The competitive effect of entry in mobile markets*

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Abstract

First-mover advantages are important in mobile markets. They arise because of direct network effects, switching costs and economies of scale. Competition authorities and regulators care about the consequences of such advantages because they can potentially deter entry. Using data for the U.S. digital mobile markets, I empirically estimate a static two-type entry model. This allows me to quantify the advantage early movers have relative to later entrants. My measure is the impact of competitors' entry on the profits of incumbents and entrants. Controlling for market characteristics, I find evidence of an asymmetric competitive effect favoring incumbents. Furthermore, I find evidence that incumbents enjoy supply-side advantages when they deploy their networks. My results have implications for policy makers who seek to promote effective competition into local mobile markets.

Keywords: First-mover advantages, competition, empirical entry model, mobile industry.

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1 Introduction

The dynamics of competition in the mobile industry is influenced by the existence of first-mover advantages. Lieberman and Montgomery (1988) explain that such advantages arise endogenously within a multi-stage process, where some asymmetry is generated in the first stage. This first-mover opportunity enables early entrants to benefit from a head start over rivals. Once this asymmetry is generated, firms may use a variety of mechanisms to exploit its position; enhancing the magnitude or durability (or both) of profits.

There are several reasons why first-mover advantages may exist.[1] On the demand side, switching costs and network externalities bind customers to firms if products are incompatible, locking them into early choices (Farrell and Klemperer (2007), Klemperer (1987)). First-mover advantages are also associated to the recognition of (and loyalty to) the brand (Schmalensee (1982), Gerpott et al. (2001)). On the supply side, there are also many factors explaining the competitive advantage of early entrants in the market, such as sunk costs and economies of scale (Schmalensee (1981)). Moreover, later entrants need time to build a reliable network, which creates coverage differences that put them in disadvantage with respect to incumbents. Finally, later entrants deal with less availability of land space for the installation of antennas with respect to incumbents.

Although first-mover advantages exist, it is not clear whether incumbents exert stronger competitive impact over entrants' profits. New competitors may enter with bigger discounts, counteracting the switching costs and network externalities' effect. Alternatively, later entrants may fight against brand-prestige by offering new services that may seem attractive as in opposition to incumbents' offer.[2] It should also be taken into account that entrants into mobile markets are not necessarily weak competitors since many of them were previously operating in other markets.

This paper studies the interaction among firms, once an important technological change occurs, as it is the introduction of digital technology. My purpose is to estimate whether the entry of incumbent cellular operators have a greater competitive impact over PCS digital entrants' profits than vice versa. Taking advantage of the existence of local markets in the United States, I use a static two-type entry model.[3] The general idea behind these models

[1] A more detailed overview about the determinants of first-mover advantages (demand- an supply-side factors) in the digital mobile markets is provided in section 2.

[2] In the U.S. digital mobile market, for example, entrants offered "free-contracts", while incumbents were known for offering long-term contracts (FCC (1997)).

[3] To the best of my knowledge, no structural entry model has been used before to analyze mobile markets.

is that one can infer information about the competitive impact of new entrants from the observed entry decisions of firms in a cross section of local markets. I find evidence of substitution among digital firms. Furthermore, the estimates show that incumbent cellular operators exert a significantly negative effect over PCS entrants' payoffs, but entrants do not exert a statistically significant competitive effect over incumbents, which it is in line with my expectations, given the presence of first-mover advantages.

The introduction of digital technologies in the United States creates a promising scenario for this study. In first place, the timing of entry is exogenously determined by the government.[4] Firms can only enter the market at times additional licenses are awarded. The Federal Communication Commission (FCC) started the licensing process of 120 MHz of spectrum for Broadband Personal Communications Services (PCS) in 1994. This process not only gave room for the entry of up to six new digital players in each local market, but it also impulsed installed analog firms to take preemptive strategies and upgrade their systems to digital technology. Therefore, the only choice firms have to make in this scenario is to enter or not to the digital market.

Secondly, the geographic market definition used by the FCC to award spectrum divide the country into different non-overlapping markets. This allow us to observe variability on entry choices and relate them with different markets' characteristics. Finally, the disruptive property of this technology somehow form a level-playing field among operators. That is why I specifically study digital mobile markets, separately from analog technology, although I consider its competitive effect as substitute technology in the specification of payoffs.

Because of the increasing importance that mobile service acquired, most of the empirical literature has focused on studying which factors determine its diffusion (Gruber and Verboven (2001), Gruber (2001), Koski and Kretschmer (2005)). In general, the debate has centred on how and when entry should be promoted, and whether digital technology standards should be imposed centrally (like the GSM technology in Europe) or selected by the market forces in a decentralized way (like digital technologies in the U.S., where three different and incompatible digital standards (CDMA, TDMA, GSM) were installed by mobile operators).[5]

[4]The majority of empirical studies on first-mover advantages estimate the effect of the order of entry over market shares (market pioneers have substantially higher market shares than later entrants). The strong association between order of entry and market share is questioned because the timing of entry of a firm might be a choice variable that depends on the perceived market expectations after entry (Bijwaard et al., 2008).

[5]Gruber and Verboven (2001), for example, study the effect of regulatory intervention on technological standardization and timing of entry to analyse the impact over diffusion. Gruber (2001) studies the effect of the total number of competitors, the timing of initial adoption, and the speed of adoption over the speed of diffusion. Both studies used cross sectional data of

Only a few empirical studies are available to inform about the strength of competition of carriers in the mobile industry. Bijwaard et al. (2008) examine the existence of first-mover advantages by using dynamic and static models of market share for 16 European mobile markets from 1990 to 2006. During this period, different technologies were used (1G in the early and mid 1990s, 2G from late 1990s until the introduction of 3G near 2006), but no technological distinction is made. They estimate the impact of market concentration (Herfindahl-Hirschman Index) and penetration rates on the development of market shares of entrant firms. Their results show evidence of early-mover advantages, mainly caused by the influence of the penetration rate: it pays to enter when still few people have contracted mobile service. They also find that it is significantly easier to enter a highly concentrated industry.

The closest empirical research to my purpose is a recent study by Seim and Viard (2011), who measure the effect of PCS digital competitors over analog cellular carriers' technological change decision and price discrimination strategies in the U.S. mobile markets between 1996 and 1998. They find that in markets with more competition, analog firms are more likely to upgrade their systems and phase out their analog plans. Furthermore, firms' entry causes an increase in the number of plans and the amount of discounts offered, specially for high-usage consumers.

Seim and Viard (2011) provide, in addition, some insights about the strategies of competition of mobile firms. They find that competition induces firms to target their offerings to the customers whose demand is best served by their chosen technology. This means that analog carriers offer more low-usage plans, given their capacity constrains, when facing more entry; and digital carriers are more focused on competing for high-usage clients. This research attempts to complement these findings by measuring the competitive interaction among firms, once digital technology is adopted.

This model is inspired by Greenstein and Mazzeo (2006), who analyzed the competitive dynamics between regional and national competitive local exchange carriers (CLECs) in the U.S. in 1999 and 2002. It is also related to Mazzeo (2002), Schaumans and Verboven (2008), and Cleeren et al. (2010) by allowing for asymmetric competitive effects.

This paper is organized as follows. Section 2 contains information about the U.S. digital mobile markets. Section 3 explains the empirical methodology. Section 4 describes the data. Parameter estimates appear in Section 5. Finally, Section 6 concludes.

different countries to compare the impact of various factors over the growth rate of mobile service.

2 The deployment of digital mobile services in the U.S.

In the United States, as in many other countries, the entry of new firms into mobile industry has been closely related to the introduction of new technologies that allowed a more efficient use of the radio spectrum. Regulatory policies related to the use of technological standards and the timing of entry have also played an important role on the dynamics of competition.

One of the most important technological changes experienced in the 1990s was the introduction of digital technologies in replace of analog systems. Analog systems, or first-generation (1G) systems, used the allocated radio spectrum in a relatively inefficient manner. The introduction of digital technologies led to a change in performance, capacity and quality of mobile telecommunications. This innovation, which first included second-generation systems (2G) and gradually evolved to third (3G) and fourth (4G) generation systems, improved capacity and sound quality of voice transmission by easier computer regeneration of digital pulses. Moreover, these systems allowed operators to offer new data services, such as short messaging services (SMS), and to secure privacy of conversations because digital signals cannot be eavesdropped (Gruber (2005)). Finally, by allowing for new features such as call waiting and caller ID, digital technology increased vertical differentiation in service provision.[6]

Before digital technology was introduced in the U.S. mobile industry, two cellular companies were operating the market. Cellular telephone service initiated in 1981, when the FCC decided to license two competing cellular systems in every cellular market area (CMA) [7]. One system should be operated by a separate subsidiary of a local telephone company and the other should be unaffiliated with any local telephone company (FCC (1995)). At that time, mobile service was conceived almost exclusively for business uses. It was not until the introduction of digital systems, due to its more efficient use of the spectrum, that mobile operators began to target their marketing strategies towards the mass consumer market, which increased the size of the market and made entry more attractive.

Cellular carriers used a specific analog technical standard, AMPS (Advanced Mobile Phone System), to operate their systems. This standard was imposed by the FCC to make it easy for subscribers to switch carriers without having to buy new equipment. In 1988,

[6] Prior to the introduction of digital technology, vertical differentiation was primarily due to differences in call quality in the local calling area (FCC (1997)).

[7] CMA is the geographic market definition used by the FCC for awarding the licenses. There were 306 metropolitan statistical areas, and 428 rural service areas covering the entire country.

this regulation was relaxed and cellular carriers were permitted to adopt new technologies, as long as they continued to support their analog systems. This decision was taken to encourage the development of new digital equipment that enables the industry to increase capacity of existing channels. Digital technology, however, was not introduced until the licensing process of digital PCS spectrum started in 1994, when some operators upgraded their systems as a preemptive competitive strategy against the entry of future digital competitors. By 1996, cellular firms installed different incompatible digital technologies: TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access).

In the early 1990s, the FCC allocated 120 MHz of spectrum for Broadband Personal Communications Services (PCS), which could support the entrance of up to six new competitors in each market. The geographic market definition for this new licensing process differed from the one used for cellular markets. The country was divided in 51 Major Trading Areas (MTAs), which contained multiple cities or states. The MTAs were subdivided into 493 Basic Trading Areas (BTAs) the same size as or slightly larger than the corresponding CMA (Seim and Viard (2011)).

The spectrum was divided into 6 bands: 3 bands of 30 MHz each -called Blocks A, B and C-, and 3 bands of 10 MHz -Blocks D, E, and F-. By June 1995, the FCC had licensed Blocks A and B for the 51 MTAs. The A and B Block auctions were open to all interested bidders. The majority of these licenses went to companies, or joint ventures of companies, that were established in the cellular business.[8] In May 1996, 493 BTAs licenses from Block C were awarded. The C Block auction was limited to entrepreneurs (companies owned by women and minority groups, as well as rural telephone companies).[9] In January 1997, the FCC completed the simultaneous D-E-F block auction. This auction attracted firms from Blocks A, B and C, seeking to increase their capacity or to expand their services to different geographic areas (FCC (1997)). The F Block licenses were limited to entrepreneurs, but entrepreneurs also won licenses in the D and E Blocks.

Broadband PCS systems operated in a digital format upon their inception. Besides

[8]Several cellular carriers used broadband PCS licenses to expand the size of their network. To ensure competition, the FCC established cellular carriers should not obtain more than 10 MHz of PCS spectrum in markets where they already owned cellular licenses. Additionally, no carrier should have more than 45 MHz of total spectrum (cellular, PCS or Specialized Mobile Radios (SMR)) in a given market.

[9]This "entrepreneurs" auction was designated to fulfill some social requirements stipulated by the Omnibus Budget Reconciliation Act of 1993. The FCC provided bidding credits and gave to entrepreneurs the chance to pay for their licenses in quarterly instalments over a ten-year period at below market interest rates. Nevertheless, due to failure in the required down payments, some of the licenses had to be reauctioned in July 1996.

TDMA and CDMA standards, some licensees installed GSM (Global System for Mobile Communications) network equipment. Because of the propagation characteristics of the broadband PCS frequencies, many more cells and base stations had to be installed to provide the service. By 1996, eight PCS licensees had already inaugurated their service in portions of 29 MTAs.[10] Many other PCS licensees from Blocks A and B introduced their service during 1997.

While PCS licenses were allocated, Nextel Communications, the most important specialized mobile radio (SMR) provider, also entered digital mobile markets by providing services with iDEN technology (TDMA standard). By 1998, Nextel had entered 71 of the 100 largest cellular markets (Seim and Viard (2011)). Despite Nextel focused on business customers and it mainly used radio technology, the FCC treated this company as a mobile carrier similar to the PCS entrants. For the purpose of this study, I also include this company as digital mobile competitor.

As it can be observed, various incompatible standards and different frequency bands were used to provide digital service in the U.S. mobile market. Since it is not my purpose to directly study neither the importance of standardization[11], nor distinguishing the specific characteristics of each type of digital technology, I am going to group all digital standards in a sole group and refer to them with the general definition of digital technology. To address my research question, among those digital carriers, I distinguish two types: those installed in an early stage and switched from analog to digital technology, cellular incumbents, and those who began operations afterwards, PCS entrants and Nextel.[12]

Competition and the presence of first-mover advantages. The dynamics of competition in the digital mobile market is influenced by the existence of first-mover advantages that put incumbents in a better position to compete against later entrants. There are several factors that generate those advantages.

On the demand side, network externalities are well recognized as an important source of early-mover advantages. Direct positive network externalities exist when a service is more valuable to a user the more users adopt the same service (Katz and Shapiro (1985)). In the context of this study, considering that firms use incompatible digital standards, consumers may prefer to contract incumbents' services, given that they count with a bigger base of

[10]Sprint, Western Wireless, Bellsouth, Powertel, Pacific Bell, Primeco PCS, Omnipoint, and GTE Mobilnet (FCC (1997)).

[11]It is indirectly considered as a factor that contributes to the creation of first-mover advantages.

[12]See Section 4 for a detailed definition.

clients in comparison with later entrants.

First-mover advantages may also arise from buyer switching costs. With switching costs, late entrants must invest extra resources to attract customers away from the first-mover firm (Klemperer (1987)). Switching costs are commonly related to the fact that consumers have to make some initial investments in adapting to firms' offer. Contractual costs associated to the sign of long-term contracts and high contract termination fees also create switching costs. The FCC reports that this type of contracts were indeed offered, especially by cellular firms (FCC (1997)).

Other forms of switching costs are associated with the cost people incur when changing their mobile number (number portability was not implemented yet during the time of this study). Bijwaard et al. (2008) point out that the time and effort it takes to inform friends or business relations of a change in number deter consumers from changing providers.

First-mover advantages are also related to the recognition of the brand. This feature is not specific to network industries, Schmalensee (1982) study how the uncertainty about the quality new firms offer may motivate consumers to contract from incumbents. An empirical study made for Germany (Gerpott et al. (2001)) shows that brand-loyalty in mobile industry is associated with the satisfaction of consumers with the quality of the service. They find that satisfied clients are less likely to change providers, even when entrants offer lower prices and good services.

On the supply side, the presence of sunk costs and economies of scale create early-mover advantages (Schmalensee (1981)). By the time that later entrants come into play, incumbents may have covered some of their sunk cost, or possess a bigger consumer base that lower the level of average costs. Then, incumbent firms may price below its competitors, thereby further increasing its market share.

Furthermore, in this particular case, because it takes time to roll-out infrastructure, the time of entry generates an advantage for cellular operators in terms of coverage. Even though roaming agreements allowed firms to use other carriers' infrastructure, the high roaming fees demotivated consumers to contract service with firms with small coverage (FCC (1995)). Additionally, later entrants usually had to deal with more stringent regulation policies, and less availability of commercial areas, for the installation of antennas.

There are also factors pointing at advantages for late entrants in mobile markets. In particular, later entrants may obtain advantages by learning from incumbents' mistakes. Furthermore, digital entrants may free ride advertisement investments made by incumbents

to make digital plans known by a large group of consumers. Finally, later movers can also benefit because technological or demand uncertainties may have decreased by the time of entry. (Bijwaard et al. (2008)).

In summary, different forces come into play to explain the dynamics of competition in digital mobile markets. This modelling approach measures the competitive strength of both types of firms, cellular digital incumbents and entrants. It is important to note, however, that it does not attempt to identify the source of this competitive strength.

3 Empirical Methodology

Structural entry models have been extensively studied after seminal works of Bresnahan and Reiss (1991) and Berry (1992) were published. These models can be divided into two big groups: static and dynamic models.[13] For the purpose of this study, I am going to use a static two-type entry model, assuming free entry equilibrium condition[14]. As in previous empirical works, it is supposed that the outcome of the static equilibrium game provides a reasonable first approximation to the underlying repeated firm interaction that determines the evolution of an industry over time.

This model allows us to make inferences about unobserved profits, and the nature of competition, from observed market-specific characteristics and firms' entry choices (Bresnahan and Reiss (1991)). It is assumed that firms choose to enter (and stay in) the market if they expect to earn positive profits *expost*. In this way, the number of firms in the market "reveal" information about firms' profitability.

This idea is related to the revealed preference arguments used by discrete choice models of consumer behavior (single-agent and multiple-agent's qualitative choice models), where consumers are assumed to maximize their latent utility. In this case, firms are assumed to maximize latent profits.

There is, however, an important difference between the discrete choice models applied to individual behaviour and those applied to oligopolistic markets like this one: behavior is driven by the strategic interaction among individual decisions' makers. It is, therefore, necessary to base estimation on an oligopolistic equilibrium concept rather than on an individual choice function. This is done by using game-theoretic models and Nash equilibrium

[13] See Berry and Reiss (2007) for a review of static models, and Draganska et al. (2008) for dynamic entry models.

[14] The allocation of spectrum allowed the entry of up to six digital firms in a given local market (FCC (1995)). All markets from this sample, except one, have less than 6 digital carriers by 1998.

concept (Berry and Reiss (2007)).

The advantage of using a two-type entry model is that it allows to model heterogeneous firms. As noted by Greenstein and Mazzeo (2006), given that differentiation may determine the strength of *expost* competition, it helps to explain the observed market structure in a more accurate way. Firms may prefer to enter in markets where their competitors offer different types of services because price competition is less tough afterwards. Additionally, it is assumed that the observed number of firms is a result of a game where two types of players interact. Not considering the strategic behavior behind this interaction may lead to obtain biased estimates of other parameters included in the profit function (Draganska et al. (2008)). Finally, heterogeneous firms may respond differently to similar economic conditions (demand- or cost-side factors).

It is important to mention that there are important assumptions underlying structural entry models. The first one is that firms' entry decisions are made on a market-by-market basis independently. It means that profits are economically independent across markets (Greenstein and Mazzeo (2006)). This is a crucial abstraction, specially when studying network industries as mobile industry. Berry and Berry and Reiss (2007) state that this assumption is more realistic if we are using a cross section of different firms in different markets, and not the same firms over different markets. Berry (1992), for airline networks, explains that ideally firms might be modelled as choosing a network in each period, considering its own sunk investments and its expectation of rival's actions. Unfortunately, the estimation of latent profits would require information of demand factors and costs at network level, information that is unavailable for this study.

Another important assumption is related to the equilibrium concept and its multiplicity nature. This nonuniqueness of equilibria creates identification problems since the same underlying conditions can result in different observed outcomes. The literature of entry models show different solutions to deal with this multiplicity issue. Modelling a sequential move game, instead of simultaneous moves, and using Subgame Perfect equilibrium concept, is one of the most popular solutions.[15] It started with Berry (1992), who introduced a sequential move structure for heterogeneous firms. The sequential move structure of the game guarantees unique predictions on the number of firms of each type.

Mazzeo (2002), following this line of research, models a two-type entry game, where it is

[15]Another solution to the multiplicity problem is proposed by Seim (2006), who model a game with incomplete information and find a unique Bayesian Nash equilibrium.

assumed that firms of the same type are identical. That is, for a given market structure, the same-type choice yields the same level of profits for every firm. However, profits may differ for the different types within the market. He models a two stage game: in the first stage, firms are assumed to play a Stackelberg entry game where they sequentially decide on entry and type (the most profitable firm move first); in the second stage, firms compete and payoffs are determined.[16]

Schaumans and Verboven (2008), and Cleeren et al. (2010) modify Mazzeo's work by assuming that firms choose their type (among two types also) before entry decision is taken. In addition, they assume that firms follow a predetermined sequence of entry move. In both cases it is assumed that one of the two types always enter first into the market, but firms may also intercalate entry order.

This model is based on this last specification for two reasons. First, the definition of types, incumbents and entrants, have already imposed a predetermined entry sequence (incumbents, by definition, have entered first to the market). Second, it simplifies the estimation procedure because the corresponding likelihood function will require the estimation of rectangular areas of integration (see figures in next subsection).[17]

3.1 Econometric Framework

This model is inspired by Greenstein and Mazzeo (2006), who apply a similar approach to test differentiation and study competitive dynamics among regional and national competitive local exchange carriers in the United States. It is also related to Mazzeo (2002), Schaumans and Verboven (2008), and Cleeren et al. (2010) by allowing for asymmetric competitive interaction. The structure of the entry game is based on Cleeren et al. (2010), as it is detailed below.

Firms are defined as incumbents (I) and entrants (E) across each local market. Market structure is now represented by an ordered pair (N_I, N_E), which indicates the number of observed firms of each type. Firms play a two periods game: in the first period, potential entrants take their entry decision; in the second period, they compete and determine their level of profits.

I assume that firms of the same type are identical, so they have the same profit function. Nevertheless, we account for differences between types. Latent profits for each type $i = I, E$

[16] The same type of game is applied in Greenstein and Mazzeo (2006).

[17] Non rectangular areas need to be estimated with Stackelberg entry game, the condition of "most profitable firms enter first" determine it (Cleeren et al. (2010)).

in local market m, Π_m^i, are given by

$$\Pi_m^i = \bar{\pi}_m^i(N_I, N_E) - \varepsilon_m^i \tag{1}$$

where $\bar{\pi}_m^i(N_I, N_E)$ denotes the deterministic part, which depends on the number of both types of firms; and ε_m^i, the type-specific error term, denotes the unobserved part of the function. The error term is assumed to be independent of the observables, and identical for each firm of the same type in a given market. A firm who does not enter receive zero profits.

The competitive interaction among firms, which relates the unobserved profitability with the observed market structure, includes the interaction within and between types. I first model the competitive interaction among the same type of firms. I assume that firms of the same type are substitutes, which means that an additional entrant of type i decreases the level of profits Π_m^i.

Assumption 1: Substitutability among firms of the same type

$$\begin{aligned} \bar{\pi}_m^I(N_I+1, N_E) &< \bar{\pi}_m^I(N_I, N_E) \\ \bar{\pi}_m^E(N_I, N_E+1) &< \bar{\pi}_m^E(N_I, N_E) \end{aligned} \tag{2}$$

Second, I model the competitive interaction among firms of different types. I assume that incumbents and entrants are substitute or independent (equation 3(a)). If the condition holds with strict inequality, an additional entry of type E (I) negatively affects Π_m^I (Π_m^E). When it holds with equality, firms are not affected by competitors of different types. Additionally, I assume that the competitive effect exerted by the same type of firms is stronger than the one exerted by firms of different type (equation 3(b)). The belief behind this assumption is that firms of the same type target a similar consumer segment with similar marketing strategies.

Assumption 2: Substitutability among firms of different types

$$\begin{aligned} &(a) \quad \begin{aligned} \bar{\pi}_m^I(N_I, N_E+1) &\leq \bar{\pi}_m^I(N_I, N_E) \\ \bar{\pi}_m^E(N_I+1, N_E) &\leq \bar{\pi}_m^E(N_I, N_E) \end{aligned} \\ &(b) \quad \begin{aligned} \bar{\pi}_m^I(N_I+1, N_E-1) &< \bar{\pi}_m^I(N_I, N_E) \\ \bar{\pi}_m^E(N_I-1, N_E+1) &< \bar{\pi}_m^E(N_I, N_E) \end{aligned} \end{aligned} \tag{3}$$

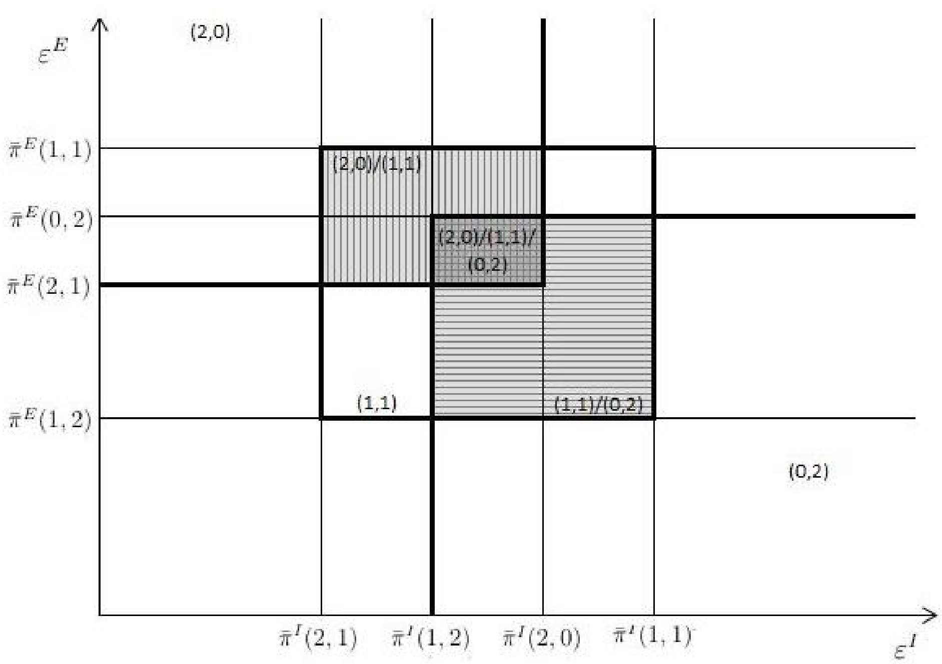
Assumptions 1 and 2 are in line with previous empirical entry literature, and together characterize the Nash equilibria of the game. (n_I, n_E) is a Nash equilibrium outcome of the entry game if and only if the error terms satisfy the following conditions:

$$\begin{aligned} \bar{\pi}^I_m(n_I+1, n_E) < \varepsilon^I_m \leq \bar{\pi}^I_m(n_I, n_E) \\ \bar{\pi}^E_m(n_I, n_E+1) < \varepsilon^E_m \leq \bar{\pi}^E_m(n_I, n_E) \end{aligned} \tag{4}$$

When (4) is satisfied, it is profitable for (n_I, n_E) firms to enter market m ($\Pi^I_m(n_I) \geq 0$,$\Pi^E_m(n_E) \geq 0$), but it is not the case for (n_I+1, n_E+1) firms ($\Pi^I_m(n_I+1) < 0$,$\Pi^E_m(n_E+1) < 0$). Assumption (1) guarantees the existence of such equilibrium.

Nevertheless, (n_I, n_E) may not be the unique Nash equilibrium outcome. For some realizations of $(\varepsilon^I, \varepsilon^E)$, there may be multiple outcomes that, given assumptions 1 and 2, satisfy conditions (4). Figure 1 illustrates one specific example for the case in which there are two potential entrants of each type. The bold lines delineate the areas of $(\varepsilon^I, \varepsilon^E)$ for which the market configuration (1,1),(0,2) and (2,0) are the Nash equilibria. It can be observed that there are areas in which (1,1) show multiplicity with (0,2) (shadow with horizontal lines), and areas in which it shows multiplicity with (2,0) (shadow with vertical lines). For some realizations of $(\varepsilon^I, \varepsilon^E)$, there are areas in which even the three outcomes are Nash equilibria.

Figure 1: Multiple Nash equilibria



Note that the area of multiplicity would disappear if firms of different types are independent, that is, if Assumption 2(a) holds with equality. For instance, if $\bar{\pi}^I_m(1,2) = \bar{\pi}^I_m(1,1)$, and $\bar{\pi}^E_m(1,2) = \bar{\pi}^E_m(0,2)$, the overlapping areas between (1,1) and (0,2) would disappear. As the degree of substitutability increases, the multiplicity area increases, but it will never be the case that both areas completely overlap since Assumption 2(b) assures that the effect of different type of firms will never be as strong as the one exerted by the same type of firms. In Figure 1, $\bar{\pi}^I_m(2,1)$ will always be lower than $\bar{\pi}^I_m(1,2)$.

Cleeren et al. (2010) show that, in general, for N_I and N_E potential entrants, the multiple Nash equilibria, under assumptions 1 and 2, can be characterized by three claims.[18] If Assumption 2(a) holds with strict inequality:

- *Claim 1.* (n_I, n_E) may only show multiplicity with Nash equilibrium outcomes of the form $(n_I + k, n_E - k)$, where k is a positive or negative integer. In Figure 1, the outcome (1,1) show multiplicity with (2,0), or (0,2), but not, for example, with (1,0). There is a unique prediction of the total number of entrants, $n = n_I + n_E$.
- *Claim 2.* (n_I, n_E) necessarily shows multiplicity with (n_I+1, n_E-1) and (n_I-1, n_E+1).
- *Claim 3.* When (n_I, n_E) shows multiplicity with $(n_I + k, n_E - k)$, the multiplicity area is necessarily a subset of the multiplicity area of $(n_I + 1, n_E - 1)$ for $k > 0$, and a subset of the multiplicity area with $(n_I - 1, n_E + 1)$ for $k < 0$. In Figure 1, whenever $(2,0)$ show multiplicity with (0,2), the multiplicity area is a subset of the multiplicity area with $(1,1)$.

Together, claims 1-3 imply that the area for which (n_I, n_E) show multiplicity with any other Nash equilibrium is given by the areas of overlap with (n_I+1, n_E-1) and (n_I-1, n_E+1). The area of multiplicity with $(n_I + 1, n_E - 1)$ is defined by:

$$\begin{aligned} &\bar{\pi}^I_m(n_I + 1, n_E) < \varepsilon^I_m \leq \bar{\pi}^I_m(n_I + 1, n_E - 1) \\ &\bar{\pi}^E_m(n_I + 1, n_E) < \varepsilon^E_m \leq \bar{\pi}^E_m(n_I, n_E). \end{aligned} \tag{5}$$

Similarly, the area of multiplicity with $(n_I - 1, n_E + 1)$ is given by:

$$\begin{aligned} &\bar{\pi}^I_m(n_I, n_E + 1) < \varepsilon^I_m \leq \bar{\pi}^I_m(n_I, n_E) \\ &\bar{\pi}^E_m(n_I, n_E + 1) < \varepsilon^E_m \leq \bar{\pi}^E_m(n_I - 1, n_E + 1). \end{aligned} \tag{6}$$

[18] The complete proof of this claims is available at Cleeren et al. (2010).

In order to obtain a unique prediction, additional structure to the game is needed. I assume that firms' entry decisions are taken sequentially, and use a refined equilibrium concept, subgame perfect Nash equilibrium. Specifically, a predetermined order of entry moves in which incumbents are the ones who move first is imposed.[19]

With this new structure, I am able to assign a unique outcome to every realization of $(\varepsilon^I, \varepsilon^E)$:

a) Whenever (n_I, n_E) and $(n_I + k, n_E - k)$, with $k > 0$, are both Nash equilibria, $(n_I + k, n_E - k)$ will be chosen as the unique subgame perfect equilibrium. In my example, when (1,1) and (2,0) are Nash equilibria, considering that incumbents move first, and that two of them could enter and obtain positive profits, the equilibrium with one incumbent will not be sustained. After one incumbent enter the market, the second incumbent will prefer to enter before an entrant take their place. Once two incumbents are present, no entrants would decide to enter and (2,0) will be the unique solution.

b) Whenever (n_I, n_E) and $(n_I + k, n_E - k)$, with $k < 0$, are both Nash equilibria, (n_I, n_E) will be the only subgame perfect Nash equilibrium. For instance, when (1,1) and (0,2) are Nash equilibria, (1,1) will be chosen as equilibrium outcome.

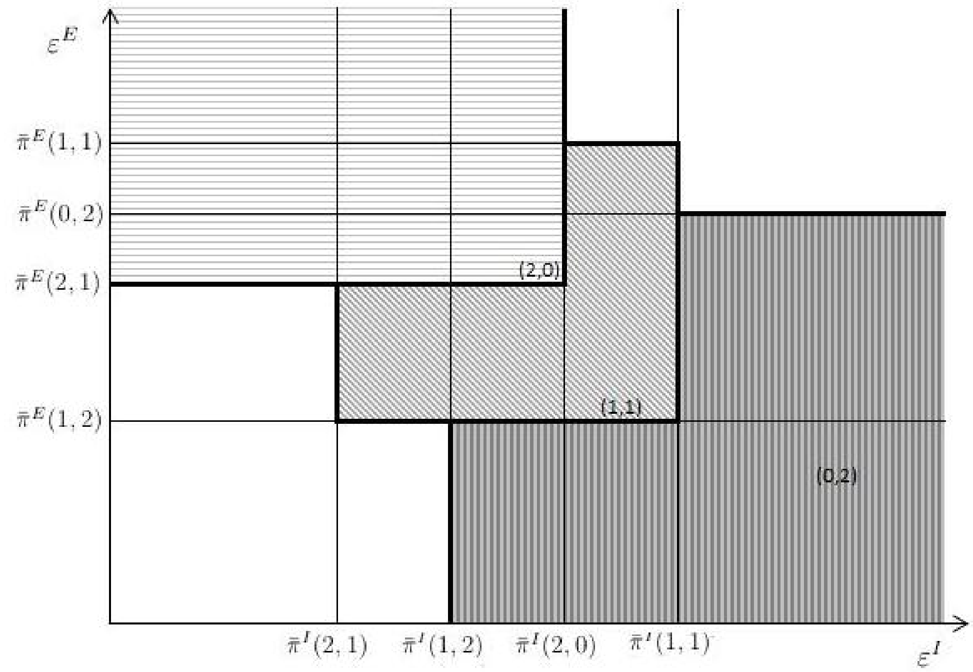
In other words, the equilibrium with the largest number of incumbent firms will be chosen as the only subgame perfect Nash equilibrium whenever multiple Nash equilibria exist. Figure 2 shows how multiple Nash equilibria become unique subgame perfect equilibria. The area where (n_I, n_E) is the equilibrium outcome is equal to the area where (n_I, n_E) is Nash equilibrium (as given by (4)) minus the area of multiplicity with $(n_I + 1, n_E - 1)$ (as given by (5)).

Assuming $(\varepsilon^I, \varepsilon^E)$ has a bivariate standard normal distribution, I can now derive the probability of observing (n_I, n_E) in market m:

$$\begin{aligned} P(N_I = n_I, N_E = n_E) = & \int_{\pi^I_{(n_I+1,n_E)}}^{\pi^I_{(n_I,n_E)}} \int_{\pi^E_{(n_I,n_E+1)}}^{\pi^E_{(n_I,n_E)}} \phi(u_I, u_E) \mathrm{d}u_I \mathrm{d}u_E \\ & - \int_{\pi^I_{(n_I+1,n_E)}}^{\pi^I_{(n_I+1,n_E-1)}} \int_{\pi^E_{(n_I+1,n_E)}}^{\pi^E_{(n_I,n_E)}} \phi(u_I, u_E) \mathrm{d}u_I \mathrm{d}u_E, \end{aligned} \tag{7}$$

[19] This new structure allow me to reproduce the actual entry process.

Figure 2: Subgame Perfect Nash equilibria



where $\phi(.)$ denotes the density function of the standard bivariate normal distribution with a correlation parameter between ε^I and ε^E, ρ. Note that if firms of different types are assumed independents, it is not necessary to subtract the second term (there would not be multiple Nash equilibria), and the model reduces to a bivariate ordered Probit model. If, in addition, I assume that ρ is equal to zero, the problem reduces to two separate ordered Probit models, i.e., one-type entry model for each type.[20] These two separate ordered Probits will be also estimated as a first step towards the two-type entry model.

Once defined the probability of observing each market configuration, I can construct the likelihood function to be maximized. The likelihood function for M local markets is defined as

$$L = \prod_{m=1}^{M} \text{Prob}[(N_I, N_E)]_m^O, \tag{8}$$

where $(N_I, N_E)_m^O$ is the observed configuration of firms in market m. Hence, if $(N_I, N_E)^O = (1,1)$ for market m, the contribution to the likelihood function for market m is Prob[(1,1)] (Mazzeo (2002)).

[20]For a detailed explanation about one-type entry model see (Cleeren et al., 2006).

3.2 Specification

The deterministic part of firms' profits in (1) is specified as a linear function of market level characteristics (X), and observed entry choices of both types of firms in the market. I allow the effects associated with the variables in vector X to vary by type of firm (β_i). In addition, I model asymmetric competitive effects by including type-specific parameters to measure the impact of an additional entry of the same-type and different-type of firms (as in Schaumans and Verboven (2008), and Cleeren et al. (2010)).

$$\begin{aligned} \bar{\pi}_m^I &= X_m\beta_I - \alpha_I^{n_I} - \gamma_I^{n_E}, \\ \bar{\pi}_m^E &= X_m\beta_E - \alpha_E^{n_E} - \gamma_E^{n_I}. \end{aligned} \tag{9}$$

X includes, as before, the demand-side and cost-side determinants, plus the effect of substitute analog technology. The parameters $\alpha_i^{n_i}$ and $\gamma_i^{n_{-i}}$ are fixed effects, measuring the impact of entry of the same-type and different-type of firms on profits, respectively. A positive difference between $\alpha_i^{n_i}$ and $\alpha_i^{n_i-1}$ is interpreted as evidence of substitution, i.e., the entry of an additional firm of the same type has a negative impact over profits. Similarly, a positive difference between $\gamma_i^{n_{-i}}$ and $\gamma_i^{n_{-i}-1}$ is interpreted as a negative effect of an additional firm of different type.

The identification of the parameters are done parametrically. As I assume that the distribution function is a standardized bivariate normal distribution, I restrict the standard deviation of the error terms to be equal to one. The scale of payoffs is not identified.

Identification of the parameters representing competitive effects comes from comparing similar markets with different structures or, conversely, different markets with similar structures (Greenstein and Mazzeo (2006)). Note that the competitive effects among firms of different types (the γs) are identified through these parametric assumptions. As Schaumans and Verboven (2008) explain, conditional on observed market characteristics, the number of incumbents and entrants may be correlated because of substitution effects, the γs, or because of unobserved market characteristics affecting both types' payoffs, captured through ρ. I can distinguish between both possibilities because I assume that the error terms have a bivariate normal distribution.

The estimated fixed effects, $\alpha_i^{n_i}$ and $\gamma_i^{n_{-i}}$, should be increasing in order to keep the model internally consistent with assumptions 1 and 2(a) (Schaumans and Verboven (2008), Cleeren et al. (2010)). To be consistent with assumption 2(b), the difference between consecutive αs should be greater than the difference between consecutive γs.

Finally, these competitive effects are not all identified. The first same-type competitive effect are set equal to zero, $\alpha_i^{1st} = 0$[21]. Analogously, the first different-type competitive effect is normalized to zero,$\gamma_i^{1st} = 0$. As the constant term β_i^0 takes the value of zero for both types, all the rest of αs and γs should take a positive value.

Note that by estimating type-specific competitive effects, it will be possible to infer whether and if so to what extent incumbent firms have stronger competitive effect over entrant's payoff. In the presence of first-mover advantages, it is expected that $|\gamma_I^{n_E}| > |\gamma_E^{n_I}|$.

It is important to mention that no substantial difference could be found because incumbent firms do not possess first-mover advantages or because firms have differentiated their products in such a way that they not affect competitor's payoffs (no substitute effect). In that case, the γs are expected to be close to zero.

Maximum likelihood estimation will select the profit function parameters that maximize the loglikelihood of the observed market configurations across data.

4 Data description

The estimation of the structural entry model requires: a) information about digital firms' entry in each local market, and b) information about the economic conditions that may affect firms' profitability in a given market.

For this study, local markets are defined at the level of Basic Trading Areas (BTAs), the geographic market definition used by the FCC to award PCS spectrum licenses. I consider it more appropriate than city level market definition because it is closely related to the entry decision of digital firms (no firm operates a given market without a license). This definition was specifically used for PCS spectrum, but it also resembles the size of corresponding CMAs (Seim and Viard (2011)).

Moreover, defining markets at the level of BTAs assures the delimitation of non-overlapping geographical areas, which guarantees that there is no relevant direct competition coming from outside the defined market. Although a mobile licensee from neighbour BTAs could offer its services by using 'home' carrier's infrastructure (roaming service), customers usually preferred to contract service from a home carrier. This is because roaming fees were relatively higher in comparison with local calls, and only frequent travelers contracted this service (FCC (1995)).

[21] The number of observed incumbents in this sample varies from 0 to 2, this means that $\alpha_I^0 = 0$. Similarly, the number of entrants goes from 1 to 4, therefore, $\alpha_E^1 = 0$.

The data set contains cross-sectional information of the 50 largest, in terms of population, Basic Trading Areas (BTAs) in the United States in 1998. These BTAs contain approximately 55% of the total population.

4.1 Endogenous variables

Information on the number of digital firms operating in each local market was obtained from Kagan World Media's database[22]. Table 1(a) presents the relative occurrence of various market structure for the total number of digital firms, information required for an entry model when no distinction between incumbents and entrants is made (one-type entry model). It can be observed that a majority of the markets in this sample have 4 digital operators (40%), 24% have 3 firms, and 16% reflected a duopoly structure.

To study competitive interaction among digital firms, I classify them into two categories, incumbents and entrants, on the basis of when they enter to the market. Incumbents refer to the cellular operators who were already installed in certain local market and switched from analog to digital technology. Those who enter later (PCS licensees and Nextel), up to 1998, are classified as entrants.

The two types selected allows me to approximate the importance of first-mover advantages of incumbent firms into mobile markets. I argue that the distinction between incumbents and entrants represents meaningful product differentiation to the extent that customers find the two types of firms to be imperfect substitutes. This classification also recover differences in other important aspects, coverage and costs.

Columns (b) and (c) of Table 1 show the market structure for each type separately, information used for entry models when assuming no interaction between each type of firms (independent firms, and $\rho = 0$). Table 2 presents counts of the observed market configurations for this two-type specification. From Table 2, it can be observed that there is no market in which digital mobile services were exclusively provided by incumbents. Additionally, a majority of markets have 3 entrants (46%), and half of them count with the presence of one incumbent. Only one market presents 2 incumbents and 4 entrants. Finally, in 12 markets no firm started operations before 1996 (there are no incumbents).

There is a negative correlation (-0.23) between the number of incumbents and entrants. The sign suggests that, even when there might be common observed and unobserved factors influencing both firms to enter the market, some substitution effects might exist, which may

[22] I thank Katja Seim for providing me access to the data

Table 1: Market configuration

	(a) Digital	(b) Digital Incumbent	(c) Digital Entrant
N. of mobile firms	N. of markets (%)	N. of markets (%)	N. of markets (%)
0		12 (24%)	
1		25 (50%)	7 (14%)
2	8 (16%)	13 (26%)	12 (24%)
3	12 (24%)		23 (46%)
4	20 (40%)		8 (16%)
5	9 (18%)		
6	1 (2%)		
Total	50 (100%)	50 (100%)	50 (100%)

Table 2: Market Configuration Two-types Models

	N. of entrants				
N. of incumbents	**1**	**2**	**3**	**4**	**Total**
0	0	3	6	3	12
1	5	4	12	4	25
2	2	5	5	1	13
Total	7	12	23	8	50

condition the entry decisions of firms. The present econometric study allows to measure this effect.

4.2 Explanatory variables

BTAs differ in their ability to generate the necessary demand to make digital firm's entry attractive. To account for these differences, I collect demand-side and supply-side variables from each local market.

As in Bresnahan and Reiss (1991), I use *population* (in logarithm), as a *proxy* of market size. The demand for mobile service is expected to increase with the number of inhabitants. Nevertheless, Seim and Viard (2011) argue that although a larger number of potential consumers attracts firms to the market, it has an ambiguous effect on entry because it also make more difficult for firms to satisfy build-out requirements imposed by the FCC. The FCC imposed every PCS licensee to provide adequate service to between 25% and 33% of the market's population of each market within 5 years.

Besides *population*, I include the total number of commercial establishments (in thousands) to approximate the demand of business clients in each local market. I expect that this variable, denominated *business*, has a positive effect over profits. Moreover, the number of commercial establishments may be correlated with the availability of commercial areas needed for the installation of antennas (see explanation of cost-side variables below). Therefore, a greater number of this variable might be associated with better conditions for firms to deploy infrastructure. This confirms my expectation of a positive effect over entry.

Finally, I include average per capita income (*income*). I expect firms are more motivated to enter those markets whose consumers possess greater purchasing power.

The information for all these demand-side variables were obtained from the U.S. Census (2000). Annual data is not available at the level of local markets, and I assume that the year on year changes in these variables are not large enough to considerably affect entry decisions (see Greenstein and Mazzeo (2006) for a similar assumption). Summary statistics are presented in Table 3.

To quantify the effect of the presence of substitute analog technology, I construct two *dummy* variables, $D_{analog1}$ and $D_{analog2}$, which indicates whether one or two analog firms were present in the local market, respectively. The source of information is Kagan World Media's database.

Even though analog service is inferior in terms of voice transmission, privacy and data

service provision, I consider that it substitutes digital service in some extent, negatively affecting the profitability of entry. Seim and Viard (2011), for example, report that analog service was mainly provided to low-usage clients. In addition, given that digital service had a limited coverage area by 1998, which was frequently restricted to the user's local calling area since the providers' use of incompatible technology standards increased the chance of inoperability when travelling, analog firms were still preferred to customers who travelled frequently outside their local region (FCC (1997)).

Table 3: Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Population (ln)	50	14.61	0.73	13.57	16.74
Business (000s)	50	79.59	90.97	17.69	536.40
Income (000s)	50	22.35	3.00	15.57	30.45
$D_{analog1}$ (dummy)	50	0.56	0.50	0.00	1.00
$D_{analog2}$ (dummy)	50	0.26	0.44	0.00	1.00
WRI	50	0.08	0.66	-1.35	1.64
Area (sq miles/000s)	50	13.48	13.36	1.51	56.87

On the supply side, I account for differences across cities in the cost of provision of the service, particularly, in the cost of rolling-out infrastructure. Seim and Viard (2011) expose that, typically, firms require approval from the local municipal land-use office in order to proceed with the installation of new cell towers. Many local ordinances prohibit towers in residential areas, but allow them in industrial and commercial areas. Hence, the stringency of local zoning laws affects the availability of tower sites in local markets and, therefore, the cost and difficulty for firms to build their network. Following Seim and Viard (2011)'s work, I include two variables to control for the difficulty of firms to install antennas: the size of BTA's land area ($Area$); and a measure of regulatory stringency (WRI).

Land area (in thousands of square miles) is a measure of the availability of space to deploy the network. This information is provided by the U.S. Census (2000), and I expect it positively affects profits and entry.

The regulatory stringency measure is the 2005 Wharton Residential Urban Land Regulation Index (WRI) created by Gyourko et al. (2008). This index is a survey-based, standardized measure of the stringency of residential growth-control policies. BTAs with high WRI values have zoning regulations that limit the growth of new residential areas, which may

result in greater availability of candidate cell tower zones. This might ease market entry, so I expect this variable exhibits a positive effect over payoffs. This data is aggregated at the MSA level, I convert it to the BTA level by using correspondences provided by the Census (2000).

I expect that the effect of both cost-side variables differ between incumbents and entrants for two reasons. First, incumbents, as first movers, have already found available cell tower sites to install their infrastructure. Second, considering that almost all of them were cellular carriers who previously used analog technology, I believe these firms were able to avoid the zoning problem and other difficulties associated with the identification of new tower locations. As Meyers (1997) states, cellular incumbents just needed to add digital capabilities to their towers, which involved minimal hardware additions. I consider that this asymmetric impact reflects the presence of first-mover advantages generated on the supply-side of the market.

5 Empirical Analysis

To discuss about the extent of competition among digital firms, I first focus on the results of this entry model assuming that there is no distinction among digital incumbents and entrants. This is a one-type entry model where all types are homogeneous. It is also assumed that digital firms are substitutes. Table 4 presents the parameter estimates of two specifications. The first focuses on the effect of competition. The second includes the market-specific control variables described above.

The estimated α^n measure the impact of competition on payoffs; a positive difference between α^{n+1} and α^n means that entry has a negative effect on profitability. The results show that the α^n follow an increasing pattern, which means that the model is internally consistent with the assumption that firms are substitutes (Assumption 1: same-type firms are substitutes). The inclusion of the rest of explanatory variables do not affect my implications over the nature of competition.

Specification (2) permits to study the relevance of market-characteristics over entry decision.[23] As expected, the total number of inhabitants, *population*, has a positive and significant effect (at 10% of significance level) over payoffs. Thus, markets with a large base of potential consumers make entry for digital firms more attractive.

The effect of the total number of commercial establishments (*business*) appears to be

[23]A likelihood ratio test shows a highly significant joint effect of the control variables.

Table 4: One-type Model for Digital Firms

Digital	**(1)**	**(2)**
Population (ln)	0.531**	1.056*
	(0.215)	(0.555)
Business (000's)		-0.007*
		(0.004)
Income (000's)		0.097
		(0.073)
WRI		0.914***
		(0.320)
Area (000's)		0.041***
		(0.014)
$D_{Analog1}$		-2.260***
		(0.550)
$D_{Analog2}$		-3.449***
		(0.664)
α^3	6.679**	13.710*
	(3.117)	(7.350)
α^4	7.485**	15.024**
	(3.142)	(7.404)
α^5	8.667***	17.074**
	(3.186)	(7.479)
α^6	9.899***	18.967**
	(3.219)	(7.508)
Observations	50	50
LR chi2	6.166	48.58
Prob < chi2	0.013	0.000
LogLikelihood	-66.37	-45.17

Notes: Standard errors in parentheses

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

significant but negative, contrary to my expectation. Its value, nevertheless, is very close to zero. The effect of per capita income is positive but not statistically significant.

Additionally, I also find evidence that substitute analog firms in a market negatively affects profits (both *dummy* variables are significantly negative), indicating it would be more digital firm's activity than in an otherwise similar market with analog competitors.

With respect to cost-side explanatory variables, the impact of the variables associated with the cost of infrastructure deployment, *WRI* and *area*, are positive and highly significant, evidencing that additional entry is more attractive in markets where rolling-out infrastructure is less problematic. These results suggest that policy makers could play an important role in inducing digital firm's entry by facilitating the construction of infrastructure through land-use regulations. This could help to ameliorate the competitive effect of digital (or analog) firms and motivate more entry to the market.

Nevertheless, it is very interesting to note how relevant are these market characteristics once I separate the dependent variable by incumbents and entrants. Table 5 shows the estimated parameters for two separate one-type structural entry models.[24] The assumption behind this estimation is that both types of firms take their entry decisions independently, and there are no common unobservables ($\rho = 0$) that determines profits.

The first specification (a), includes the same market variables as before. From the results it can be observed that, in the case of incumbents, the only significant variable (at 10% of significance level) is *WRI*, with a negative sign. This indicates that more availability of candidate cell tower sites outside of constrained residential areas would decrease its profitability. In an opposite manner, *WRI* and *area* are significantly positive for entrants. These results are in accordance to my intuition that building network infrastructure is determinant for entrants, but not for incumbents, given that these last have already installed antennas to serve the markets. As I mentioned before, this effect can be explained by the fact that all incumbents were analog firms who just needed to upgrade their systems from analog to digital. The negative sign for incumbents may be indicating that entry to digital markets was more attractive for incumbents in those markets where entrants find difficulties to install their equipment.

These results, nevertheless, should be taken with care because not considering the competitive effect of different-type's entry over payoffs may bias the estimated parameters. As explained by Cleeren et al. (2010), if strategic effects matter and are ignored, then the other

[24]The dependent variable is a count of the number of firms for each type, as showed in Table 1 (b) and (c).

Table 5: One-type Entry Model for Incumbents and Entrants

	Digital Incumbent		**Digital Entrant**	
	(a)	**(b)**	**(a)**	**(b)**
Population (ln)	1.230	4.595*	0.569	1.044*
	(1.073)	(2.678)	(0.528)	(0.575)
Business (000's)	-0.009	-0.0458	-0.005	-0.007*
	-0.012	(0.0296)	(0.004)	(0.004)
Income (000's)	0.181	0.717*	0.043	0.107
	(0.125)	(0.394)	(0.071)	(0.077)
WRI	-1.066*	-1.474	1.073***	0.900***
	(0.579)	(1.373)	(0.311)	(0.326)
Area (000's)	-0.024	0.082	0.044***	0.045***
	(0.030)	(0.085)	(0.015)	(0.015)
$D_{Analog1}$	-7.749	-18.958	-0.594	-2.156***
	(724.1)	(775.6)	(0.478)	(0.694)
$D_{Analog2}$	-12.396	-31.208	0.002	-3.332***
	(724.1)	(775.8)	(0.512)	(1.168)
N. different-type		-3.230**		-1.730***
		(1.367)		(0.537)
α^1	10.098	44.332		
	(724.2)	(776.3)		
α^2	14.403	56.306	7.725	12.108
	(724.2)	(776.3)	(6.979)	(7.466)
α^3			8.783	13.336*
			(7.005)	(7.503)
α^4			10.622	15.517**
			(7.031)	(7.581)
Observations	50	50	50	50
LR chi2	70.81	88.25	27.14	38.29
Prob < chi2	0.000	0.000	0.000	0.000
LogLikelihood	-16.56	-7.84	-49.84	-44.27

Standard errors in parentheses

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

factors included in the payoffs will be estimated with a bias. The magnitude of this bias will depend on the degree to which strategic effects matter. In some cases, these can be severe and even change the sign of the effects of interest.

As first approximation of this competitive effect, I consider the number of different-type competitors as control variable, i.e., the number of incumbents (entrants) is included as determinant of entrants (incumbents)'s payoffs. Specification (b) shows the results.

The estimated parameters indicate that *population* is an important determinant for both types' profits. The effect of the number of commercial establishments (*business*) is negative in both cases and significant only for entrants (although close to zero as before). It is relevant to note that *WRI* and *area* remain significantly positive for entrants, and they do not constitute a significant variable for incumbents. Finally, the presence of analog firms impact negatively on entrant's payoffs, but the effect over incumbents is not significantly different from zero.

About the competitive effect, the results indicate that there is a significant effect of a different-type firm's entry over payoffs. The negative sign are in line with the Assumption (3a) about substitution between entrants and incumbents. These results manifest how important is modelling the competitive interaction among digital firms, taking into account heterogeneity of firms.

Using the number of different-type competitors as a control variable, however, creates endogeneity problems. Common unobservable factors that attract firms to the market make this variable correlated to the error term. Furthermore, the relationship between this variable and payoffs may be bidirectional, i.e., the number of incumbents determine entrant's payoffs, and therefore their entry decisions; which at the same time determine the number of incumbents. The two-type entry model allows to overcome this problem by modelling both the number of incumbents and the number of entrants as endogenous variables.

The two-type entry model with substitution Assumptions 1 and 2 is given by (8), where the probabilities are defined by (7). We started estimating it with the most flexible specification of payoffs, given by (9). Nevertheless, the estimated fixed effects ($\alpha_i^{n_i}$ and $\gamma_i^{n_{-i}}$) were not internally consistent with the assumptions of the model. In particular, some estimated fixed effect parameters resulted to be equal, which occurs when the estimated upper bound level of payoffs for $(n+1)$ firms hit the lower bound level for the same number of firms (which is equal to the upper bound for n firms).[25]

[25] Recall from Figure 2 that rectangular areas are formed by upper bound and lower bounds of payoffs. Each rectangular area

To solve this problem, I decide to impose some additional conditions to the fixed effect parameters. These assumptions impose an increasing pattern to the fixed effect parameters. If estimates are significant and positive, the model is then internally consistent. For incumbents, it is set:

$$
\begin{aligned}
\alpha_I^2 &= 2\alpha_I^1, \\
\gamma_I^3 &= 1.5\gamma_I^2, \\
\gamma_I^4 &= 2\gamma_I^2.
\end{aligned}
\tag{10}
$$

Similarly, for entrants' payoffs it is assumed that

$$
\begin{aligned}
\alpha_E^3 &= 1.5\alpha_E^2, \\
\alpha_E^4 &= 2\alpha_E^2, \\
\gamma_E^2 &= 2\gamma_E^1.
\end{aligned}
\tag{11}
$$

Table 6 presents parameter estimates of the best specification that showed convergence under these new conditions.[26] About the competitive interaction among the same type of firms, the results show evidence that firms of the same type negatively impact the level of profits (the estimated $\alpha_I^{n_I}$ and $\alpha_E^{n_E}$ are positive and significant at 5% and 1% of significance level, respectively).

The effect of entry of a different-type competitor, measured by $\gamma_I^{n_E}$ and $\gamma_E^{n_I}$, differ by type. For incumbent firms, the effect of an additional entrant to the market is not significantly different from zero. On the contrary, an additional incumbent in the market negatively affects the level of an entrant's payoffs. These results are in line with my idea that, given the presence of first-mover advantages, incumbents are in a better position to exert stronger competitive effect over later entrants.[27]

About demand-side variables, the number of inhabitants (*population*) is the most important market characteristic affecting incumbents' and entrants' payoffs.[28] However, the

represents the probability of observing (n_I, n_E) firms in market m. The definition of these bounds results from the assumptions related to the competitive interaction among firms (in this case, substitution assumptions 1 and 2).

[26] *Dummy* variables indicating the presence of analog firms are not included in this specification. I estimated an alternative specification in which all variables are kept, except *business*. In replace I added $D_{analog1}$. The estimated fixed effects (and their significance level) remained the same, $D_{analog1}$ was not significant neither for incumbents nor for entrants.

[27] I perform a two-tailed t-test to corroborate whether there is a significant difference between $\alpha_E^{n_E}$ and $\gamma_E^{n_I}$, and the null hypothesis that they are equal is rejected. In other words, I reject the null hypothesis that they have the same competitive effect, as if both types were homogeneous.

[28] Around 70% of each type's predicted payoffs is explained by this variable.

Table 6: Two-types Entry Model

Parameter	**Estimate**	**Standard Error**
Effect on incumbent-type payoffs		
Population (ln)	0.153*	(0.090)
Business (000's)	0.002	(0.002)
Income (000's)	0.028	(0.061)
WRI	0.155	(0.249)
Area (000's)	0.014	(0.015)
α_I^1	1.364**	(0.190)
γ_I^2	1.065	(0.797)
Effect on entrant-type payoffs		
Population (ln)	0.248**	(0.102)
Business (000's)	0.000	(0.002)
Income (000's)	0.058	(0.058)
WRI	0.559*	(0.317)
Area (000's)	0.034**	(0.015)
α_E^2	2.674***	(0.865)
γ_E^1	1.119**	(0.472)
ρ	0.924***	(0.164)
Observations	50	
LogLikelihood	-110.78	

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

Note: The value of α_I^2, γ_I^3, γ_I^4, α_E^3, α_E^4, γ_E^2 are calculated with conditions (17) and (18).

effect is stronger for entrants, which indicates that as the market size increases, the relative attractiveness of being an entrant-type in the market increases as well. This may explain why many analog cellular carriers decided to acquire new PCS licenses to enter new markets (FCC (1997)).

Besides *population*, and contrary to my expectations, neither per capita income nor the number of commercial establishments are significant to explain both types' profits. Additionally, about the importance of cost-side determinants, interesting asymmetries are found. It can be observed that *WRI* and *area* are positive and significant to explain entrants' payoffs, but they are not significant for incumbents. These results indicate that cost-side variables related to the deployment of infrastructure is only determinant for entrants. Therefore, incumbents possess a supply-side advantage with respect to entrants, specially if land-use regulations related to the installation of antennas are stringent.

Finally, it is interesting to note the significantly high value of the estimated parameter $\rho = 0.96$. This value indicates that the unobserved part of incumbent's and entrant's payoffs is highly correlated.

In summary, the estimation of a two-type entry models for digital mobile markets in the U.S. show evidence of the asymmetric strength of competition of incumbents and entrants. Incumbents exert a significantly negative competitive effect over entrants' payoffs. The competitive effect of entrants is, on the contrary, not significant to explain incumbents' performance. This asymmetry is in line with the presence of first-mover advantages in favor of incumbents.

Furthermore, the competitive advantage of incumbent cellular operators are also related to the fact that their payoffs are not affected by the availability of commercial areas to deploy infrastructure. This is a problem that it only seems to affect entrant's profitability.

6 Conclusions

The introduction of digital technology is considered one of the most important innovations in the mobile industry because it allowed a more efficient use of the radio spectrum. In the United States, this disruptive innovation gradually displaced analog technology and allowed the entrance of new firms in the market.

In this context, and taking advantage of the definition of local mobile markets, I use a structural two-type entry model to empirically examine the competitive interaction among

digital carriers. In particular, provided that first-mover advantages my determine the competitive dynamics, I compare the strength of competition of incumbent cellular operators with respect to the one of later entrants. This setting allows me to estimate incumbents' and entrants' unobserved payoffs. I control for observed market-specific characteristics and market structure, and other unobserved determinants.

My results evidence the existence of substitution among digital mobile firms. They also show that there is an asymmetric competitive strength in favor of incumbents. Specifically, my estimates indicate that incumbents exert a negative competitive effect over entrant's payoffs, but entrants do not affect incumbents' profitability. This result supports the notion that incumbents posses first-mover advantages that allow them to have a stronger competitive effect over later rivals. I also show that incumbents possess cost-side advantages in terms of deployment of infrastructure. Their payoffs are not affected by the availability of proper commercial zones for the installation of new antennas. This cost-side factor, however, is determinant to explain entrant's performance.

From a policy perspective, this study shows how important is the recognition of asymmetries among competitors to create a level-playing field between operators. Regulatory and competition authorities should assure that those who enter the market will find adequate conditions to operate and compete against early rivals. The standardization of local municipal regulations in relation of the deployment of infrastructure is an example of the key role policy makers could play. There are other policies that may also mitigate the larger competitive strength of incumbents. Some regulators have considered the implementation of asymmetric interconnection charges, for example. In any case, the allocation of new licenses is not enough to create more competition against incumbents.

References

Berry, S. (1992). Estimation of a Model of Entry in the Airline Industry. *Econometrica*, 60(4):889–917.

Berry, S. and Reiss, P. (2007). Empirical models of entry and market structure. In *Handbook of Industrial Organization, Vol III. Amsterdam: Elsevier*, volume 3, pages 1845–1886.

Bijwaard, G. E., Janssen, M. C., and Maasland, E. (2008). Early mover advantages: An empirical analysis of European mobile phone markets. *Telecommunications Policy*, 32:246–261.

Bresnahan, T. F. and Reiss, P. C. (1991). Entry and Competition in Concentrated Markets. *Journal of Political Economy*, 99(5):977–1009.

Cleeren, K., Dekimpe, M. G., and Verboven, F. (2006). Competition in local-service sectors. *International Journal of Research in Marketing*, 23(4):357–367.

Cleeren, K., Dekimpe, M. G., Verboven, F., and Gielens, K. (2010). Intra- and inter-format competition among discounters and supermarkets. *Marketing Science*, 29(3):456–473.

Draganska, M., Misra, S., Aguirregabiria, V., Bajari, P., Einav, L., Ellickson, P., Horsky, D., Narayanan, S., Orhun, Y., Reiss, P., Seim, K., Singh, V., Thomadsen, R., and Zhu, T. (2008). Discrete choice models of firms strategic decisions. *Marketing Letters*, 19:399–416.

Farrell, J. and Klemperer, P. (2007). Chapter 31. Coordination and Lock-In: Competition with Switching Costs and Network Effects. In *Handbook of Industrial Organization*, volume 3, pages 1967–2072.

FCC (1995). First Annual Commercial Mobile Radio Services Competition Report. In *http://www.fcc.gov/reports/commercial-mobile-radio-services-cmrs-competition-report-1st-annual*, volume 6002.

FCC (1997). Second Annual Commercial Mobile Radio Services Competition Report. In *http://www.fcc.gov/reports/commercial-mobile-radio-services-cmrs-competition-report-2nd-annual*.

Gerpott, T., Rams, W., and Schindler, A. (2001). Customer retention, loyalty, and satisfaction in the German mobile cellular telecommunications market. *Telecommunications Policy*, 25:249–269.

Greenstein, S. and Mazzeo, M. (2006). The role of differentiation strategy in local telecommunication entry and market evolution:1999-2002. *The Journal of Industrial Economics*, LIV(3):323–350.

Gruber, H. (2001). Competition and Innovation: The Diffusion of Mobile Telecommunications in Central and Eastern Europe. *Information Economics and Policy*, 13:19–34.

Gruber, H. (2005). The Economics of Mobile Telecommunications. *Cambridge University Press*.

Gruber, H. and Verboven, F. (2001). The evolution of markets under entry and standards regulation the case of global mobile telecommunications. *International Journal of Industrial Organization*, 19(7):1189–1212.

Gyourko, J., Saiz, A., and Summers, A. A. (2008). A new measure of the local regulatory environment for housing markets: The Wharton Residential Land Use Regulatory Index. *Urban Studies*, 45(3):693–729.

Katz, M. and Shapiro, C. (1985). Network Externalities , Competition , and Compatibility. *The American Economic Review*, 75(3):424–440.

Klemperer, P. (1987). The competitiveness of markets with switching costs. *The Rand journal of economics*, 18(1):138–150.

Koski, H. and Kretschmer, T. (2005). Entry, Standards and Competition: Firm Strategies and the Diffusion of Mobile Telephony. *Review of Industrial Organization*, 26:89–113.

Lieberman, M. B. and Montgomery, D. B. (1988). First-mover advantages. *Strategic Management Journal*, 9(Special Issue:Strategy Content Research (Summer, 1988)):41–58.

Mazzeo, M. (2002). Product choice and oligopoly market. *RAND Journal of Economics*, 33(2):221–242.

Meyers, J. (1997). Cellular Revisited: Afraid to Let PCS Newcomers Tarnish their Hard-Earned Image, Cellular Operators are Sallying Forth with Enhanced Digital Services and Marketing Efforts. *Telephony*, 232(9).

Schaumans, C. and Verboven, F. (2008). Entry and regulation: evidence from health care professions. *The Rand journal of economics*, 39(4):949–72.

Schmalensee, R. (1981). Economies of scale and barriers to entry. *Journal of Political Economy*, 89(6):1228–1238.

Schmalensee, R. (1982). Product differentiation advantages of pioneering brands. *The American Economic Review*, 72(3):349–365.

Seim, K. (2006). An empirical model of firm entry with endogenous product-type choices. *The RAND Journal of Economics*, 37(3):619–640.

Seim, K. and Viard, V. B. (2011). The Effect of Market Structure on Cellular Technology Adoption and Pricing. *American Economic Journal: Microeconomics*, 3:221–251.