile telecommunications sector. However, their results are mixed and do not take account of market structure.

[12] See Armstrong and Sappington (2006); Ramamurti (2000); Villalonga (2000); Levy and Spiller (1994, 1996).

S-shaped epidemic growth curve (see Fig. 2 below). We therefore adopt the standard logistic specification for our empirical model.[13] This implies that, for example, an increase in competition will have a greater percentage point impact on penetration when around half the population has adopted a mobile network, as compared with when the product is either new and trying to gain traction in the market, or mature and nearing market saturation.

More specifically, let $MobPen_{it}$ denote the number of people (per 100 inhabitants) that have adopted a mobile network service in country *i* at time *t*. Let M_i^* denote the full saturation level of mobile network adoption (also as a percentage of the population). If the growth rate of penetration is proportional to the proportion of the market that is as yet unserved, with the factor of proportion being, b_{it}, we have:

$$MobPen_{it} = \frac{M_i^*}{1+\exp(-(a_{it}+b_{it}t))} \tag{1}$$

a_{it} shifts the diffusion curve forwards or backwards without changing its basic shape. We return to this below. Rearrangement of (1) provides the following model for estimation:

$$y_{it} = \ln\left(\frac{MobPen_{it}}{M^* - MobPen_{it}}\right) = a_{it} + b_{it}t + u_i + \varepsilon_{it} \tag{2}$$

where u_i is a country specific error (i.e. time invariant unobserved heterogeneity for each country *i*);[14] and ε_{it} is a standard white noise error term. The factors determining the timing and speed of diffusion are specified as:[15]

$$a_{it} = \alpha_i^0 + \sum_{n=1}^{\bar{\mathrm{N}}} \alpha^n \mathrm{N}_{it}^n + \sum_{j\in J} \alpha^j D_{it}^j + x_{it}\alpha$$

$$b_{it} = \beta_i^0 + \sum_{n=1}^{\bar{\mathrm{N}}} \beta^n \mathrm{N}_{it}^n + \sum_{j\in J} \beta^j D_{it}^j + x_{it}\beta$$

α_i^0 is the individual fixed effect for each country *i*, and is determined by each country's initial position of network adoption. $\bar{\mathrm{N}}$ is the maximum number of firms observed. N_{it}^n is the set of market structure dummies equal to one when the number of firms equals *n*, D_{it}^j is a set of *J* regulatory and ownership dummy variables (including interactions) and x_{it} is a vector of continuously measured variables that influence diffusion (in particular, consumer prosperity).

[13] See Griliches (1957) and Mansfield (1961) for early analysis of the logistic growth curve, and Geroski (2000) for an evaluation of its merits.

[14] This is determined by unobserved demographic, social, political and technological factors.

[15] This follows Gruber and Verboven (2001b).

Following Gruber and Verboven (2001b) we impose restrictions on the coefficients of discrete (dummy) variables such that there are no sharp jumps in penetration (i.e. penetration should be the same immediately after entry as it was immediately before entry or privatisation or regulatory independence). They only consider a single entry event and we generalise the parameter constraints necessary to avoid discontinuities. We later test this set of restrictions. Write T_i^n as the year of entry of the n'th firm in country i. Penetration is zero immediately before entry, $\alpha_i^0 + x_{it}\alpha = -\left[\beta_i^0 + x_{it}\beta\right]T_i^1$, and the same immediately after, which implies $\alpha^1 = -\beta^1 T_i^1$. Full derivation is in Appendix E. Substituting these restrictions into the general diffusion equation and again assuming no jump in penetration on second entry, this further requires $\alpha^2 = \beta^1\left[T_i^2 - T_i^1\right] - \beta^2 T_i^2$. Continuing the pattern, we obtain the general restriction for smooth transitions: $\alpha^n = \left\{\sum_{k=1}^{n-1}\beta^k\left[T_i^{k+1} - T_i^k\right]\right\} - \beta^n T_i^n$. Substituting into (2), we have

$$y_{it} = \sum_{n=1}^{\bar{N}}\beta^n N_{it}^n + \sum_{j\in J}\beta^j D_{it}^j\left[t - T_i^j\right] + \left[\beta_i^0 + x_{it}\beta\right]\left[t - T_i^1\right] + u_i + \varepsilon_{it} \qquad (3)$$

where $N_{it}^n = \left\{\mathrm{N}_{it}^n\left[t - T_i^n\right] + \sum_{k=n+1}^{\bar{N}}\mathrm{N}_{it}^k\left[T_i^{n+1} - T_i^n\right]\right\}$. Note that for all $t \geq T_i^{n+1}$, $N_{it}^n = \left[T_i^{n+1} - T_i^n\right]$. Thus, the history of earlier market structures matters because it provides the starting point from which market penetration grows in the new competitive environment.

The intuition behind the construction of our market structure variables, N_{it}^n, is illustrated in Figure 2. y_{it} is forced to start at zero when the market opens at $t = T_i^1$. This locates the diffusion curve for monopoly. The second term in N_{it}^1 locks in the level of mobile penetration achieved when the second firm enters. The duopoly diffusion curve is constrained to locate such that y_{it} is the same at T_{it}^2 as for the monopoly curve at that time. The duopoly curve is steeper if duopoly diffusion is faster than under monopoly. The rate of diffusion may also fall with entry as illustrated in the figure with the entry of the fourth firm.

Fig. 1 near here

The $D_{it}^j\left[t - T_i^j\right]$ variables in equation (3) follow directly from the simple restriction of smooth transition at the time of discrete events. Applied to privatisation and independent regulation, we have $PrvT = Prv_{it}\left[t - T_i^{Prv}\right]$ and $IndRegT = IndReg_{it}\left[t - T_i^{IR}\right]$. As discussed in section 2, we also investigate interactions between independent regulation, privatisation and market structure. Each of these is similarly specified in relation to elapsed time.

Finally, we allow for the underlying rate of diffusion to depend on the date of opening of the market: $\beta_i^0 = \beta^0 + \gamma \frac{t}{t - T_i^1}$. $\gamma > 0$ implies catch-up, as more recently opened markets grow faster than early ones, with the catch-up effect declining over time.[16] Noting that $\sum_{n=1}^{\bar{N}} N_{it}^n = t - T_i^1$, we need to drop one variable from the estimation to avoid perfect multicollinearity. We substitute for N_{it}^1 in order to focus on market structure effects relative to monopoly. Writing $\tilde{\beta}^0 = \beta^0 + \beta^1$, we therefore estimate:

$$y_{it} = \left\{ \sum_{n=2}^{\bar{N}} \left[\beta^n - \beta^1 \right] N_{it}^n \right\} + \left\{ \sum_{j \in J} \beta^j D_{it}^j \left[t - T_i^j \right] \right\} + \tilde{\beta} \left[t - T_i^1 \right] + \gamma t + x_{it} \beta \left[t - T_i^1 \right] + u_i + \varepsilon_{it} \quad (4)$$

4. Data and measurement

The dependent variable is mobile network penetration (*MobPen*) measured by the number of mobile phone subscribers per 100 inhabitants as reported by the International Telecommunications Union (ITU) for our panel of 30 countries over 16 years (1991-2006). Cross-country averages are reported in Table 1 alongside fixed line penetration to provide perspective. The cross-country range of penetration rates and average growth curve are shown in Figure 2. Table 1 also shows fixed line penetration for comparison. Average mobile penetration overtook fixed line in 2000.

It may seem natural to assume that the maximal level of adoption, M^*, should be 100%. However, some countries in our sample have already achieved a mobile penetration rate exceeding 100% in recent years, probably due to multiple-subscriptions with different networks (e.g. separate private and work mobiles). In the absence of a natural saturation point, we sensitivity-test different values for a common saturation level in two ways. We set various levels of $M^* \geq 100\%$ then ensure that observed penetration never reaches M^* either by withholding observations of $MobPen_{it} \geq M^*$ or by capping them at a level $< M^*$. More precisely, we either excluded observations at or above given ‘saturation’ thresholds (100, 150 and 200), or fixed the ceiling at 100 and capped observed penetration rates at or above the ceiling at 99. In our econometrics, we find that neither the values nor the significance of estimated coefficients are substantially changed by using these alternatives. For convenience, in the text we only report results for *M**=100 and exclude observations with penetration greater than 99%. Sensitivity tests are reported in Appendix D-2

[16] ‘Catch-up’ may incorporate, for example, international demonstration effects and technological improvements.

Fig. 2 near here

Market structure is measured by the number of mobile network operators (*N*).[17] The average number grew from 1.2 to 3.8 over the period (see Table 1). Most national mobile network markets were a monopoly in 1991 (see Appendix B). The number of duopolies grew until 1998, peaking at 19 countries. The last three monopolies were eliminated a year later and by 2000, 19 out of the 30 countries had at least three operators. By 2006, there were only three duopolies left (including China). As described in the previous section, we investigate possible non-monotoncity of the effect of market structure by constructing a set of dummy variables.

Tables 1 and 2 near here

Just 17% of mobile network operators were private in 1991 but this grew to 90% by 2003 (see Table 1). The year in which mobile providers were privatized in each country is given in Table 2, with 14 countries privatizing in 1996-98.[1] Privatization (*Prv*) is measured as a dummy variable that equals one if at least 50% of assets were held by the private sector for the full year, and equals zero otherwise.[1] We require a full year of privatization both because the change of ownership may take place late in a year and because it may take some months to have an effect. We adopt the same principle for the establishment of an independent regulator and entry or exit of a network operator. Since the most recent full privatization, which was of the Korean mobile market in 2002, there are only three countries (i.e. China, Mexico and Turkey) where the mobile incumbents are still state-owned.

We define a regulator as independent only if it is backed by legislation and can claim operational decision-making independent of any other government bodies.[18] As can be seen from Table 1, the establishment of an independent regulator is fairly closely related to privatization, but there are some significant differences in timing. An equal number (eleven) were established before and after privatization, though four of the latter were before the start of our sample (see Table 2). Four independent regulators were established in the same year as privatization and four countries have yet to establish an independent regulator. Independent regulation (*IndReg*) is measured as a dummy variable that equals one if present and zero otherwise.

[17] The information on the actual number of mobile network operators (MNOs) in each national market year-by-year are collected from the OECD (for data from 1990 to 2000) and from countries' telecom regulators' websites as well as from some MNOs' websites (for data from 2000 to 2006). See OECD report: DSTI/ICCP/TISP(99)11/FINAL, online available at: http://www.oecd.org/dataoecd/54/42/2538118.pdf

[18] The information on the year and conditions when an independent regulatory authority was established in each country are extracted from the ITU-BDT online telecom regulatory database. Available on: http://www.itu.int/ITU-D/ICTEYE/Regulators/Regulators.aspx#.

In Appendix A, we provide a stylised graph of how market penetration is related to various combinations of these features of the market environment. The largest steps appear to be associated with independent regulation. However, extreme caution is required in interpreting this graph because it takes no account of the way these features tend to evolve over time. This is crucial because penetration also evolves over time independently of any change in, say, regulation.

For reasons explained in the previous section, we include two time trends in our econometrics. *Timeopen* ($= t - T_i^1$) is country-specific and starts with the first full year that the market opened. This picks up the core national diffusion process as late adopters follow pioneers into the market. *Time* (= *t*) picks up international influences as late-starting countries catch-up.

The principal demand-side variable explaining adoption and diffusion is per capita GDP, *GDPpc*.[19] We expect to observe positive income effects. Prices are excluded from our core model in order to focus on the effect of market structure. Complex pricing schemes also make it difficult to summarise price effects in a single number. However, we go on to investigate one dimension of price in order to gain insight into one of the mechanisms through which market structure effects may operate. Data are available for 'standard' calls and we use this to examine the extent to which market structure and regulation effects operate through price level as distinct from the other elements of the consumer offer.

Mobile service price (*MobPrice*) is measured by the cost of 3-minute local call.[20] The mobile call price was relatively stable 1991-97, then declined sharply until 2001, after which it began to rise again (see Table 2). Over the full period, there has been an average annual decrease of 2% pa. The average fixed-line price of a 3-minute local call *FLPrice* (as reported by ITU) is also included to test for possible complementarities or a substitution effect between fixed and mobile usages. Complementarities may arise early in the diffusion process because fixed line termination opportunities are relatively important for a subscriber. As mobile penetration increases, however, mobile-to-mobile calls become more important and the substitution effect with fixed line services may dominate.

When mobile price is included directly in our model, we adopt instrumental variable estimation methods to take account of the likely endogeneity of *MobPrice* due to strategies used by firms to encourage early uptake. We include three variables as instruments for identification: lagged mobile service price (i.e., the mobile service price of the previous year); mobile labour

[19] Data are taken from the International Monetary Fund.

[20] This is also as reported by the ITU. Prices are adjusted by the current exchange rate (USD$) and inflation.

productivity (i.e. the number of mobile phone subscribers served per person employed in the mobile service segment) as an inverted cost driver; and national population (*Pop*) to capture potential market size and possible economies of scale.

5. Empirical results and discussion

The results from four variants of our model are presented in Table 3. Hausman tests rejected variable effects in favour of fixed effects, so all reported results were estimated with fixed effects. Models 3 and 4 include call prices and are estimated by instrumental variable FE.[21] A summary of the variables and their definitions is given in Appendix C.

Model 1 is our core model as specified in equation (4). Market structures with two, three and five firms each have a significantly faster diffusion rate as compared with monopoly. Triopoly is the fastest, with pentopoly and duopoly roughly equal next best.[22] The strong significance of these market structures is robust across specifications, as is the insignificance of tetropoly.[23] Market structures with six or seven firms are, if anything, slower than the monopoly diffusion rate, but these coefficients are mostly statistically insignificant.[24]

The quantitative significance of market structure is substantial and depends on the current level of mobile penetration.[25] Estimated $\beta^3 - \beta^1 = 0.29$, so triopoly penetrates the market at a maximum of 7.3 percentage points faster than monopoly *ceteris paribus* when penetration is around 50%, and 4.7 percentage points faster when penetration is around either 20% or 80%.

Table 3 near here

Privatisation is a strongly significant and positive influence on mobile diffusion. In the absence of an independent regulator, a coefficient of 0.18 translates into an incremental boost to the diffusion rate of 4.5 percentage points when penetration is around 50%, and of 2.9 percentage points at penetration of 20% or 80%. The benefit of privatisation is almost halved if there is already an independent regulator. We find a quantitatively smaller impact of

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[21] We test for the endogeneity of price by applying the Hausman specification test for panel instrumental models (Hausman, 1978; Hausman and Taylor, 1981).

[22] F-tests on Model 1 find that the coefficient associated with triopoly is significantly higher than that of duopoly, with F =10.69 >F(1, 405)=3.84; whereas, there is no significant difference between the coefficients of triopoly and pentopoly (F = 1.34).

[23] We have been unable to explain the latter.

[24] Note also that all but one of our observations of six or seven firm market structures are for the USA, with Canada in 2006 being the other one.

[25] This can be seen by noting: $\frac{dMobPen_{it}}{dx} = [\frac{MobPen_{it}}{100}][100 - MobPen_{it}]\frac{dy_{it}}{dx}$.

independent regulation in the absence of privatisation and, in the Model 1 specification, little incremental impact of independent regulation in the presence of privatised firms. Model 2 includes an interaction between independent regulation and the number of firms to test for the influence of market structure on the efficacy of regulation. We find a positive coefficient which suggests that, within the range of observed firm numbers, regulation is made more effective when the regulator is able to use rival operators as benchmarks to reduce the asymmetry of information between regulator and regulated.[26] For example, with three firms: the marginal effect of independent regulation in the absence of privatisation is almost exactly the same as the marginal effect of privatisation without independent regulation; and the regulation effect is halved in the presence of privatisation.

In both models 1 and 2, per capita income has a surprisingly negative effect on the early adoption of mobile telephony. Both the elapsed time since the market opened (*Timeopen*) and the common time trend (*Time*) are highly significant. The former picks up the underlying diffusion process while the latter implies catch-up in the form of faster diffusion in late-starting countries.

Models 3 and 4 investigate call price effects. We did not expect strong results given the difficulty of summarising complex pricing plans in a single price. Nevertheless, we do find a significant and quantitatively relevant negative own-price effect on the rate of take-up of mobiles. There is also an interesting, if not particularly robust, fixed line effect. The positive coefficient suggests a substitution effect between fixed lines and mobiles, but this is only marginally significant. We also tested for a changing role of fixed lines over time by allowing $\beta_i^F = \beta^{F1} + \beta^{F2}\left[t - T_i^1\right]$. As discussed in section 4, we expected fixed lines to be complementary to mobiles in the early years, but to evolve into substitutes over time as more people can be called mobile-to-mobile; i.e. we expect $\beta^{F1} < 0$ and $\beta^{F2} > 0$. Our results are presented in Appendix D-1. We find some weak support for this hypothesis, with fixed lines becoming substitutes for mobiles after seven or eight years.[27]

Comparing the results with and without prices (i.e. Models 1 and 2 with Models 3 and 4), we find that the significance of the market structure variables is largely unchanged, and there is only a marginal fall in the size of the duopoly and triopoly coefficients. This suggests that mobile call

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[26] We also investigated a quadratic effect for the interaction between firm numbers and independent regulation, expecting to find a maximum impact of independent regulation with a small number of firms, above which competition would negate the value of regulation. However, both the linear and quadratic terms were positive and insignificant.

[27] However, the statistical significance of fixed line prices is not robust to the exclusion of China from the sample.

price is not a major component of the competition effect on diffusion – other dimensions of competition such as price structure, investment in quality and better service appear more important. The latter are the elements of the offer that may be harder to regulate than a standard price. Consistent with this interpretation, the size and significance of the independent regulation variables diminishes when prices are included. It is as if regulation can substitute for basic price competition better than it can for non-price-level effects.

We conducted a number of robustness tests. First, we checked to see whether the exclusion of China, our single non-OECD country, would affect our results (see Table 4). Given China's duopolistic market structure, particular interest focuses on the duopoly variable, but the exclusion of China makes no difference to the duopoly coefficient either quantitatively or in statistical significance. The same applies to other variables in the model, with the single exception of fixed line prices which tend lose significance when China is excluded.

Table 4 near here

Second, we tested the smooth transition restrictions embodied in the construction of our market structure variables. These cannot be rejected for any specification (see Appendix D-2). Third, we tested a range of alternative assumptions about maximum penetration. Our results remain robust to the range of specifications set out in section 4 (see Appendix D-3).

Finally, although the number of mobile network operators is determined by spectrum constraints and regulators in all countries, we tested for the possible endogeneity of the number of firms. We should expect the number of operators to be positively associated with the potential size of the market if market structure was relevantly endogenous to the diffusion process. However, we found no evidence that the number of operators was determined by the size of market, even when excluding China (see Appendix D-4).

6. Conclusions

The aim of this paper was to identify the structural features of the market that provide the best competitive environment to maximise the market penetration of a new product – mobile telephony. Unlike earlier studies, we are able to use data that covers the core period of the diffusion process. We find a non-monotonic effect of market structure on mobile penetration. Like earlier studies, we confirm the benefit of moving from monopoly to duopoly, but the advantage of using more recent data is that we now have experience of a much wider range of market structures. This reveals that triopoly is a major competitive improvement on duopoly but there is no further improvement in diffusion with more firms.

It is interesting to relate this to the wider empirical literature that relates market structure and competitive outcomes. Much of this now exploits data on local geographical markets to investigate the implied effects of competition on margins, price and productivity.[28] An emerging stylised fact is that a relatively small number of firms, often between two and four depending on the product, is sufficient to generate most of the benefits of competition in traditional homogeneous product markets (e.g. professional services, retailing, concrete). That research uses genuinely local markets (compared with national markets in this paper) to provide the cross-section dimension. It also investigates totally different dependent variables. Nevertheless, our results feed into the emerging stylised fact for relatively homogeneous product markets.

However, there is an important difference between mobile networks and more traditional markets because spectrum limitations have been addressed by strict licensing of operators. This eliminates the threat of entry as a mechanism by which competition works. The institutional response has been that mobile networks are typically regulated, though the independence of the regulator has varied across countries and over time. We find that the independence of the regulator has a positive role to play in addition to market structure, and that this role is more effective when the regulator is able to observe a greater number of rival operators. In line with some of the earlier literature, privatisation also has a substantial impact particularly in the absence of independent regulation.

Our findings are consistent with the view that a balance needs to be struck between investment incentives for network industries characterised by large sunk costs and the benefits of an apparently more competitive market structure. This is particularly relevant when determining the number of spectrum licenses to be granted, but it is also relevant for merger policy. Our findings are consistent with the view that three private firms are sufficient to maximise the incentive to invest in a network, but independent regulation is also necessary to guard against collusion possibilities or unilateral market power.

Another of our findings is that market structure still matters when we control for the standard price of a call. This confirms that competition is multidimensional, and that price level is only one element of the product offer that is influenced by structure and influential on consumer uptake.

Finally, the data in this paper covers the core period of diffusion in thirty countries. Average market penetration across these countries rose from less than 2% to nearly 97% in sixteen years. As the market matures, the consumer focus naturally turns to usage and product development. Future research could usefully identify whether the features of the market we have found to be important for uptake are different to those necessary for an efficient mature market.

[28] For example, Bresnahan and Reiss (1991), Manuszak and Moul (2008) and Syverson (2004).

Table 1: Summary Statistics for Cross-Country Trends in Telecoms in 30 Countries (1991-2006)

year	Mobile penetration %	Fixed-line penetration %	Mobile price of 3-min local call (USD)	Number MNOs	Mobile incumbents privatized	Independent regulator established	Privatization & Independent regulator
				Mean			
1991	1.66	39.21	1.36	1.2	17%	20%	10%
1992	2.11	40.40	1.44	1.2	20%	20%	10%
1993	2.88	41.60	1.38	1.5	23%	23%	10%
1994	4.49	42.84	1.40	1.6	27%	27%	10%
1995	7.14	44.10	1.42	1.8	33%	30%	10%
1996	11.03	45.53	1.45	1.9	37%	30%	13%
1997	15.91	47.38	1.31	2.2	50%	37%	23%
1998	24.22	48.27	1.22	2.4	60%	60%	37%
1999	37.57	49.79	1.04	2.9	83%	67%	57%
2000	52.87	50.83	0.94	3.1	83%	70%	60%
2001	63.85	50.47	0.77	3.5	87%	80%	70%
2002	70.09	50.09	0.89	3.4	87%	83%	73%
2003	76.15	49.30	0.99	3..5	90%	87%	80%
2004	83.72	48.81	0.98	3.5	90%	87%	80%
2005	90.30	47.34	1.00	3.7	90%	87%	80%
2006	96.79	46.87	1.00	3.8	90%	87%	80%
Average annual change rate	33%	1%	-2%	8%	12%	11%	17%

Data source: based on a variety of sources, including ITU database on the world telecommunication/ICT indicators (2006), ITU-BDT online regulatory information database, OECD regulatory database (2000), countries' telecom regulators' websites and mobile network operators' websites. See text for details.

Table 2: Summary Statistics for Mobile Sector Reforms by County

Country	Year incumbents privatized	Year independent regulator established	Number MNOs in 2006	Country	Year incumbents privatized	Year independent regulator established	Number MNOs in 2006
Australia	1997	1997	4	**Japan**	always	n/a	5
Austria	1998	1997	4	**Korea**	2002	1997	3
Belgium	1996	1993	5	**Luxemburg**	1998	1997	3
Canada	always	1976	6	**Mexico**	n/a	1996	4
China	n/a	n/a	2	**Netherlands**	1994	1997	5
Czech Republic	1994	2000	4	**New Zealand**	always	2001	2
Denmark	1991	dep.	4	**Norway**	1998	1987	2
Finland	1998	1988	4	**Poland**	1998	2000	3
France	1997	1997	4	**Portugal**	1995	1989	3
Germany	1996	1998	4	**Spain**	1992	1996	3
Greece	1996	1992	3	**Sweden**	2000	1992	4
Hungary	1993	1999	3	**Switzerland**	1998	dep.	4
Iceland	1997	1997	4	**Turkey**	n/a	2000	3
Ireland	1996	2002	4	**UK**	always	1984	5
Italy	1998	1998	4	**US**	always	1934	6

Data source: author compiled based on a variety of sources, including ITU-BDT online regulatory information database, countries' telecom regulators' websites and mobile network operators' websites. See text.

1. N/A: event yet to occur;
2. Dep.: a separate regulator is subject to several other governmental bodies in its decision making;
3. **Privatization** is recorded for those where at least 50% of assets of state-owned companies have been sold to private sector; **Independent regulator** is recorded only if it is created backed by legislation and claims to be independent of decision making.

Table 3: Estimation Results under Panel Equation-by-Equation and Panel Instrumental Approaches

Dependent variable: y_{it} = ln$(MobPen_{it}/(100\text{-}MobPen_{it}))$

	Model 1	**Model 2**	**Model 3**	**Model 4**
Market structure:				
N=2	0.1822***	0.2028***	0.1462**	0.1771**
	2.31	*2.63*	*1.85*	*2.27*
N=3	0.2934***	0.2914***	0.2739***	0.2846***
	3.52	*3.58*	*3.22*	*3.41*
N=4	-0.0233	-0.0318	-0.0589	-0.0554
	-0.29	*-0.41*	*-0.74*	*-0.71*
N=5	0.2157***	0.1392*	0.2146***	0.1542**
	2.45	*1.59*	*2.39*	*1.73*
N=6	-0.4217**	-0.1176	-0.4299**	-0.1547
	-1.86	*-0.51*	*-1.94*	*-0.68*
N=7	-0.0984	-0.2580***	-0.1477*	-0.2840***
	-1.04	*-2.62*	*-1.56*	*-2.91*
Ownership:				
PrvT	0.1817***	0.1932***	0.1685***	0.1814***
	6.01	*6.53*	*5.63*	*6.14*
Independent regulator:				
IndRegT	0.1011***	0.0600***	0.0620**	0.0335
	3.67	*2.12*	*2.04*	*1.10*
*IR*PrvT*	-0.0781***	-0.0900***	-0.0323	-0.0524**
	-3.20	*-3.75*	*-1.11*	*-1.80*
*IR*NT*		0.0403***		0.0364***
		4.61		*4.15*
Other:				
lnGDPpctT1	-0.1134***	-0.1066***	-0.1136***	-0.1068***
	-6.49	*-6.23*	*-6.63*	*-6.33*
Timeopen	0.3793***	0.3931***	0.3438***	0.3695***
	4.46	*4.73*	*4.02*	*4.39*
Time	1.4079***	1.3171***	1.4562***	1.3571***
	7.21	*6.88*	*7.58*	*7.14*
lnMobPricetT1			-0.0591***	-0.0500**
			-2.40	*-2.05*
lnFixedPricetT1			0.1960**	0.1261
			1.86	*1.20*
	n = 447	n = 447	n = 447	n = 447
	R-sq = 0.9394 (within)	R-sq = 0.9424 (within)	R-sq = 0.9426 (within)	R-sq = 0.9450 (within)
Estimation Procedure	FE	FE	FEIV	FEIV

Note: In all models, ***, **, and * indicate significant levels at 1%, 5%, and 10%, respectively; z-statistics are reported below each coefficient in *italic* type.

Estimation: Models (1) and (2) are estimated by standard *fixed-effects* (FE). Models (3) and (4) are estimated by *panel fixed-effects instrumental estimation* (FEIV) with *MobPrice* endogenous.

Table 4: Estimation Results (excl. China) under Panel Equation-by-Equation and Panel Instrumental Approaches

Dependent variable: $y_{it} = \ln(MobPen_{it}/(100\text{-}MobPen_{it}))$

	Model 1	**Model 2**	**Model 3**	**Model 4**
Market structure:				
N=2	0.1861***	0.2073***	0.1447**	0.1757**
	2.33	*2.66*	*1.80*	*2.23*
N=3	0.2982***	0.2965***	0.2704***	0.2808***
	3.54	*3.62*	*3.14*	*3.33*
N=4	-0.0232	-0.0321	-0.0634	-0.0606
	-0.29	*-0.41*	*-0.79*	*-0.77*
N=5	0.2146***	0.1348*	0.2061**	0.1432*
	2.41	*1.53*	*2.26*	*1.58*
N=6	-0.4475**	-0.1359	-0.4531**	-0.1733
	-1.95	*0.58*	*-2.02*	*-0.76*
N=7	-0.1007	-0.2666***	-0.1498*	-0.2902**
	-1.05	*-2.68*	*-1.57*	*-2.95*
Ownership:				
PrvT	0.1927***	0.2069***	0.1783***	0.1929***
	5.96	*6.55*	*5.53*	*6.07*
Independent regulator:				
IndRegT	0.1116***	0.0710***	0.0694**	0.0412*
	3.81	*2.38*	*2.15*	*1.29*
*IR*PrvT*	-0.0853***	-0.0987***	-0.0374	-0.0583**
	-3.41	*-4.02*	*-1.25*	*-1.95*
*IR*NT*		0.0417***		0.0373***
		4.73		*4.21*
Other:				
lnGDPpctT1	-0.1013***	-0.0932***	-0.1022***	-0.0944***
	-5.50	*-5.17*	*-5.67*	*-5.32*
Timeopen	0.3843***	0.4002***	0.3413***	0.3680***
	4.43	*4.74*	*3.93*	*4.32*
Time	1.2670***	1.1598***	1.3263***	1.2151***
	6.17	*5.76*	*6.58*	*6.10*
lnMobPricetT1			-0.0586***	-0.0497**
			-2.36	*-2.03*
lnFixedPricetT1			0.2296**	0.1621*
			2.13	*1.52*
	n = 431	n = 431	n = 431	n = 431
	R-sq = 0.9375 (within)	R-sq = 0.9409 (within)	R-sq = 0.9411 (within)	R-sq = 0.9434 (within)
Estimation Procedure	FE	FE	FEIV	FEIV

Note: In all models, ***, **, and * indicate significant levels at 1%, 5%, and 10%, respectively; z-statistics are reported below each coefficient in *italic* type.

Estimation: Models (1) and (2) are estimated by standard *fixed-effects* (FE). Models (3) and (4) are estimated by *panel fixed-effects instrumental estimation* (FEIV) with *MobPrice* endogenous.

Figure 1: Market structure and diffusion (illustrative)

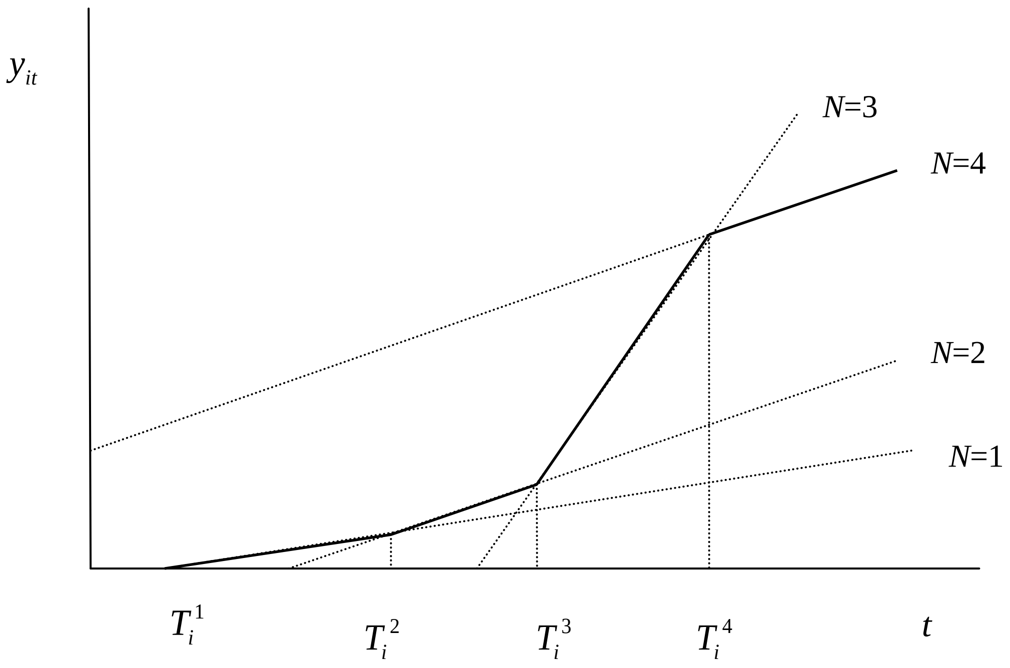
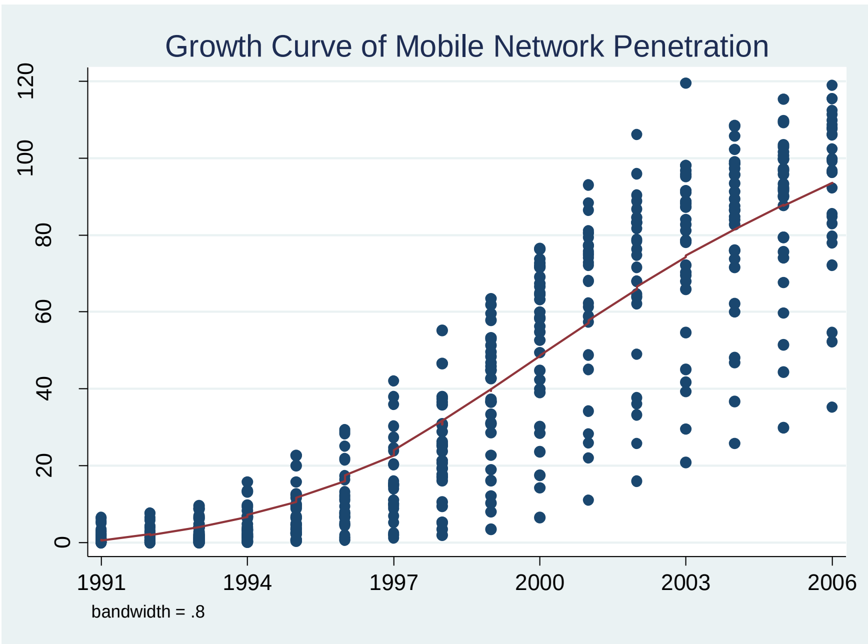


Figure 2: Growth of mobile network penetration



Note: Each dot represents one of the 30 countries in our sample. The line connects the mean penetration rate across 30 countries in each year.

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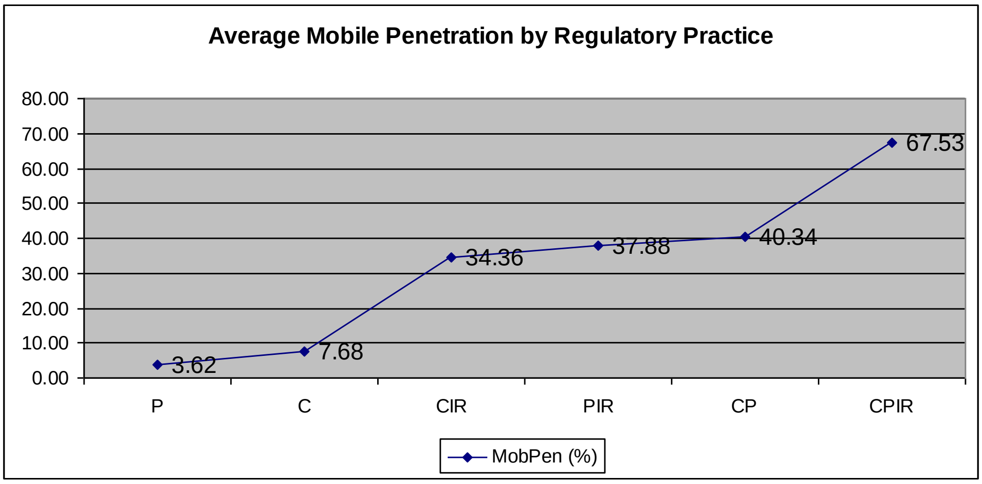
Appendix A



***P**: the mobile market is characterized by private monopoly, without an independent regulator;*

***C**: the mobile market is characterized by public ownership and operates in a 'competitive environment' (i.e. N≥2, without an independent regulator;*

***PIR**: the mobile market is characterized by private monopoly, with an independent regulator;*

***CIR**: the mobile market is characterized by public ownership and operates in a 'competitive environment', with an independent regulator;*

***CP**: the mobile market is characterized by private ownership and operates in a 'competitive environment', without an independent regulator;*

***CPIR**: the mobile market is characterized by private ownership and operates in a 'competitive environment', with an independent regulator.*

Appendix B

The Number of Mobile Network Operators by Country from 1991 to 2006

		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	**China**	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
2	**Australia**	1	1	1	3	3	3	3	3	3	4	4	4	5	4	4	4
3	**Austria**	1	1	1	1	1	1	1	2	3	3	3	3	3	3	5	4
4	**Belgium**	1	1	1	1	1	2	2	2	2	2	3	3	3	4	5	5
5	**Canada**	2	2	2	2	2	2	3	4	4	4	4	4	4	4	5	6
6	**Czech Republic**	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	4
7	**Denmark**	1	1	2	2	2	2	2	2	4	4	4	5	5	5	5	4
8	**Finland**	1	1	2	2	2	2	2	2	4	4	4	4	4	4	4	4
9	**France**	2	2	2	2	2	2	2	2	2	2	3	3	3	4	4	4
10	**Germany**	1	1	2	2	3	3	3	3	4	4	4	4	4	4	4	4
11	**Greece**	0	0	2	2	2	2	2	2	3	3	3	3	3	3	3	3
12	**Hungary**	1	1	1	1	2	2	2	2	2	2	4	3	3	3	3	3
13	**Iceland**	1	1	1	1	1	1	1	1	2	2	2	3	3	3	3	4
14	**Ireland**	1	1	1	1	1	1	1	2	2	2	3	3	3	3	3	4
15	**Italy**	1	1	1	1	1	1	2	2	2	3	4	4	4	4	4	4
16	**Japan**	2	2	2	2	2	3	4	4	4	4	4	4	4	4	5	5
17	**Korea**	1	1	1	1	1	1	2	5	5	5	5	3	3	3	3	3
18	**Luxembourg**	1	1	1	1	1	1	1	1	2	2	3	3	3	3	3	3
19	**Mexico**	2	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4
20	**Netherlands**	1	1	1	1	1	1	2	2	4	5	5	5	5	5	5	5
21	**New Zealand**	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
22	**Norway**	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
23	**Poland**	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3
24	**Portugal**	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3
25	**Spain**	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	3
26	**Sweden**	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4
27	**Switzerland**	1	1	1	1	1	1	1	1	2	3	3	3	3	3	4	4
28	**Turkey**	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3
29	**United Kingdom**	2	2	2	3	4	4	4	4	4	4	4	4	4	5	5	5
30	**United States**	2	2	2	2	2	3	6	6	7	7	7	7	7	7	6	6
	Total	36	36	44	49	55	58	67	73	88	94	104	103	104	106	112	114
	Average	1.2	1.2	1.5	1.6	1.8	1.9	2.2	2.4	2.9	3.1	3.5	3.4	3.5	3.5	3.7	3.8

Data source: compiled by author based on a variety of sources, including OECD regulatory database, countries' telecom regulators' websites and mobile network operators' website

Appendix C

Summary of Variables

	Ab.	Description	Source
Dependent variable	y_{it}	**Logistically transformed number of mobile subscribers per 100 inhabitants**	ITU
Reform variables	N_{it}	number of mobile network operators, used to set entry dummies	ITU, WB, OECD, regulators' & MNOs' websites
	$IndReg_{it}$	dummy variable for independent regulator: 1, if created backed by legislation and independent of decisions making; 0, otherwise;	
	Prv_{it}	dummy variable for privatization: 1, if at least 50% of assets held by private sector; 0, otherwise;	
	$IR*N_{it}$	interaction of independent regulation & the number of firms;	
	$IR*P_{it}$	Interaction of privatization & independent regulation;	
Exogenous control variables	$lnFLPrice_{it}$	fixed-line price of 3-minute local call;	ITU
	$lnGDPpc_{it}$	per capita GDP;	IMF
	t	time trend;	
Instrumented variable	$lnMobPrice_{it}$	mobile price of 3-minute local call	ITU
Additional instrumental variables	$lnPop_{it}$	total national population;	WBG-HNP
	$lnMblp_{it}$	The number of mobile subscribers served per mobile staff	ITU & MII
	$lnL1MobPrice_{it}$	1-lagged mobile price of 3-minute local call	ITU

Note: All explanatory variables are in logarithmic form, except for time trend and dummies.

Appendix D-1: Time-dependent fixed line price effect

	Including China		Excluding China	
Market structure:				
N=2	0.1306**	0.1612**	0.1333**	0.1645**
	1.66	*2.08*	*1.67*	*2.09*
N=3	0.2641***	0.2748***	0.2637***	0.2743***
	3.13	*3.32*	*3.07*	*3.26*
N=4	-0.0924	-0.0874	-0.0885	-0.0831
	-1.17	*-1.13*	*-1.10*	*-1.05*
N=5	0.1713**	0.1151*	0.1738**	0.1160*
	1.90	*1.28*	*1.89*	*1.28*
N=6	-0.3877**	-0.1248	-0.4108**	-0.1445
	-1.76	*-0.55*	*-1.84*	*-0.63*
N=7	-0.1603**	-0.2907***	-0.1582**	-0.2930***
	-1.71	*-3.00*	*-1.67*	*-2.98*
Ownership:				
PrvT	0.1974	0.2085***	0.1981***	0.2103***
	6.29	*6.75*	*5.93*	*6.40*
Independent regulator:				
IndRegT	0.0705	0.0429*	0.0741**	0.0465*
	2.32	*1.41*	*2.30*	*1.45*
*IR*PrvT*	-0.0274	-0.0471*	-0.0324	-0.0534**
	-0.95	*-1.63*	*-1.09*	*-1.79*
*IR*NT*		0.0350***		0.0361***
		4.02		*4.08*
Other:				
lnGDPpctT1	-0.1563***	-0.1477***	-0.1402***	-0.1288***
	-6.98	*-6.70*	*-5.63*	*-5.24*
Timeopen	0.3811***	0.4040***	0.3719***	0.3946***
	4.44	*4.79*	*4.24*	*4.59*
Time	1.8840***	1.7678***	1.7112***	1.5644***
	7.87	*7.48*	*6.43*	*5.94*
lnMobPricetT1	-0.0709***	-0.0614***	-0.0672***	-0.0573***
	-2.90	*-2.54*	*-2.69*	*-2.33*
lnFixedPricetT1	-0.4565**	-0.4923**	-0.3088	-0.3197
	-1.85	*-2.04*	*-1.15*	*-1.22*
lnFixedPricetT1sq	0.0303***	0.0289***	0.0244**	0.0220**
	2.95	*2.86*	*2.20*	*2.01*
	n = 447	n = 447	n = 431	n = 431
	R-sq = 0.9436 (within)	R-sq = 0.9460 (within)	R-sq = 0.9414 (within)	R-sq = 0.9440 (within)
Estimation Procedure	FEIV	FEIV	FEIV	FEIV

Appendix D-2: Joint significant test for model specification

Standard F-test:

Unrestricted Model

```
Fixed-effects (within) regression               Number of obs      =       447
Group variable: country_code                    Number of groups   =        30

R-sq:  within  = 0.9406                         Obs per group: min =        11
       between = 0.0037                                        avg =      14.9
       overall = 0.7662                                        max =        16

                                                F(21,396)          =    298.67
corr(u_i, Xb)  = -0.1021                        Prob > F           =    0.0000
```

y	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
dumNoF2	.6505017	.2294478	2.84	0.005	.1994137	1.10159
dumNoF3	.1155003	.3791463	0.30	0.761	-.6298909	.8608915
dumNoF4	-.0679834	.4828393	-0.14	0.888	-1.017232	.8812654
dumNoF5	2.403331	.9072008	2.65	0.008	.6197992	4.186863
dumNoF6	.9670847	1.032365	0.94	0.349	-1.062517	2.996686
dumNoF7	1.305356	1.851042	0.71	0.481	-2.333741	4.944453
Prv	.5001617	.2807797	1.78	0.076	-.0518435	1.052167
IndReg	.4784884	.2760584	1.73	0.084	-.0642349	1.021212
itcIndPrv	-.3892514	.4050173	-0.96	0.337	-1.185504	.4070014
lnGDPpc	.5021703	.5182983	0.97	0.333	-.51679	1.521131
dumN2t	-.007805	.0463616	-0.17	0.866	-.0989506	.0833406
dumN3t	.1112333	.0545214	2.04	0.042	.0040458	.2184209
dumN4t	.0818464	.0565853	1.45	0.149	-.0293988	.1930915
dumN5t	-.0798601	.0806627	-0.99	0.323	-.2384408	.0787207
dumN6t	-.0990981	.0885009	-1.12	0.264	-.2730884	.0748922
dumN7t	-.1338679	.1641095	-0.82	0.415	-.4565027	.1887669
Prvt	-.0313775	.0447403	-0.70	0.484	-.1193356	.0565807
IndRegt	-.0854706	.0404026	-2.12	0.035	-.1649011	-.0060402
itcIndPrvt	.1161292	.0495007	2.35	0.019	.0188122	.2134461
lnGDPpcT	-.0989183	.0219415	-4.51	0.000	-.1420547	-.055782
t	1.437561	.221735	6.48	0.000	1.001636	1.873485
_cons	-10.86474	4.904024	-2.22	0.027	-20.50592	-1.223561
sigma_u	1.1860362					
sigma_e	.65449683					
rho	.76656409	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(29, 396) =    12.06            Prob > F = 0.0000
```

Restricted Core Model

```
Fixed-effects (within) regression               Number of obs      =       447
Group variable: country_code                    Number of groups   =        30

R-sq:  within  = 0.9394                         Obs per group: min =        11
       between = 0.2986                                        avg =      14.9
       overall = 0.1926                                        max =        16

                                                F(12,405)          =    523.28
corr(u_i, Xb)  = -0.7316                        Prob > F           =    0.0000
```

y	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
N2	.1821789	.078856	2.31	0.021	.0271607	.3371971
N3	.2934269	.0832961	3.52	0.000	.1296802	.4571736
N4	-.023275	.0794031	-0.29	0.770	-.1793688	.1328188
N5	.2157196	.0880878	2.45	0.015	.0425532	.388886
N6	-.4217322	.2265503	-1.86	0.063	-.8670935	.0236292
N7	-.098461	.0945685	-1.04	0.298	-.2843673	.0874454

```
        PrvT |   .1816734   .0302353     6.01   0.000     .1222357     .241111
     IndRegT |   .1011156   .0275704     3.67   0.000     .0469166    .1553146
  itcIndPrvT |   -.078136   .0244475    -3.20   0.002     -.126196   -.0300761
  lnGDPpctT1 |  -.1133781   .0174702    -6.49   0.000    -.1477217   -.0790345
         tt1 |   .3793468   .0851389     4.46   0.000     .2119774    .5467161
           t |   1.407879   .1951713     7.21   0.000     1.024204    1.791554
       _cons |  -3.744138   .6854233    -5.46   0.000     -5.09157   -2.396707
-------------+----------------------------------------------------------------
     sigma_u |   3.560193
     sigma_e |  .65369414
         rho |  .96738616   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(29, 405) =    23.44            Prob > F = 0.0000
```

$$F - statistic = \frac{(R_u - R_r)/r}{(1-R_u)/(N-k_u-1)} = \frac{(0.9406-0.9394)/9}{(1-0.9406)/(447-(21+29)-1)} = 0.8889$$

Therefore, joint significance test: F-statistic = 0.8889< F(9,396)=1.94; we cannot reject the restricted model, so the restricted model specification is preferred.

Appendix D-3: Sensitivity check for different thresholds of mobile penetration

	Ceiling at 100	Ceiling at 150	Ceiling at 200	Ceiling capped at 99
Market structure:				
N=2	0.1822***	0.1280**	0.1285***	0.1628**
	2.31	*2.30*	*2.53*	*2.02*
N=3	0.2934***	0.1337**	0.1433**	0.2829***
	3.52	*2.10*	*2.17*	*3.36*
N=4	-0.0233	-0.0220	-0.0161	0.0037
	-0.29	*-0.37*	*-0.28*	*0.05*
N=5	0.2157***	0.0621	0.0620	0.1773**
	2.45	*0.95*	*0.97*	*1.96*
N=6	-0.4217**	-0.1083	-0.0203	-0.6232***
	-1.86	*-0.62*	*-0.12*	*-2.59*
N=7	-0.0984	-0.0334	-0.0152	-0.1250
	-1.04	*-0.44*	*-0.21*	*-1.19*
Ownership:				
PrvT	0.1817***	0.1207***	0.1061***	0.1907***
	6.01	*5.08*	*4.59*	*5.80*
Independent regulator:				
IndRegT	0.1011***	0.0516***	0.0425**	0.1026***
	3.67	*2.38*	*2.01*	*3.41*
*IR*PrvT*	-0.0781***	-0.0720***	-0.0712***	-0.0777***
	-3.20	*-3.70*	*-3.75*	*-2.88*
Other:				
lnGDPpctT1	-0.1134***	-0.1619***	-0.1661***	-0.0776***
	-6.49	*-12.86*	*-13.84*	*-4.54*
Timeopen	0.3793***	0.3398***	0.3442***	0.3718***
	4.46	*5.42*	*5.64*	*4.28*
Time	1.4079***	1.9311***	1.9571***	1.0646***
	7.21	*13.61*	*14.47*	*5.53*
	n = 447	n = 475	n = 477	n = 477
	R-sq = 0.9394 (within)	R-sq = 0.9427 (within)	R-sq = 0.9394 (within)	R-sq = 0.9365 (within)
Estimation Procedure	FE	FE	FE	FE

Appendix D-4: Number of firms and potential market size

```
Fixed-effects (within) regression               Number of obs      =       478
Group variable: country_code                    Number of groups   =        30

R-sq:  within  = 0.7284                         Obs per group: min =        14
       between = 0.1850                                        avg =      15.9
       overall = 0.3553                                        max =        16

                                                F(5,443)           =    237.61
corr(u_i, Xb)  = -0.7354                        Prob > F           =    0.0000

------------------------------------------------------------------------------
       lnNoF |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lnGDPpc |  -.1666108   .1565375    -1.06   0.288    -.4742591    .1410375
       lnPop |   .3090859   .5548317     0.56   0.578    -.7813434    1.399515
         Prv |   .1517693   .0425212     3.57   0.000     .0682009    .2353378
      IndReg |   .1118349   .0414607     2.70   0.007     .0303508     .193319
           t |   .0754698   .0087876     8.59   0.000     .0581993    .0927403
       _cons |  -3.485755   9.206409    -0.38   0.705    -21.57942    14.60791
-------------+----------------------------------------------------------------
     sigma_u |  .52336633
     sigma_e |  .25048085
         rho |  .81363404   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(29, 443) =     7.03             Prob > F = 0.0000
```

<u>Excluding China</u>

```
Fixed-effects (within) regression               Number of obs      =       462
Group variable: country_code                    Number of groups   =        29

R-sq:  within  = 0.7316                         Obs per group: min =        14
       between = 0.4526                                        avg =      15.9
       overall = 0.5672                                        max =        16

                                                F(5,428)           =    233.37
corr(u_i, Xb)  = -0.5695                        Prob > F           =    0.0000

------------------------------------------------------------------------------
       lnNoF |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lnGDPpc |  -.0152608   .2134314    -0.07   0.943     -.434765    .4042434
       lnPop |   .2630333   .5576969     0.47   0.637    -.8331323    1.359199
         Prv |   .1413675   .0434453     3.25   0.001     .0559748    .2267601
      IndReg |   .1055272   .0420218     2.51   0.012     .0229325     .188122
           t |   .0705064     .01027     6.87   0.000     .0503205    .0906923
       _cons |  -4.116812   9.295393    -0.44   0.658    -22.38711    14.15349
-------------+----------------------------------------------------------------
     sigma_u |  .31201032
     sigma_e |  .25151485
         rho |  .60612877   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(28, 428) =     6.47             Prob > F = 0.0000
```

Appendix E: Specification of market structure in the diffusion model

We suppress the regulation and privatisation dummy variables and error terms to focus on the construction of the market structure variables.

$$y_{it} = a_{it} + b_{it}t$$

$$a_{it} = \alpha_i^0 + \sum_{n=1}^{\bar{\mathrm{N}}} \alpha^n \mathrm{N}_{it}^n + x_{it}\alpha$$

$$b_{it} = \beta_i^0 + \sum_{n=1}^{\bar{\mathrm{N}}} \beta^n \mathrm{N}_{it}^n + x_{it}\beta$$

So, $y_{it} = \alpha_i^0 + \sum_{n=1}^{\bar{\mathrm{N}}} \alpha^n \mathrm{N}_{it}^n + x_{it}\alpha + \left[\beta_i^0 + \sum_{n=1}^{\bar{\mathrm{N}}} \beta^n \mathrm{N}_{it}^n + x_{it}\beta \right] t$

We want to put restrictions on the coefficients such that initial penetration is zero and there are no jumps in penetration on further entry. Penetration is zero both the day before and the day after the first entry:

$$y_{it} = 0 = \alpha_i^0 + x_{it}\alpha + \left[\beta_i^0 + x_{it}\beta\right]T_i^1 = \alpha_i^0 + \alpha^1 + x_{it}\alpha + \left[\beta_i^0 + \beta^1 + x_{it}\beta\right]T_i^1$$

These constraints imply $\alpha_i^0 + x_{it}\alpha = -\left[\beta_i^0 + x_{it}\beta\right]T_i^1$ and $\alpha^1 = -\beta^1 T_i^1$. Substituting the former:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[t - T_i^1\right] + \sum_{n=1}^{\bar{\mathrm{N}}} \alpha^n \mathrm{N}_{it}^n + t\sum_{n=1}^{\bar{\mathrm{N}}} \beta^n \mathrm{N}_{it}^n .$$

Substituting the second restriction into the diffusion equation for the monopoly period:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[t - T_i^1\right] + \beta^1\left[t - T_i^1\right]$$

Similarly, penetration should be the same just before and just after the second entry:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[T_i^2 - T_i^1\right] + \beta^1\left[T_i^2 - T_i^1\right] = \left[\beta_i^0 + x_{it}\beta\right]\left[T_i^2 - T_i^1\right] + \alpha^2 + \beta^2 T_i^2 .$$

So, $\alpha^2 = \beta^1\left[T_i^2 - T_i^1\right] - \beta^2 T_i^2$

Substituting back into the diffusion equation for the duopoly period:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[t - T_i^1\right] + \beta^1\left[T_i^2 - T_i^1\right] + \beta^2\left[t - T_i^2\right]$$

For no jump with the third entrant:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[T_i^3 - T_i^1\right] + \beta^1\left[T_i^2 - T_i^1\right] + \beta^2\left[T_i^3 - T_i^2\right] = \left[\beta_i^0 + x_{it}\beta\right]\left[T_i^3 - T_i^1\right] + \alpha^3 + \beta^3 T_i^3$$

So, $\alpha^3 = \beta^1\left[T_i^2 - T_i^1\right] + \beta^2\left[T_i^3 - T_i^2\right] - \beta^3 T_i^3$

Substituting back into the diffusion equation for the triopoly period:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[t - T_i^1\right] + \beta^1\left[T_i^2 - T_i^1\right] + \beta^2\left[T_i^3 - T_i^2\right] + \beta^3\left[t - T_i^3\right]$$

For no jump with the n^{th} entrant, $\alpha^n = \left\{\sum_{k=1}^{n-1} \beta^k\left[T_i^{k+1} - T_i^k\right]\right\} - \beta^n T_i^n$. Substituting into the general diffusion equation applicable for all periods:

$$y_{it} = \left[\beta_i^0 + x_{it}\beta\right]\left[t - T_i^1\right] + \sum_{n=1}^{\bar{\mathrm{N}}} \beta^n N_{it}^n \text{, where } N_{it}^n = \left\{\mathrm{N}_{it}^n\left[t - T_i^n\right] + \sum_{k=n+1}^{\bar{N}} \mathrm{N}_{it}^k\left[T_i^{n+1} - T_i^n\right]\right\}.$$