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ABSTRACT

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This dissertation contains three essays that look at competition, entry and capacity spectrum investment of wireless telecommunication firms in the U.S. The first two essays (Chapters 1-2) examine wireless firm's entry decision while the final essay studies their investment behavior.

The first essay examines how wireless firm compete against each other assuming that symmetric wireless firms produce homogenous goods. Specifically, I estimate an ordered probit model and compute the minimum population needed to support an addition firm. Though I have a national data set, I also look at a subsample of 498 isolated towns to minimize the possible biases caused by cross market correlation. I find evidence indicating a strong competition between regional and national firms. In isolated towns, the presence of national firm reduces the probability that two regional firms enter by 14% while it does not significant affect the probability one or three regional firms enters. The presence of regional firm only reduce the probability more than two national firm enter. In the full sample, the presences of a national firm always reduce the probability regional firm enter, while the presence of regional firm only reduce the probability all five national firm enters together.

The second essay also deals with wireless firm's entry decision. It emphasizes the heterogeneity among national wireless firms and deals with strategic interactions. Through analyzing the wireless carriers' entry decisions at the city level, I uncover important details about industry competition that were overlooked by existing county-level analyses. The entry decision for each nationwide wireless carrier, together with the number of regional carriers, is formalized as the equilibrium outcome of a

simultaneous-move game with complete information. The model identifies strategic interactions that arise from a competitor's market presence without imposing the specific restriction of positive or negative impact from such presence. I find that Cingular's entry decisions are a strategic complement to those of all nationwide carriers except Verizon. The market presence of Sprint raises the entry propensity of regional carriers, while Verizon's reduces their entry propensity. These findings suggest that it is important to account for strategic complementarities in firms' entry decisions. Failure to do so can overstate the degree of competition.

In the third essay, I look at the capacity investment decision of wireless telecommunication firms. In particular, I investigate the investment pattern of wireless firms in the Advanced Wireless Service auction by exploring a unique data set. I document several empirical regularities on incumbent and entrant's firm's behavior. First, I find that presence of an entrant bidder drives up the winning bid much greater than the presence of an incumbent. This suggests that the extent of winner's curse might be greater for entrant. Secondly, the investment winning bids are monotonic in the number of entrant bidder and in the number of incumbent bidder. Thus little evidence of entry preemption could be found. Finally, I construct measures of competition based on the number of the firm and their geographical penetration rate and look at how a firm's willingness to invest varies as the market becomes more competitive. I find that the incumbent invest more when they face intense competitions from competitors with both full coverage and limited coverage. The entrants invest more only when they face moderate competition from the firm with limited coverage. These findings suggest that incumbent and entrant firm compete in different market segments.

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Finally, I dedicate this dissertation to my parents. Their unconditional love and support made me what I am today.

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1 Entry and Competition: An Empirical Analysis in U.S. Mobile Telecommunications Industry

1.1 Introduction

The prevalence and consequences of industry structure is one of the fundamental issues in economics studies. In this paper, I document the determinants of entry and its effect on competition using a unique data set of U.S. wireless telecommunication markets in 2005. In particular, I look at how different types of wireless firms compete against each other.

In 2007, the wireless telecommunication industry contributed 138.9 billion dollars in revenue to the economy and the number of wireless subscribers exceeded 255.4 million. Additionally, the wireless voice and data services play a central role in promoting productivity growth in the U.S. The benefit resulting from the use of wireless services include reduction of travel time, faster and more efficient decision-making and savings in production cost. According to an independent study conducted by Ovum, the consumer surplus per year based on the improved efficiencies associated with wireless voice service is estimated to be $157 billion in 2005. The overall increased efficiencies resulting from the use of wireless broadband applications can be expected to yield savings of over $528 billion during 2005-2016.

The bloom of wireless industry is quite recent. The average monthly bill was as high as $98.02 in 1988 and the cellular service was exclusive and unaffordable to most people. At that time, the Federal Communication Commission (FCC) allowed only two wireless firms to operate in each geographical area. Lack of competition was partly blamed for the high price. In 1994, the FCC allows addition wireless entry by auctioning off new wireless licenses. In the following years, many cities experienced competitive entry and wireless service price dropped considerably.

Focusing on the entry behavior of wireless firm addresses the motivation for the deregulation in this industry, namely to promote market competition and service availability. It also helps to understand how wireless firm compete against each other and how nationwide firm compete against regional firm in the local market.

I assemble a unique data set based on the actual service provision decision of wireless firms in 2005. It contains entry information in as many markets as possible, extending in many medium and small cities. The empirical framework of the paper employs the entry model in Bresnahan and Reiss (1991). Assuming that firm will enter the market if it earns non-negative post entry profit and additional entry will reduce the margin, the number of firm in a particular market reveals the profitability of operating in that market. By observing how the number of firm operating in a market varies with the market size, we recover the average variable profit of operating in the market.

There are several findings of the paper. I find evidence for a strong competition between different types of firms: the presence of a regional firm reduces the probability that five national firms enter by 17% in full sample, and by 7% in a subsample of isolated towns. In addition, the presence of national firm always reduces the probability regional firm enters in the full sample, while it has no effect on the entry of the first regional firm in isolated towns. The entry threshold indicates that the margin falls most rapidly when the market structure changes from monopoly to duopoly.

The rest of this paper is organized as follows. The next section outlines some industrial background and section 2.3 provides a review of different streams of literature related to this study, and. Section 2.4 describes the data. Section 2.5 outlines the empirical approach. Section 2.6 presents the main empirical specifications and a discussion of results. The final section concludes with implications for future research.

1.2 Industrial Background

Production Technology The mobile telecommunication service needs spectrum as input. When cell phone functions, the wireless signals are transmitted in the air at a certain frequency. If multiple signals are transmitted at the same frequency, interference will happen. Thus a major obstacle to the widely available wireless telecommunication is to carry a large amount of transmission using limited spectrum resource. To solve this problem, the wireless service areas are divided into small virtual "cells" so that the radio frequencies could be reused across non-adjacent cells without causing interference. The scheme allows many people to use their mobile phone at the same time thereby allowing the mass production of the wireless service.

Within each cell, cell sites are built to receive and transmit signals emitted from personal wireless device. When cell phone is on network, it automatically registered with public switch through cell site (via wired facilities), so that the public switch would know where to route any incoming or outgoing call. When moving toward the edge of each cell, base stations automatically coordinates and switches the wireless phone to the new site. As people travel, the signal is passed from cell to cell.

The working range of a cell site typically varied with a number of factors such as the type of signal (e.g. GSM or CDMA), height of cell site, geographical and weather conditions. For GSM technology, there is a fixed maximum of 35 km working range. For CDMA and iDEN technology, there in general no such build-in restriction, however, the ability for a low-powered personal cell phone to transmit back to the cell site is limited. As a rough estimate, if the cell site is tall enough and terrain is flat, the working range of a cell site could be between 50 and 70km for CDMA technology.

One other important constriction besides the geological and the technological is the utilization capacity of cell site. Each site can only handle a limited number of calls at a given time. In practice, how many cell sites to build in a given geographical range depend crucially on the number of people who use their cell phones at the same time. In suburban area, cell sites are commonly spaced 2-3 km apart, while in dense populated areas, cell sites could be placed as close as 500-1000 meters apart.

Regulation Background The first modern cellular system was initiated in 1983 in Chicago, and then in L.A. during 1984 Olympics Games. Within next year, operations began in top 30 metropolitan statistical areas and subsequently spread the rest of the country. As early as 1970s, the cellular technology was sufficiently developed to begin commercial operation. However, cellular service in the U.S. was delayed until 1983 because of the indecision on regulatory rule and cellular spectrum licensing procedure. The controversy focused on whether to give AT&T, who invented cellular technology, an exclusive right to provide cellular service.

The FCC finally decided to allow two cellular carriers to operate in each "market". The continental United Stated was divided into 734 cellular market areas (CMA), which includes all Metropolitan Statistical Areas (MSA), all Rural Statistical Areas (RSA) plus one market for Gulf of Mexico. In each CMA, a 50 megahertz spectrum in the 800 MHz frequency band was assigned to the two competing cellular operator with 25 megahertz for each. One of the two must be awarded to a local wire line carrier with experience in traditional fixed line telephony (typically license B), i.e. a fixed telephony company. The other license (typically license A) was awarded by either comparative hearing or lottery to any private entity other than the local wire line incumbent.

The duopoly market structure prevailed until 1994 when the FCC allows additional companies to serve the market by auctioning off personal communication service (PCS) spectrum. The PCS band was divided into three blocks of 20 megahertz blocks (block A, b, and C) and three blocks of 10 megahertz (D, E and F). Block A and B are assigned based on Major Trading Areas (MTA) and the rest are based on Basic Trading Areas (BTA). The auctions of the PCS licenses took a few rounds and raised 20 billion for the U.S. treasury. It attracts entrants into the cellular industry and the number of wireless service providers started to vary across geographical markets depending on market conditions.

Currently FCC allows up to eight different mobile telephone licenses (two cellular and six PCS). Spectrum licensees are permitted to buy and sell licenses, in whole or in part, on the secondary market (subject to FCC's approval). Licensees could lease all or a portion of their spectrum usage rights for any length of time within the license term, and over any geographic area encompassed by the license. FCC also gives permission to licensees to disaggregate (divide the spectrum into smaller amounts of bandwidth) or partition (divide the license into smaller geographical areas) their licenses, or do both, to other entities.

In my analysis, I focus on facility-based wireless firms. One other important industrial player is reseller, who offers service to consumers by purchasing airtime at wholesale rates from facilities-based providers and reselling it at retail prices. The entry cost between facility-based carrier and resellers differs drastically. For instance, the cost in acquiring spectrum capacity and building out wireless facilities consists majority of startup cost for facility based carriers while reseller's entry cost are less transparent. According to the FCC, wireless resellers serve approximately 9 percent of all mobile telephone subscribers.

As of June 2005, there were five nationwide mobile telephone operators in the United States: Sprint PCS, Verizon Wireless, T-Mobile, Cingular Wireless and Nextel. Though they are referred to as national carriers, neither their license nor the service area covers the entire land area of the country. Each of the five national carriers has networks covering at least 200 million people while the next largest provider covers less than 62 million of people. Aside from national carriers, a number of regional carriers (e.g. such as Alltel, United states Cellular Corp, and Dobson etc.) serve and concentrate on smaller areas.

1.3 Literature Review

The present work draws from two streams of literature. Starting with Bresnahan and Reiss (1991), there has been a significant body of empirical entry research. In their seminal paper, BR relate the number of the firm to a set of market characteristics and compute the entry threshold ratios which shed light on how concentration affects firm's profitability. BR's model relies heavily on the symmetry assumption, i.e. symmetric firms are assumed to produce homogenous goods. In response, Berry (1992) extends BR to allow firm heterogeneity. In Berry's model, heterogeneous firm differs from each other through differences in production cost and the strategic interactions that arise from a competitor's market presence are assumed to be symmetric. More recently, Mazzeo (2002) extends BR's model to allow firm to produce vertically differentiated goods. In Mazzeo's model, firms' product quality choice is incorporated into their entry decisions and he finds substantial return to differentiation. In parallel, Seim (2007) explore the horizontal product attributes that is built in firm's entry decision. She finds evidence of spacial differentiation and firms shy away from competition by locating further away from each other.

This paper also grows out of the studies on wireless telecommunication industry. In 80's and early 90's, the wireless telecommunication industry in the U.S. was highly regulated. The duopoly market structure arises due to the FCC's regulation rule. Academic studies focusing on this time period explores many interesting aspects of this industry (e.g. collusive conduct, parallel pricing and consumer's preferences for wireless plans) by taking the market structure as exogenously given. Paker and Roller (1997) find the collusive conduct that lead to high price by exploring a data set between 1984 and 1988. Busee (2000) utilizes the same data set to identify parallel pricing as a mechanism for coordinating price. She finds that any pair of wireless carriers is more likely to price their service at similar level when they face each other more often in the market. Miravete and Roller (2004) explore the information contained in the wireless service plans and recover consumer preferences for service plans. A few more papers look at more recent years. Seim and Viard (2004) study the technology adoption decision of wireless firms between 1996 and 1998. They find that the incumbent firms are more likely to adopt digital technology when they face more entry. Ward and Woroch (2005) study the substitutability between wireless and land-line telephone using survey data. They find that cell phone is a substitute for the second landline phone. Bajari, Fox and Ryan (2005) develop a semi-parametric estimator to recover consumer's valuation for national coverage by looking at ranking data collected from amazon.com. To my knowledge, this paper is first to look at competition among wireless firms.

In summary, the main contributions of this study lie in using detailed micro-level data to shed light on competition among wireless firms. It generates useful policy implications on this highly regulated industry.

1.4 Data

Data Sources I study the entry decisions of wireless firms across different geographical market in 2005. There are several data sources. The service provision information of wireless firm is collected from letstalk.com, a leading online wireless service retailer. The demographics data is downloaded from the census web site. Additionally, I adopt the geographical reference data from Missouri Census Data Center (MCDC) to aggregate ZCTA code to other geographical level such as city and county.

Data Description The service provision data is collected from letstalk.com in December 2005. An automated process inputs the list of Census's ZCTA codes into the website while retrieving the service provision information (e.g. the identity of service provider, types of services plan and the price of the plan etc.) for each ZCTA. According to the Census, ZCTAs are statistical entity developed for tabulating summary statistics to overcome the difficulties in precisely defining the land area covered by each ZIP Code. In most instances the ZCTA code equals the ZIP Code for an area.

I choose to collect service provision information from Letstalk.com because it carries a wide selection of wireless brands. In the sampling year, all of the top 15 facility-based wireless service providers in the U.S. retail their service plan through Letstalk.com.

To ensure the information from letstalk.com is accurate, I perform two additional robustness checks. First, I collect similar information by inputting a subsample of ZCTA codes to amazon.com. I match and compare it with the data from Letstalk.com. The information from both sources agrees with each other. Secondly, to ensure that representative wireless carriers list their service on Letstalk.com, I identify the complete list of wireless carriers in 19 representative states using the telephone number assignment information from North American Numbering Plan (NANP). The result indicates that a number of local carriers generally use their own retail channels while all national carriers and major regional carriers vend their service plan through Letstalk.com. The blocks of telephone number assigned to the local carriers shows that they typically serve less than

10,000 customers within a rate center and their footprint seldom appears across rate centers. Therefore, the local carriers are excluded from my analysis.

Market Definition The FCC has licensed wireless services based on MSA/RSA and MTA/BTA. The literature of wireless telecommunication has widely adopts MSA/RSA for historical reasons. Since, MTA/BTA can be effectively subdivide into county, part of the FCC's annual competition report bases on the counts of wireless carriers at county level. By contrast, I collect entry data at the ZCTA level, which is finer than county.

This paper uses city as unit of observation for several reasons. There is no guarantee that carriers provide service everywhere inside the geographic areas they are licensed. Instead, I find substantial variations in the same firm's service decision within county.

Defining Entry In this paper, the wireless firm is considered as having made an entry decision if it offers services to new customer. This definition is appropriate for the purpose of this paper. On the demand side, when the consumer shops around for wireless services, they check service availability by entering their zip code in letstalk.com. On the supply side, wireless firm don't sign up new customers in roaming areas. This point is mentioned several times through multiple rounds of interviews. It is supported indirectly by Fox (2006), though he focuses on early 90's. He shows that roaming agreements are merely the substitute for geographical coverage because of high roaming cost.

Summary Statistics The full sample encompasses 19407 cities, almost all populated places across continental U.S. The summary statistics is displayed in Table 1.1. Table 1.2 shows the descriptive statistics for a sample of 428 isolated towns[1]. In the full sample, each market is served by 4.1 wireless

[1] The sample is constructed using the method proposed by Allen Collar-Wexler. It's a set of cities populated by more than 2000 inhabitant with no neighbors in 20, 30 or 40 miles. There are many very tiny cities in the U.S. For

firms, 3.2 national and 0.9 regional while in the subsample, each market is served by 3.4 wireless carriers which include 2.3 national wireless carriers and 1.0 regional carrier. The footprint of regional firm does not differ much between full sample and subsample, while in the full sample, one more national firm serve each market on average. The national wireless carrier differs substantially from regional carriers. The correlation between number of national firm and number of regional firm is -0.24, while in the subsample, it is -0.15. Generally, national firm and regional firm exclude each other regardless of market demand.

The independent variables measure the extent of market and the cost of providing services. Generally, the variable in the full sample vary greater than subsample. To account for the possible spillover in firm's entry decision, I include the distance discounted population in nearby places as control variables.

Table 1.1: Summary Statistics for Key Variables (Full Sample, N=19407)

	Mean	Std. Deviation	Min	Max
Dependent Variable				
Number of wireless firms	4.1	1.7	0	8
Number of national wireless firms	3.2	1.8	0	5
Number of regional wireless firms	0.9	0.8	0	4
Explanatory Variable				
log (population)	7.4	1.7	1.1	15.9
log(per capita income)	9.7	0.3	0	12.4
Rural population (%)	0.6	0.5	0	1
log(average time commute to work in minute)	3.2	0.3	0	4.7
log(area in square miles)	0.7	1.4	-4.7	6.6
log (population in cities within 10 miles/distance)	33.6	58.4	-0.3	593.3
log (population in cities within 15 miles/distance)	33.5	47.1	0	430.0
log (population in cities within 20 miles/distance)	39.7	50.4	-1.1	511.3

instance New Amsterdam, IN has only 1 inhabitant as of 2004. Too small towns are not likely to support wireless services without subsidy. However, the distance weighted population is computed using the full sample.

MSA	0.5	0.5	0	1
South	0.3	0.4	0	1
Western	0.21	0.4	0	1

Note: All statistics uses city as the unit of observation. The Dependent variable was constructed for the year 2005. The demographics are from U.S. Census 2000.

Table 1.2: Summary Statistics for Key Variables (Isolated Towns, N=428)

	Mean	**Std. Deviation**	**Min**	**Max**
Dependent Variable				
Number of wireless firms	3.2	1.8	0	8
Number of national wireless firms	2.3	1.5	0	8
Number of regional wireless firms	1.0	0.7	0	3
Explanatory Variable				
log (population)	9.1	0.7	8.3	12.1
log(per capita income)	9.7	0.2	8.7	10.6
Rural population (%)	0.1	0.1	0	1
log(average time commute to work in minute)	2.8	0.2	2.2	3.5
log(area in square miles)	2.0	0.8	0.4	6.6
log (population in cities within 10 miles/distance)	6.7	7.4	0	38.8
log (population in cities within 15 miles/distance)	8.5	8.6	0	45
log (population in cities within 20 miles/distance)	10.2	9.6	-0.3	48.9
MSA	0.1	0.3	0	1
South	0.3	0.5	0	1
Western	0.3	0.5	0	1

1.5 Empirical Model

This paper ultimately models the determinants of the number of wireless service providers in a local market. The entry decision of an individual firm, which collectively determines the number of the firm in a market, can be represented by discrete decision enter or do not enter a particular market. However, entry might be less profitable if other firms have also entered the market. The ordered model naturally generates an ordinal response as the level of market profitability changes. Following Bresnahan and Reiss (1991), the number of the firm (N_m) in a market depends on a number of the supply and demand factors. Equations (1.0) represent the underlying profit function that governs the number of firms in a market. μ_N is a constant that changes with the number of firm. *m* indexes the market (city).

$$N_m = f(supply, demand) = X\beta - \mu_N + \varepsilon \tag{1.0}$$

Thus the observed number of service providers is a categorical variable determined by (1.1).

$$N_m = 1 \quad if \quad X\beta < \mu_1$$

$$N_m = 2 \quad if \quad \mu_1 < X\beta < \mu_2$$

$$\dots$$

$$N_m = n \quad if \quad \mu_{n-1} < X\beta \tag{1.1}$$

Let the cumulative distribution of ε denoted by $F(.)$, and let $\mu_1 = 0$, then

$$\Pr(N = k) = F(\mu_k - X\beta) \quad \text{if} \quad k = 1$$

$$\Pr(N = k) = F(\mu_k - X\beta) - F(\mu_{k-1} - X\beta) \quad \text{if} \quad k = n - 1$$

$$\Pr(N = k) = 1 - F(\mu_k - X\beta) \quad \text{if} \quad k = n \tag{1.2}$$

The maximum likelihood selects the parameters that maximize the probability of observed number of firms (1.3) across the dataset.

$$L = \sum_{t=1}^{obs}\sum_{k=1}^{n} Pr(N_t = k)$$

We could easily estimate the model with ordered probit. As the level of market profit $X\beta$ exceeds a certain threshold μ, we could observe the number of firms which associates with that threshold.

The effect of a continuous explanatory variable on probabilities of falling into a specific category (marginal effect) can be evaluated from taking the partial derivative of equations.

$$\frac{\partial \Pr(N = k)}{\partial x} = -\mathrm{F}'(\mu_k - X\beta) * \beta \quad \text{if} \quad k = 1$$

$$\frac{\partial \Pr(N = k)}{\partial x} = [\mathrm{F}'(\mu_{k-1} - X\beta) - \mathrm{F}'(\mu_k - X\beta)] * \beta \ \text{ if } \ k = n - 1$$

$$\frac{\partial \Pr(N = k)}{\partial x} = \mathrm{F}'(\mu_k - X\beta) * \beta \quad if \quad k = n$$

There are two benefits associated with using ordered model. First, it does not overweight extreme values that are associated with very large or very small market. Second, it allows us to infer competitive status and/or scale economies through the threshold value μ. Bresnahan and Reiss (1991) find that the difference between μ increases progressively and then stabilizes, which means the market profit that are need to support n firms are larger than n time the market profit that are needed to support one firm. They infer that as the number of firm increases, competition causes price and per firm profit drop. When threshold values stabilize, no more firms could enter and operate profitably. For instance, we observe N firms if

$$\Pi_{N,m} = \beta_p \ln(population) + X_m\beta - \mu_N$$

$$\mu_N < \beta_p \ln(population) + X_m\beta < \mu_{N+1}$$

Thus the minimum population needed to support *N* firms is

$$population_N = \exp\left(\frac{\mu_N - \bar{X}\beta}{\beta_p}\right)$$

Let S_N be predicted minimum average population per firm in a market with n firms, (i.e. $S_N = Population_N/N$). We could then compute the threshold ratio S_N/S_{N-1}. If we expect margin falls as the number of firms increase, the threshold ratio should exceed 1. As market become more competitive, the threshold value converges to 1. Alternatively, holding price constant (across markets), the threshold value informs the pattern of scale and scope economies.

1.6 Results

I estimate the ordered model described in section 1.5 and the result is presented in Table 1.3. The dependent variable is the total number of wireless firms in the market. Most of the estimates are precisely estimated due to large within sample variations in explanatory variables. Population, income and time travel to work are positively associated with the total number of wireless service providers. Median age is negatively associated with the number of wireless service providers. Percentage of rural population is negative in full sample estimation while it's positively in a subsample of isolated towns. Size of land area is negative in full sample and is not significant in subsample. We expect more wireless carriers in southern areas and within MSAs, and less in western and central areas. Notice that in the ordered model for the full sample, population in nearby cities positively affects the number of wireless firms. If we expect that city correctly bounded the relevant economical market, then the demand in nearby market should have no effect on firm's entry decision. If scale economy is important for wireless firms, then demand in nearby market should positively affect the number of them firm in the ordered model. The scale economies should be of fewer concerns in a subsample of moderate sized isolated towns. All of the cut values are statistically significant, suggesting that the categorizations are distinct from each other.

Table 1.3: Ordered Model

Dependent Variable: Total number of wireless firms

	Full Sample	Sub Sample
log (population)	0.19***	0.46***
	(0.01)	(0.14)
log (per capita income)	0.68***	0.84**
	(0.03)	(0.32)
rural population %	-0.39***	0.33***
	(0.03)	(0.83)
log (time commute to work)	0.26***	1.14***
	(0.04)	(0.27)
median age	-0.03***	-0.02*
	(0.00)	(0.01)
log(size of land area)	-0.08***	-0.10
	(0.01)	(0.12)
log(population in 10 mi/distance)	0.00***	0.02*
	(0.00)	(0.01)
log(population in 15 mi/distance)	0.00	0.02**
	(0.00)	(0.01)
log(population in 20 mi/distance)	0.00***	0.01**
	(0.00)	(0.01)
msa	0.87***	0.38**
	(0.02)	(0.17)
south	0.41***	0.52***
	(0.02)	(0.13)
west	-0.17***	0.33**
	(0.02)	(0.13)
central	-0.22***	-0.27***
	(0.02)	(0.11)
cut1	4.74***	12.54***
cut2	5.82***	13.45***
cut3	6.71***	14.64***

cut4	7.22***	15.24***
cut5	7.78***	15.83***
cut6	8.76***	16.59***
cut7	9.90***	17.71***
cut8	11.19***	18.45***
Number of Observations	19407	428

Note: Regression carried out at city level. Standard errors are reported in parentheses.

**** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

It is hard to directly interpret the estimates in column 1 because they measure the change in unobserved latent value associated with the change in explanatory variable. I compute the marginal effect, which measures the change in probability with respect to the change in explanatory variable. In Table 1.4, the marginal effect of *log(population)* indicates that when population increases 1%, holding all other variables at its mean, the probability of observing one, two, three or four wireless firm goes down by 1%,3%,2% and1% respectively, while the probability of observing five, six and seven wireless firms increases 3%, 4% and 1%. It's more likely to have more than four wireless carriers in the Southern part of the U.S. Similarly, it's less likely to observe more than four wireless firms in Western and Central part. Table 1.4 also demonstrates an interesting pattern. The sign of most of the explanatory variables differs between the cases where more entry occurs (more than four wireless firms) and where less entry occurs (four or less firms). The result for subsample is presented in Table 1.5. As we expected, the effect of nearby market is much less important in the subsample, suggesting that the market boundary is more appropriate for the subsample. The limitation of looking only at subsample is that we seldom observe the market with more than 6 carriers, thus the marginal effects are imprecisely estimated in these cases. Thus I conduct my analysis on both full sample and subsample.

Table 1.4: Marginal Effect (Full Sample)

Dependent Variable: Total number of wireless firms

	p_1=0.03	p_2=0.12	p_3=0.15	p_4=0.21	p_5=0.33	p_6=0.14	p_7=0.02	p_8=0.00
log (population)	-0.01***	-0.03***	-0.02***	-0.01***	0.03***	0.04***	-0.02***	0.00***
log (per capita income)	-0.04***	-0.12***	-0.08***	-0.03***	0.11***	-0.14***	0.03***	0.00***
rural population %	0.02***	0.07***	0.05***	0.02***	-0.06***	-0.08***	-0.02***	0.00***
log(time commute)	-0.01***	-0.04***	-0.03***	-0.01***	0.04***	0.05***	0.01***	0.00***
median age	0.00***	0.01***	0.00***	0.00***	0.00***	0.01***	0.00***	0.00***
log(size of land area)	0.00***	0.01***	0.01***	0.00***	-0.01***	0.02***	0.00***	0.01***
log(pop in 10 mi/dist)	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
log(pop in 15 mi/dist)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
log(pop in 20 mi/dist)	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
msa	-0.05***	-0.14***	-0.09***	-0.04***	0.12***	0.04***	0.04***	0.00***
south	-0.02***	-0.06***	-0.05***	-0.03***	0.05***	0.02***	0.02***	0.00***
west	0.01***	0.03***	0.02***	0.01***	-0.03***	-0.01***	-0.01***	0.00***
central	0.01***	0.04***	0.02***	0.01***	-0.04***	-0.01***	-0.01***	0.00***

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

Table 1.5: Marginal Effect (Isolated Towns)

Dependent Variable: Total number of wireless firms

	p_1=0.04	p_2=0.27	p_3=0.23	p_4=0.21	p_5=0.17	p_6=0.14	p_7=0.02	p_8=0.00
log (population)	-0.04***	-0.12***	-0.02**	0.04***	0.08***	0.05***	0.02*	0.00
log (per capita income)	-0.09***	-0.28***	-0.04**	0.10***	0.19***	0.12***	0.01*	0.00
rural population %	-0.06***	-0.20	0.29	0.07	0.13	0.09	0.00	0.00
log(time commute)	-0.09	-0.29***	-0.04**	0.10***	0.20***	0.12***	0.01*	-0.00
median age	0.00***	0.00*	0.00	-0.00*	-0.00*	-0.00*	-0.00	-0.00
log(size of land area)	0.01	0.03	0.00	-0.01	-0.03	-0.00	-0.00	-0.00
log(pop in 10 mi/dist)	0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00
log(pop in 15 mi/dist)	-0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
log(pop in 20 mi/dist)	-0.00**	0.00**	-0.00*	0.00**	0.00**	0.00*	0.00	0.00
Msa	-0.02***	-0.10**	-0.03	0.02***	0.07**	0.06**	0.01	0.00
South	-0.04***	-0.13***	-0.03**	0.04***	0.09***	0.07***	0.01	0.00
West	0.04***	-0.15***	-0.04**	0.03***	0.10***	0.08***	0.01	0.00
Central	0.01	0.03	0.02	-0.01	-0.02	-0.02	-0.00	0.00

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

One prominent feature of the wireless telecommunication market in the U.S. is that several major firms dominate the market. Each of them has the wireless systems that cover at least 200 million people, while the next largest carrier could cover only 62 million people. The national wireless firms are Cingular, Nextel, Sprint, T-mobile and Verizon, as recognized by the FCC. Table 1.6 shows the correlation among national firm's entry decision and between national and regional firm's entry decision. National carriers tend to enter different market than regional carriers. The model without distinction between national and regional firms is mis-specified.

When firms enter and compete in a local market, differentiation softens competition by blunting competition across different types. In wireless telecom market, one such difference is geographical scope. Is the local market strongly segmented between firms with narrow geographical scope (i.e. regional firms) and those with broad scope (i.e. national firms) as documented by Mazzeo (2002), Greenstein and Mazzeo (2006). Table 1.6 split the wireless firms into two exclusive categories, national and regional. For instance, in 4939 markets with 5 wireless carriers operating, 3234 consists of five national firms with no regional firms. Thus we didn't find clear indication for differentiation in coverage scope. If differentiation is optimal, in a market with 2 national and 1 regional firm, a regional firm is more likely to enter than national. Thus we should be much more likely to observe the configuration such as at least one national and at least one regional entered. In the full sample, we far more frequently observe the case where all five national firms enter and zero or one regional firm enters. It appears that regional firm tends to avoid national firms and national firms tend to enter together. In the subsample, the entry pattern is different. In a market that supports two wireless firms, market configuration (1, 1) is more likely to present than (2, 0) or (0, 2). In a market with three or more wireless firms, (1, 2) and (2, 1) are more likely to occur than (3, 0) or (0, 3). The frequency that five national firm enters together is identical to the frequency that no national firm enters. There is descriptive evidence for differentiation in a subsample of isolated towns.

Table 1.6: National and Regional Carriers

Full Sample

	National Carrier					
Regional Carrier	0	1	2	3	4	5
0	194	393	459	633	954	3236
1	971	1911	1257	1260	1221	2912
2	636	484	501	390	747	688
3	15	42	89	87	265	47
4	3	3	8	1	0	0
Total	1819	2833	2314	2371	3187	6833

Subsample

	National Carrier					
Regional Carrier	0	1	2	3	4	5
0	5	10	14	12	9	19
1	19	86	52	50	42	18
2	16	19	17	10	19	3
3	1	2	1	1	2	1
Total	41	117	84	73	72	41

To account for the differences between national and regional wireless carriers, I estimate an ordered model for national firm and regional firm separately, taking the rival type firm's entry decisions as given. The results are displayed in Table 1.7 through Table 1.10. The effect of cost and demand shifters differs significantly between national (Table 1.7 and Table 1.8) and regional (Table 1.9 and

Table 1.10) firms across all specifications, suggesting that we shouldn't treat national and regional firm identical to each other.

Competitions across different firm types (#regional firm>0, #regional and log #regional +1 in Table 1.7 and Table 1.8 and #national firm>0, #national and log #national +1 in Table 1.9 and 1.10) are both quantitatively and qualitatively significant. For instance, the presence of a regional competitor (-0.44) is more than twice as great as the effect of population (0.20) in the full sample. In the subsample, presence of a regional competitor (-0.50) is as important as the population (0.47). Similarly, for a regional firm, presence of a national competitor (-0.36) is nine times the effect of population (0.04). In isolated towns, presence of a national competitor (-0.52) is almost three times the effect of population (0.18).

To understand the absolute magnitude of the competition coefficients, I compute the marginal effect. The results are displayed in Table 1. 11. For example, any regional firm's presence reduces the probability that all national firms enter together by 16.7%. However, it raises the probability in all other cases. This pattern is robust across all specifications of full sample. When looking at isolated towns, the presence of regional firm raises the probability 1 or 2 national firm enters, however, it decreases the probability that more than two national firms enter. The sign and significance level of marginal effect in the case where either 1 or 2 national firm enters changes, as I replace the presence of regional firm with the number of regional firm and log number of regional firm. This suggests that national firm's entry decision is sensitive to the number of regional firm and effect of regional firm on national firm is non-linear. On the other hand, the presence of a national firm always reduce the probability regional firm enters in full sample. In isolated towns, presence of national firm is marginally significant in the case where the first regional firm decide whether to enter or not. It always reduce the probability that two or three regional firm enters.

To investigate the effect of competition across the same types, I compute minimum population that is needed to sustain N firms using the estimated coefficient from specification 4 in isolated towns. Table 1.12 displays the results[2]. A national monopolist needs 315 customers to break even while a regional monopolist firm needs only 74. When we try to evaluate the entry threshold as in Bresnahan and Reiss (1991), the entry threshold is much greater than theoretical values. As noted by Berry and Tamer (2006), Bresnahan and Reiss type model might not be robust to monotonic transformation of variable profit. However, the threshold does indicate that the margin decreases as the number of firm increases.

Table 1.7: Ordered Model (Full Sample, N=19407)

Dependent Variable: Number of National Carrier

	1	2	3	4
log (population)	0.19***	0.20***	0.21***	0.21***
	(0.01)	(0.01)	(0.01)	(0.01)
log (per capita income)	0.87***	0.85***	0.89***	0.88***
	(0.04)	(0.04)	(0.04)	(0.04)
rural population %	-0.34***	-0.34***	-0.34***	-0.34***
	(0.03)	(0.03)	(0.03)	(0.03)
log (time commute to work)	0.49***	0.45***	0.46***	0.45***
	(0.03)	(0.03)	(0.03)	(0.03)
median age	-0.04***	-0.04***	-0.04***	-0.04***
	(0.00)	(0.00)	(0.00)	(0.00)
log(size of land area)	0.00	0.00	-0.02	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)
log(population in 10 mi/distance)	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
log(population in 15 mi/distance)	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
log(population in 20 mi/distance)	0.01***	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)
msa	0.72***	0.72***	0.74***	0.73***
	(0.02)	(0.02)	(0.02)	(0.02)
south	0.41***	0.43***	0.46***	0.45***
	(0.02)	(0.02)	(0.02)	(0.02)
west	0.18***	0.13***	0.14***	0.13***
	(0.02)	(0.02)	(0.02)	(0.02)
central	-0.19***	-0.11***	-0.15***	-0.13***
	(0.02)	(0.02)	(0.02)	(0.02)
#regional carrier > 0		-0.44***		

[2] The result computed using other specifications available upon request.

	1	2	3	4
		(0.02)		
#regional carrier			-0.29*** (0.01)	
log (#regional carrier +1)				-0.56*** (0.02)
cut 1	8.71*** (0.37)	8.04*** (0.37)	8.65*** (0.37)	8.38*** (0.37)
cut2	9.62*** (0.37)	8.96*** (0.37)	9.58*** (0.37)	9.31*** (0.37)
cut3	10.20*** (0.37)	9.55*** (0.37)	10.16*** (0.37)	9.90*** (0.37)
cut4	10.76*** (0.37)	10.12*** (0.37)	10.73*** (0.37)	10.47*** (0.37)
cut5	11.57*** (0.37)	10.95*** (0.37)	11.57*** (0.37)	11.31*** (0.37)

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

Table 1.8: Ordered Model (Isolated Towns, N=428)

Dependent Variable: Number of National Carrier

	1	2	3	4
log (population)	0.43*** (0.14)	0.47*** (0.15)	0.47*** (0.15)	0.47*** (0.15)
log (per capita income)	0.81*** (0.33)	0.85*** (0.33)	0.91*** (0.33)	0.90*** (0.33)
rural population %	1.19*** (0.87)	1.21*** (0.87)	1.13*** (0.87)	1.16*** (0.87)
log (time commute to work)	1.46*** (0.28)	1.35*** (0.28)	1.38*** (0.28)	1.36*** (0.28)
median age	-0.03*** (0.01)	-0.03*** (0.01)	-0.03*** (0.01)	-0.03*** (0.01)
log(size of land area)	-0.12*** (0.12)	-0.12*** (0.12)	-0.14*** (0.12)	-0.13*** (0.12)
log(population in 10 mi/distance)	0.01*** (0.01)	0.01*** (0.01)	0.01*** (0.01)	0.01*** (0.01)
log(population in 15 mi/distance)	0.01*** (0.01)	0.01*** (0.01)	0.01*** (0.01)	0.01*** (0.01)
log(population in 20 mi/distance)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)
msa	0.37*** (0.17)	0.38*** (0.17)	0.41*** (0.17)	0.40*** (0.17)
south	0.44*** (0.16)	0.49*** (0.16)	0.48*** (0.16)	0.49*** (0.16)
west	0.69*** (0.17)	0.71*** (0.17)	0.70*** (0.17)	0.70*** (0.17)
central	-0.18*** (0.15)	-0.12*** (0.16)	-0.16*** (0.15)	-0.14*** (0.15)
#regional carrier > 0		-0.50*** (0.15)		
#regional carrier			-0.31*** (0.08)	
log (#regional carrier +1)				-0.63***

				(0.16)
cut 1	13.66***	13.73***	14.48***	14.28***
	(3.22)	(3.22)	(3.23)	(3.23)
cut2	14.81***	14.89***	15.66***	15.46***
	(3.22)	(3.23)	(3.24)	(3.24)
cut3	15.43***	15.51***	16.28***	16.08***
	(3.23)	(3.23)	(3.24)	(3.24)
cut4	16.00***	16.09***	16.85***	16.66***
	(3.23)	(3.24)	(3.25)	(3.24)
cut5	16.79***	16.90***	17.66***	17.47***
	(3.24)	(3.25)	(3.25)	(3.25)

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

Table 1.9: Ordered Model (Full Sample, N=19407)

Dependent Variable: Number of Regional Carrier

	1	2	3	4
log (population)	0.08***	0.09***	0.11***	0.10***
	(0.01)	(0.01)	(0.01)	(0.01)
log (per capita income)	-0.08***	-0.05	0.05	0.03
	(0.03)	(0.03)	(0.03)	(0.03)
rural population %	0.10***	0.09***	0.02	0.04
	(0.03)	(0.03)	(0.03)	(0.03)
log (time commute to work)	-0.25***	-0.23***	-0.18***	-0.19***
	(0.03)	(0.03)	(0.03)	(0.03)
median age	0.01***	0.00***	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
log(size of land area)	-0.06***	-0.06***	-0.07***	-0.07***
	(0.01)	(0.01)	(0.01)	(0.01)
log(population in 10 mi/distance)	0.00***	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)
log(population in 15 mi/distance)	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
log(population in 20 mi/distance)	0.00***	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)
msa	-0.02	0.01	0.15***	0.11***
	(0.02)	(0.02)	(0.02)	(0.02)
south	0.21***	0.24***	0.27***	0.26***
	(0.02)	(0.02)	(0.02)	(0.02)
west	-0.21***	-0.23***	-0.22***	-0.23***
	(0.02)	(0.02)	(0.02)	(0.02)
central	0.22***	0.18***	0.16***	0.15***
	(0.02)	(0.02)	(0.02)	(0.02)
#national carrier > 0		-0.36***		
		(0.03)		
#national carrier			-0.15***	
			(0.01)	
log (#national carrier +1)				-0.39***
				(0.02)
cut 1	-1.45***	-1.44***	-0.37	-0.71***
	(0.32)	(0.32)	(0.32)	(0.32)
cut2	-0.02***	0.01***	1.10	0.74***

	(0.32)	(0.32)	(0.32)	(0.32)
cut3	1.09*** (0.32)	1.12*** (0.32)	2.22 (0.32)	1.86*** (0.32)
cut4	2.37*** (0.33)	2.40*** (0.33)	3.52 (0.33)	3.15*** (0.33)
cut5	0.08*** (0.01)	0.09*** (0.01)	0.11*** (0.01)	0.10*** (0.01)

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

Table 1.10: Ordered Model (Isolated Towns, N=428)

Dependent Variable: Number of Regional Carrier

	1	2	3	4
log (population)	0.14*** (0.15)	0.18*** (0.16)	0.22*** (0.16)	0.22*** (0.16)
log (per capita income)	0.47*** (0.36)	0.48*** (0.36)	0.65*** (0.36)	0.62*** (0.36)
rural population %	-0.48*** (0.92)	-0.38*** (0.93)	-0.30*** (0.93)	-0.31*** (0.93)
log (time commute to work)	-0.65*** (0.29)	-0.63*** (0.29)	-0.38*** (0.31)	-0.41*** (0.30)
median age	0.03*** (0.01)	0.03*** (0.01)	0.02*** (0.01)	0.02*** (0.01)
log(size of land area)	-0.06*** (0.13)	-0.08*** (0.13)	-0.08*** (0.13)	-0.08*** (0.13)
log(population in 10 mi/distance)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)
log(population in 15 mi/distance)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)
log(population in 20 mi/distance)	-0.01*** (0.01)	-0.01*** (0.01)	-0.01*** (0.01)	-0.01*** (0.01)
msa	0.17*** (0.19)	0.21*** (0.19)	0.24*** (0.19)	0.25*** (0.19)
south	0.24*** (0.17)	0.30*** (0.17)	0.33*** (0.18)	0.34*** (0.18)
west	-0.05*** (0.18)	0.02*** (0.18)	0.08*** (0.18)	0.08*** (0.18)
central	0.12*** (0.17)	0.09*** (0.17)	0.10*** (0.17)	0.10*** (0.17)
#national carrier > 0		-0.52*** (0.20)		
#national carrier			-0.15*** (0.04)	
log (#national carrier +1)				-0.44*** (0.13)
cut 1	4.02*** (3.47)	4.15*** (3.48)	6.68*** (3.57)	6.27*** (3.54)
cut2	5.90*** (3.47)	6.06*** (3.48)	8.60*** (3.57)	8.19*** (3.55)
cut3	7.28***	7.45***	9.99***	9.59***

(3.48)	(3.49)	(3.58)	(3.56)

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

Table 1.11: Marginal Effect of Competition

	#regional > 0	#regional	log(#regional+1)
		Full Sample	
Prob (1 national firm enters)	0.04***	0.03***	0.05***
Prob (2 national firms enter)	0.05***	0.04***	0.07***
Prob (3 national firms enter)	0.06***	0.04***	0.07***
Prob (4 national firm enters)	0.02***	0.00***	0.01***
Prob (5 national firm enters)	-0.17***	-0.11***	-0.21***
		Isolated Towns	
Prob (1 national firm enters)	0.12***	-0.08***	0.16***
Prob (2 national firm enters)	0.03**	0.00	0.02
Prob (3 national firm enters)	-0.03***	-0.03***	-0.06***
Prob (4 national firm enters)	-0.09***	-0.05***	-0.11***
Prob (5 national firm enters)	-0.07***	-0.03***	-0.07***
	#national > 0	#national	log(#national+1)
		Full Sample	
Prob (1 regional firm enters)	-0.01***	-0.01***	-0.03***
Prob (2 regional firm enters)	-0.08***	-0.03***	-0.08***
Prob (3 regional firm enters)	-0.02***	-0.01***	-0.02***
Prob (4 regional firm enters)	-0.00***	-0.00***	-0.00***
		Isolated Towns	
Prob (1 regional firm enters)	0.07	0.00*	-0.02*
Prob (2 regional firm enters)	-0.14**	-0.04***	-0.11***
Prob (3 regional firm enters)	-0.03	-0.00**	-0.01**

*Note: *** signifies p<.01, ** signifies p<.05 and * signifies p<.1*

Table 1.12: Minimum Population to Support Wireless Firms in Isolated Towns

	# of Firms to Support				
	1	2	3	4	5
Minimum Population to Support National firms	315	1880	4698	11801	52575
Minimum Population to Support Regional firms	74	418697	2.16E+8		

We recognize the endogeneity if the number of firm of different type (i.e. the number of regional firm in the equation for national firm and the number of national firm in regional's). The market structure is endogenous to the extent of market. Thus the coefficient of #regional>0, #regional and log (#regional + 1) might pick up any omitted variables associated with the extent of the market. Separating competitive effect from the extent of market is a difficult econometric problem. We are unable to identify an exogenous variable associated with regional firm's entry decision yet independent of local demand for wireless telecommunication services. Valid instrument could be cost shifters which affects firm's entry decision yet unrelated with the nature of local demand. The estimated coefficient on the number of rival firms could be deemed as an upper bound. I explicitly address the endogeneity in the number of rival firms in chapter 2 using a structural model.

1.7 Concluding Remarks

In this paper I examine the effect of competition on firm's profitability. Specifically, I study how the rival's market presence affects firm's profitability. In order to do so, I adopt an ordered probit model that recovers firm's underlying profitability. By assuming that the rival's market presence always decreases the average variable profit, the average variable profit is reveals by number of the firm in that market. Using the model, I find evidence for a strong competition between different types of firms: the presence of a regional firm reduces the probability that five national firms enter by 17% in full sample, and by 7% in a subsample of isolated towns. In addition, the presence of national firm always reduces the probability regional firm enters in the full sample, while it has no effect on the entry decision of the first regional firm in isolated towns. The estimated result confirms that entry of the same type firm always reduces the margin.

2 Strategic Interactions and Market Structure in the U.S. Mobile Telecommunications Industry

2.1 Introduction

The U.S. mobile telecommunications industry has experienced substantial growth in the past decades. It contributed $92 billion to the U.S. GDP and served over 200 million subscribers in 2005. The industry wisdom maintains that the wireless coverage in the U.S. is sufficient such that all who want a cell phone already have one.[3] However, rural residents often complain of insufficient coverage. Lack of wireless coverage creates inconvenience and prompts safety concerns for rural residents.[4]

In response, many state governments have adopted policies to encourage wireless entry. For example, Vermont has attempted to facilitate wireless expansion by establishing a telecommunications authority and by providing public funds. Missouri subsidizes cellular phone

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[3] From "AT&T eager to wield its iWeapon," USA Today, May 27, 2007: "Anybody who wants a cell phone has one. Those who don't, he (Charles Golvin, a wireless industry analyst at Forrester Research) says `are the very young, the very old and the economically challenged.' Those groups are not particularly attractive to the big carriers, which also are valued on how much revenue per subscriber they generate."

[4] From "Tower of Trouble," Economist Jul 12, 2007: "Other parts of New England are also lobbying for more coverage, for safety reasons… In January a man died of hypothermia there after his car broke down and he could not summon help."

companies offering service in rural areas with funds from the federal Universal Service Fund,[5] which is maintained through a surcharge on nearly every American telephone line.

While government policies have focused on how to pay for rural coverage, surprisingly little attention has been directed at understanding how wireless carriers make their entry decisions or how to effectively stimulate entry. For example, as the incentive to serve a specific location differs across wireless carriers, choosing the carrier with the highest incentive could potentially reduce the amount of subsidy.

This paper investigates the determinants of wireless service provision across geographic locations. Specifically, I identify the competitor-specific strategic interactions that arise from a rival's market presence without imposing the specific restriction of positive or negative impact from such presence. The entry decision of each nationwide wireless carrier, together with the number of regional carriers, is formalized as the equilibrium outcome of a simultaneous-move game with complete information. Contrary to the assumption made by prior studies (e.g., Berry 1992), I find that competing firms' entry decisions do not necessarily constitute strategic substitutes. For instance, I find that Cingular's entry decisions constitute strategic complements to all nationwide carriers' except Verizon's. This result also highlights the relatively intense rivalry between Cingular and Verizon. Entry by Sprint promotes the entry of regional carriers, while entry by Verizon reduces the entry of regional carriers. In a policy experiment, I examine the disincentive for nationwide wireless carriers to serve small cities. The results suggest that Sprint is on average more likely to serve municipalities with populations less than 500.

[5] From "Rural Wireless Coverage in Jeopardy," Columbia Tribune, Nov 2, 2007: "The fund was created in 1996 by Congress to create competition and increase access to telecommunications services for consumers in rural and hard-to-serve areas. It has collected $44 billion during its lifetime from a surcharge on the phone bills of nearly every American."

The contributions of this paper are threefold. First, I collect a novel dataset and introduce the city as the unit of analysis. The study of the U.S. mobile telecommunications industry has been hampered by lack of data. Parker and Roller (1997), Busse (2000) and Miravete and Roller (2003) study various aspects of the industry with a similar dataset covering the mid-1980s. While Seim and Viard (2006) and Bajari, Fox and Ryan (2006) use data from other sources, they rely on the Metropolitan Statistical Area (MSA) as the unit of analysis, as does other work. Since 1995, the Federal Communications Commission (FCC) has conducted an annual analysis of the competitive status of the industry. Their most recent analysis relies on several measures, including counts of wireless carriers at the county level,[6] and makes the critical assumption that if one part of a county is covered, then every part of that county is covered. In a competitive analysis, this assumption could potentially overstate the degree of competition,[7] as recognized by the FCC.[8,9] I collect the wireless carriers' entry decisions at the ZIP Code Tabulated Area[10] (ZCTA) level almost everywhere in the U.S. and find that carriers' entry decisions vary substantially within counties. My study suggests that competitive analysis using broader geographic units can lead to inaccurate estimates.

[6] MSA/Rural Statistical Area (RSA) can be subdivided into counties.

[7] For example, suppose there are two cities in a county, each served by a different wireless carrier. The market structure is perceived as a duopoly at the county level and a monopoly at the city level.

[8] From Statement of Commissioner Michael J. Copps: "As today's report acknowledges, one important flaw in our present methodology is the assumption that if one part of a county (such as an interstate highway) receives coverage, then every part of the county receives coverage. Though gathering more granular data may be difficult, I think we need to investigate whether a sampling methodology may be appropriate. The present method distorts reality."

[9] From "Eleventh Annual Report to Congress on the State of Competition in the Commercial Mobile Radio Services (CMRS) Industry," the FCC: "As mentioned in previous reports, there are several important caveats to note when considering the data. First, to be considered as "covering" a county, an operator need only be offering any service in a portion of that county. Second, multiple operators shown as covering the same county are not necessarily providing service to the same portion of that county…Therefore, our analysis overstates to some unknown and unavoidable degree the total coverage in terms of both geographic areas and population covered. On the other hand, we believe our analysis to be the most accurate in the industry today given the coverage data that are publicly available."

[10] According to the US Census's own definition, ZCTAs are generalized area representations of U.S. Postal Service (USPS) zip code service areas. They are built by aggregating the Census 2000 blocks, whose addresses use zip codes, into a ZCTA, which gets that zip code assigned as its ZCTA code. Most of the time, ZCTA codes represent the majority USPS five-digit zip code found in a given area.

Second, this paper is the first attempt to study entry and the endogenous market structure for the mobile telecommunications industry. Before the mid-1990s, the industry was highly regulated.[11] The literature has taken the market structure as given and focused on other aspects of the industry, such as collusive conduct (Parker and Roller, 1997), multi-market contact (Busse, 2000) and consumer tastes (Miravete and Roller, 2003). Since the mid-1990s, papers have examined technology adoption (Seim and Viard, 2006), consumer tastes (Bajari, Fox and Ryan, 2006) and the history of wireless consolidation (Fox, 2005). This paper complements the current literature by studying the entry behavior of wireless carriers. It provides an overview on how nationwide carriers interact with each other and with regional carriers. Understanding strategic interactions among wireless carriers helps shed light on the market outcome as the competitive environment changes in this dynamic industry. It also generates implications on how to motivate firms to enter a particular market.

Third, this paper develops a model featuring flexible forms of strategic interactions among a rich set of players. In the empirical literature of strategic entry (e.g., Berry, 1992; Bresnahan and Reiss, 1991; Mazzeo, 2002), entry decisions are assumed to be strategic substitutes and the entry decision of a firm depends only on the number of competitors in the market, rather than their identities. This paper extends their work and allows the strategic effects to be sign-free and identity-specific.[12] The results of the paper indicate that effects of competitors' entry vary widely depending on their identities, and the pair-wise entry decision between some carriers forms strategic complements. Failure to account for strategic complementarities in carriers' entry decisions can misidentify the degree of competition.

[11] Before the mid-1990s, the FCC allowed only two wireless carriers in each MSA or RSA. The resulting duopoly market structure was a consequence of mandated legislation. As a result, it revealed neither the source of firm profitability nor the nature of competitive interaction.

[12] Jia (2006) also allows identity-specific interactions between two players and her results indicate that their entry decisions are strategic substitutes. Ciliberto and Tamer (2003) study the identity-specific strategic interactions with a semi-parametric interval estimator in airline industry.

This paper proceeds as follows. Section 2 presents background information on various aspects of the industry, including regulatory details. Section 3 describes the data and discusses the unit of observation. Section 4 sets up the model and illustrates estimation details. Section 5 presents results. Section 6 concludes with a discussion of the implications of the results.

2.2 The U.S. Wireless Telecommunications Market

The mobile phone is commonly known as cell phone because the service areas are divided into small "cells", where the spectrum is reused across non-adjacent cells. This allows many people to use their mobile phone simultaneously without interfering with one other. Within each cell, a number of base stations (or cell sites) are built to receive signals emitted from personal wireless devices and inter-connect them to the Public Switch Telephone Network (PSTN) via wired facility. When talking on cell phone, the wireless signal is sent back and forth between personal wireless device and base station. In the U.S., different wireless technology standard are deployed in transmitting the wireless signal. Cingular and T-Mobile use Global System for Mobile communications (GSM) technology, while Sprint and Verizon use Code Division Multiple Access (CDMA) technology, and Nextel's Integrated Digital Enhanced Network (iDen) technology is independently developed by Motorola.

The base station is usually capacity constrained in that it can only handle a limited number of calls at any one time, within a limited working range. For GSM technology, there is a fixed maximum of a 35 km radius working range; while no such build-in limitation applies to CDMA and iDen technology, the ability that low-powered personal cell phones transmit back to the cell site is limited. In practice, the cell sites are usually spaced 2-3 km apart in suburban area, and could be as close as 500-1000 meters in densely populated area.

When multiple signals are transmitted at the same frequency, they interfere with one another. To prevent this, the Federal Communication Committee began issuing spectrum licenses to wireless service providers. The licensee enjoys the privilege of using a certain amount of the spectrum in a confined geographic area. In the infancy of the industry, cellular spectrum licenses were awarded by either comparative hearing or lottery. The United States was divided into 734 Cellular Market Areas (CMA), including 305 metropolitan statistical areas, 428 rural statistical areas and a market for the Gulf of Mexico. Two cellular licenses were granted in each CMA, one to a local wire line carrier and the other to a carrier other than a local wire line incumbent. By nurturing the duopoly market structure, the FCC wished to foster competition and prevent any one carrier from monopolizing the industry.

In 1993, the FCC began auctioning off the Personal Communication Service (PCS) spectrum[13] and the previous duopoly market structure broke down. Compared with traditional cellular technology, the PCS spectrum operates at a higher frequency band and fully utilizes digital technology. The PCS spectrum is divided into six blocks, two of which are designated based on 51 Major Trading Areas (MTA) and the rest on 493 Basic Trading Areas (BTA).[14]

The spectrum license holders are given the flexibility to partition (divide the license into smaller geographical areas) and/or disaggregate (divide the spectrum into smaller amounts of bandwidth) their licenses to other entities. The auctions took several rounds and raised about 20 billion for the

[13] The iDen technology adopted by Nextel utilizes neither Cellular nor PCS spectrum. Instead, it operates on Specialized Mobile Radio (SMR) spectrum which is traditionally used by dispatch services, between fixed units and mobile units (e.g., between a taxicab dispatch office and a taxi) or between two or more mobile units (e.g., between a car and a truck).

[14] MTA/BTA is geographic area, based on the Rand McNally 1992 Commercial Atlas & Marketing Guide, 123rd Edition, pages 38-39. Figure 2 and Figure 3 shows the map of MTA and BTA. The geographical boundary of MTA does not overlap the state boundary. BTA is contained in MTA. Both MTA and BTA could be effectively divided into counties.

U.S. Treasury. In addition, they attracted more firms to enter the wireless telecom industry and the number of carriers serving each geographical area started to vary with market conditions.[15]

The U.S. wireless telecommunications industry is dominated by five wireless operators: Cingular, Nextel, Sprint, T-mobile, and Verizon. Each firm has wireless systems that cover, geographically, at least 200 million people, while the next largest carrier, Alltel, covers 62 million people (Commercial Mobile Radio Services Competition Reports 2006).

Both Cingular and Verizon share a strong Bell background.[16] They enjoy well-built strength in local telephone exchange and broadband markets. Cingular was a joint venture between Southwestern Bell Corporation (or SBC communications) and BellSouth. It was the second largest wireless carrier and acquired AT&T Wireless, who was previously the third largest carrier, in 2004. After Cingular completed its merger, it leapfrogged Verizon and became the leading wireless carrier in the U.S. Verizon, on the other hand, roots from the consolidation of Bell Atlantic and GTE, the latter of which was formerly the largest independent local exchange telephone (i.e. non-Bell) company in the U.S.[17]

As shown in Figure 4, Cingular and Verizon enjoy incumbency in different geographic areas as the divesture of the Bell Company in the early 80s was based on geographical region. For instance,

[15] The 1996 act doesn't directly address the wireless sector, and wireless service is essentially fully exempt from wholesale and retail price regulation. The rates charged for interconnecting wireless calls with the traditional wire-based network are subject to the requirements of the 1996 law. See R. Crandall and J. Hausman (2000) for detail.

[16] In 1984, AT&T Corp. divested its local exchange service operating companies in return for a chance to go into the Internet services industry. The Local operations were split into seven independent Regional Bell Operating Companies known as "Baby Bells."

[17]Verizon Wireless is a joint venture between Bell Atlantic and UK-base Vodafone.

Verizon enjoys incumbency in the northeastern part of the U.S. while Cingular enjoys incumbency in just about everywhere besides where Verizon and Qwest reside.[18]

The rivalry between Cingular and Verizon is publicly well-known. Verizon acquired MCI (formally WorldCom), previously the largest long distance phone service provider in the U.S., just months before the marriage of Cingular and AT&T. In the bidding war for AT&T, Verizon successfully made Cingular pay twice the market value of AT&T. Currently Cingular has 62.2 million customers, while Verizon and Sprint have 60.7 million and 53.6 million, respectively. In their ad campaign, Cingular (AT&T) broadcasts that "Only AT&T keeps you connected in over 190 countries on the GSM network, the one used by 84% of wireless customers worldwide." Verizon claims they have the fewest dropped calls, whose nationwide ad campaign "can you hear me now" attempts to highlight their service quality. Cingular's subsequent campaign "raising the bar" is considered to directly target Verizon. Currently, Cingular has slightly more subscribers (after its merger with AT&T) while Verizon claims to have the highest revenue. Both claim to be No.1 American wireless provider.

Cingular and T-mobile are the only two GSM carriers among nationwide carriers. Their wireless networks are technologically compatible with each other, making it feasible to share their network facility. In reality, they maintained and shared their GSM network, through a joint venture known as GSM Facilities. Their network sharing agreement allowed Cingular to offer local service in northern New Jersey and New York City and T-Mobile to offer service in California and Nevada. After Cingular's acquisition of AT&T in 2004, the network was transferred to T-Mobile, and Cingular continued operating on the GSM facilities from AT&T Wireless sites. Currently, Cingular and T-mobile are still roaming partners and they enjoy each other's network with low roaming cost.

[18] Qwest does not offer its own wireless service. It has an agreement with Sprint and resells Sprint wireless services to consumer within its local service area.

Nextel differs from the rest of national carriers because it adopts a technology called iDEN, which is incompatible with either GSM or CDMA network.[19] However, iDEN technology could use the radio frequency that was formally used by paging services. Cingular wireless used to own the bulk of spectrum for paging services. As demand for paging service declines, the spectrum was sold. Recently, Nextel purchased Velocita Wireless, who used to provide paging service as a part of Cingular, to supplement its capacity and coverage for iDEN-based network.

Sprint has a strong non-Bell local exchange background. It was the next largest incumbent local exchange carrier (ILEC) after Baby Bells and GTE and serves 18 states (its biggest market is Las Vegas, Nevada). Sprint expanded its wireless service to rural areas primarily through affiliation with regional companies. These smaller companies build network infrastructure and operate their own retail stores. In exchange, the smaller companies receive usage of Sprint's brand name, radio spectrum, customer service and billing.[20] In most cases, these affiliate carriers are transparent to the end user or consumer. However, Sprint often gets complained about poor the quality service.[21]

2.3 Data

2.3.1 Data Sources

The data comes from three major sources: (1) service provision data from cellular service retailer's website; (2) demographic data from Census; and (3) geographic reference data from Missouri Census

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[19] The iDen technology is invented and wholly owned by Motorola. Nextel suffers from not being able to offer diverse selection of cell phones. Most of the device makers will not manufacture iDen phone. Nextel could offer cell phone of only two brands: most of time Motorola and occasionally Blackberry.

[20] Sprint's local exchange (landline) services spun off as part of the deal to get the merger with Nextel approved in 2005. Again, since the entry decision occurred long before the sampling year, and the change is not likely to take place immediately, I still treat Sprint as an independent firm

[21] In addition, Sprint offers services for Qwest through agreement.

Data Center (MCDC). Numbering data from North America Numbering Plan[22] (NANPA) is cross-checked with service provision data.

The service provision data is collected in December 2005 from letstalk.com, a leading online wireless service retailer. An automated process inputs a list of Census's ZCTA codes into the website while retrieving the service provision information (e.g. the identity of service provider, types of services plan and the price of the plan etc.) for each ZCTA.

I choose to collect service provision information from Letstalk.com because it carries a wide selection of wireless brands.[23] In the sampling year, all of the top 15 facility-based wireless service providers in the U.S. retail their service plan through Letstalk.com.[24]

I perform two additional robustness checks with the information from letstalk.com. First, I collect similar information by inputting a subsample of ZCTA codes to amazon.com. I match and compare it with the data from Letstalk.com. The information from both sources agrees with each other. Secondly, to ensure that representative wireless carriers list their service on Letstalk.com, I identify the complete list of wireless carriers in 19 representative states using the numbering information from NANPA. I match the names of carriers collected from Letstalk.com with the names identified from NANPA. The result indicates that major regional carriers and all national carriers vend their service plan through Letstalk.com; smaller carriers, however, generally use their own retail channels. To quantify the strength of local carriers' service provision, I inspect the blocks of telephone numbers assigned to them. The local carriers typically serve less than 10,000 customers within a rate

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[22] The North American Numbering Plan Association administers the numbering resources, who serve 19 North American countries. NANP numbers are ten-digit numbers consisting of a three-digit Numbering Plan Area (NPA) code, commonly called an area code, followed by a seven-digit local number. The format is usually represented as NXX-NXX-XXXX where N is any digit from 2 through 9 and X is any digit from 0 through 9.

[23] For example, Amazon.com carries only national brands and several brands from resellers. Letstalk.com carries both national and regional brands. The major regional brands include Alltel, Circket, Cellular One, Centennial, Edge, Einstein, Metro PCS, Suncom, Surewest, US Cellular etc.

[24] The rank and name of top wireless carrier are listed in the FCC's 10th CMRS competition report.

center and their footprint seldom appears across rate centers. The rest of the analysis in the paper will focus on national and major regional carriers with local carriers omitted.

The list of ZCTA codes is obtained from the Census. According to the Census, ZCTAs are statistical entity developed for tabulating summary statistics to overcome the difficulties in precisely defining the land area covered by each ZIP Code. Defining the extent of an area is necessary in order to accurately tabulate census data for that area. In most instances the ZCTA code equals the ZIP Code for an area.

2.3.2 Discussion

The paper focuses exclusively on facility-based wireless carrier and omits coverage of wireless resellers.[25] Resellers run their business by purchasing airtime from facilities-based providers and selling service to the public using their own channels. Typically they offer prepaid plans rather than monthly billing, and focus on groups of individuals who lack traditional wireless service, such as people who are credit-challenged, teenagers, and those who want a cell phone for limited use. In the U.S., the leading resellers include TracFone, Virgin Mobile, etc. Most of the large resellers are partially (or wholly) owned by facility-based carriers. The resale sector accounted for approximately 6 percent of all mobile telephone subscribers at the end of June 2005. Since facility-based carriers are the ones generating the vast majority of industry revenue and also have a significant different cost structure from resellers, this paper chooses to focus exclusively on facility-based carriers.

[25] They are referred to as Mobile Virtual Network Operators (MVNO) in the FCC's terminology.

From the data collection process, entry is defined as a facility-based wireless carrier's decision to provide actual service. The industry wisdom recommends that wireless carriers not take in new consumers in roaming areas.[26]

Fox (2006) further supports this point by finding that roaming agreements are merely the substitute for branching out and expanding one's own geographic coverage area. Since the cost of accessing spectrum and building wireless facilities are often considered major sources of entry cost, whoever has to incur this cost should be counted as someone entering the market. The facility-based carriers' actual service provision decision properly defines carriers' entry decision.

During the sample period, Sprint had just completed the takeover of Nextel. They will be treated as two different firms in this paper for two reasons. First, it's impossible for two firms to merge their wireless coverage areas since they use different wireless technology. Secondly, the entry decision is made long before the consolidation.

The information on service plan offering at ZCTA code level is collected as well. Almost no variation in plan offerings could be found as per Seim and Viard (2005). Though the FCC compiles market share data at the Economic Area[27] level by looking at usage of telephone numbers, they do not disclose their market share findings due to confidentiality reasons. I investigate and find the publicly available information on phone number usage to be quite noisy.[28]

[26] Cingular's term of service directly states that "Cingular reserves the right to terminate your service if less than 50% of your usage over three consecutive billing cycles is on Cingular-owned systems. Customer must ... have a mailing address and live in the immediate geographic area in which subscription is made." Amazon.com used to ship cell phone only if the zip of shipping address is the same as the zip where the subscription is made.

[27] Economic Area (EA) is defined by the Department of Commerce's Bureau of Economic. There are 172 EA across in the U.S. The geographical scope of EA is broader than MSA/RSA. EA could be divided into county as well.

[28] The information the FCC holds might be more detailed than what's public available. The public available data specifies which carrier holds the blocks of telephone numbers (usually in thousands) in terms of (123)-456-XXXX.

First, there is no clean mapping from rate center to alternative geographic unit such as county or city.[29] Secondly and more importantly, it is well possible for a wireless carrier to use telephone number issued for one rate center to serve other rate centers.[30] Third, it is also possible that wireless carriers hold idle capacity in the telephone number resources. And lastly, the local number portability has been implemented only since 2004, meaning that phone numbers initially assigned to one company could be served by another company.

2.3.3 Market Definition

Most customers use mobile wireless services in close proximity to their workplaces and homes. That is, when customers subscribe to mobile wireless telecommunications services, they choose from the list of services providers and select one that offers service where they are located and/or where they travel to on a regular basis: home, work, and other areas they commonly visit. As such, demand for mobile wireless services is by nature local: they environ where the population concentrate and stretch towards its edge.

From the supply side, the FCC has licensed a limited number of mobile wireless services providers in different geographic areas. In the literature, MSA/RSA has been widely adopted to define relevant wireless market. However, as more firms enter the market using PCS spectrum (which is assigned based on MTA/BTA), the validity of MSA/RSA in investigating market structure becomes more questionable. Moreover, there is no guarantee that carriers provide service everywhere inside the geographic areas they are licensed in. The FCC's annual competition report counts the number of

[29] Rate center is the industrial term used by local exchange carriers to set rate boundaries for billing and for issuing phone numbers. For example, only telephone call made within rate center is considered local. There are about 18,000 rate center in the country.

[30] My own wireless number was issued to T-mobile at a rate center Called Barrington, while the place I live, Evanston, is another rate center. Both rate centers share the same area code and it masks the consumer of the true geographical affiliation in their numbers. This is why the FCC has to analyze the share at an aggregated EA level. Currently the same number that was initially assigned to T-mobile is ported to another carrier when I switch service provider.

wireless carriers at county level, which is finer than any of the spectrum license area, under the criterion that an operator needs only be offering some service in a portion of that county to be considered as "covering" a county.

By contrast, I collect carriers' entry data at the ZCTA level, a geographical unit smaller than county. This method of data collection ensures that demand is properly classified, as the ZCTA unit does not simply contain binary information on whether or not wireless service is supplied; it traces how the consumer shopped for the wireless service and essentially helps to filter out subjects irrelevant to the purpose of this study (e.g. customers who reside in one geographic area and who sign up online for a wireless service provided in an entirely different part of the country).

To address possible concerns with FCC's sampling methodology, I check whether national carrier's service decision varies within county. First I identify the ZCTA codes within the same county and then I check whether the ZCTA level market configurations (in terms of national carriers' entry decision) vary within the county.[31]

I count how many different configurations within one county can be found, by going through each ZCTA which belongs to that county.[32]

On average, each county contains 2.2 different market configurations, with a standard deviation of 1.3. **Table 2.1** shows the distribution on the counts of different market configurations within each county. The dataset contains 3068 counties, which includes almost all counties in the U.S. except for those in Alaska and Hawaii. Less than half of the county with unique market configuration could be

[31] For example, there are five national carriers in the sample and therefore the market configuration in terms of national carrier's decision is a 1 by 5 vector, out of the 32 possibilities ranging from (0 0 0 0 0) to (1 1 1 1 1), where each digit in the vector denotes whether one specific carrier provide service or not.
It's possible that one ZCTA code belongs to multiple counties. In this case, MCDC provide the primary county assignment and secondary county assignment. I adopt the primary county assignment.

[32] It's possible that one ZCTA code belongs to multiple counties. In this case, MCDC provide the primary county assignment and secondary county assignment. I adopt the primary county assignment.

found. Adopting county as the unit of observation would have completely overlooked the within-county variations in service provision,[33] a critical aspect in analyzing market structure.

Table 2.1: Distribution of Market Configuration Counts at County Level

Percentile	1%	5%	10%	25%	50%	75%	90%	95%	99%	#obs	3068
Min	1	1	1	1	2	3	4	5	6	Mean	2.181
Max	1	1	1	1	2	8	8	9	9	Std	1.269

In this paper, the unit of analysis is city, or technically speaking, place. According to Census's definition, a place is a concentration of population, which typically has a residential nucleus, a closely spaced street pattern, and commercial or other urban types of land use; it's a natural entity where social and economic activities take place. When aggregating ZCTA level entry information into place level, within-place variation on national carrier's service decision could hardly be found.[34] Finally, the data set contains 19407 different cities in the 2005 sampling year.

The clustering in the location of cities could result in the clustering of entry decision. For instance, a small city that's neighboring a big city is more likely to receive coverage than an isolated town, all else being equal. To control for this I include the distance-weighted population in geographically adjacent places. Specifically, I create three distance bands of 10, 15, and 20 miles for each city in the sample. Within each distance band, I identify the population of neighboring cities, discount the population by their distance to the central city, and sum them up. Three variables denoting distance discounted population within each band are created and included as exogenous variables in the regression.

[33] I double check whether the within county variations in the service provision is driven by those ZCTA which belong to multiple counties. When focusing on a subsample without ZCTA that have multiple county assignments, substantial variation in market configuration could still be found.

[34] Carriers' service provision varies only in less than 100 places. When the within place variation in service provision happens, I did case by case checks. I first re-investigate service provision information on both Lettalk.com and carriers' own website, to make sure the information is accurate. Then I identify the all ZCTA code within the city and how many people live under each ZCTA. If the carrier provides service to more than 50% of the city population, it is coded as entering the city.

The final estimation result will show that the city's neighborhood within 10 miles does have significant effect on national carrier's service provision decision. The impact starts to taper off when the distance grows to 15 miles and become insignificant for most of carriers beyond 15 miles. In the data, the average distance of a city to its nearest neighbor is 6 miles. Almost 90% of the cities in the data are neighboring another city within 10 miles. Looking back at the counties, the average distance between any county and its nearest neighbor (calculating using county's primary latitude and longitude) is 23 miles and the median is 21 miles. The within-county variation in market configuration is not at all surprising if we believe city/place to be the de facto unit of wireless service supply.

2.3.4 Data Description

Based on Seim and Viard (2006), and Bajari and Fox (2005), the market determinants of carrier's profitability include: population, median age, income, time to commute to work etc. Additionally, I include the land area of the city, portion of rural population, an indicator for MSA and the distance discounted population of neighboring place. The geographic dummy south is included in Cingular's profit function and west in T-mobile's to account for their strength in those regions. As described before, the distance discounted populations in adjacent cities (in log form) are included as well. **Table 2.2** shows all place level characteristics. Only 10% of the places are completely urban (i.e. without any rural population).

Table 2.3 shows basic information about service provision. Each of the national carriers has limited market exposure, especially T-mobile. On average, T-mobile serves 46% of the cities in the sample while the rest of the national carriers serve 68%-69% of the cities. Collectively, the national carriers have strong geographical presence, and 90% of the cities in the sample are served by at least one national carrier. The entry pattern in the data also suggests that national carriers tend to show up together (in about 6900 cities or 35% of the sample). On average, each city is served by three national carriers and one regional carrier.

Table 2.2: Summary Statistics of Exogenous variables (N=19407)

Variable	Mean	Std. Dev.	Min	Max
lpop	7.45	1.73	1.10	15.9
linc	9.74	0.34	0	12.4
rural	0.57	0.48	0	1
ltime	3.15	0.29	0	4.7
medage	37.6	5.97	14.3	77.7
larea	0.69	1.40	-4.67	6.6
dp10	33.6	58.4	-0.34	593.3
dp15	33.5	47.1	0	430.0
dp20	39.7	50.4	-1.06	511.3
msa	0.47	0.50	0	1
south	0.25	0.43	0	1
western	0.21	0.41	0	1

Note:
lpop: log of population, linc: log of per capita income. Census data shows that per capita income is zero in very few places, the linc is actually log(income+1). rural: percentage of rural population. ltime: aggregate time travel to work divided by population. dp1-dp3: log of population in places within 10, 15, 20 miles discounted by distance. msa: equals 1 is that place locates in MSA area.

Table 2.3: Service Provision Information (N=19407)

Variable	Mean	Std. dev.	Min	Max
cingular	0.68	0.47	0	1
nextel	0.68	0.47	0	1
sprint	0.69	0.46	0	1
tmobile	0.46	0.50	0	1
verizon	0.68	0.47	0	1
#national	3.18	1.76	0	5
#regional	0.93	0.77	0	4
#national>0	0.90	0.29	0	1
#regional>0	0.70	0.46	0	1

#national: total number of national carriers,
#regional: total number of regional carriers,
#national>0 : whether any national carrier serves the place,
#regional>0: whether any regional carrier serves the place

Table 2.4 shows the correlation in carriers' entry decision. National carriers tend to enter together and their service decisions are positively correlated with one another's. However, Verizon's entry is relatively less positively correlated with the entry of other national carriers. The entry of national carriers generally correlates negatively with the entry of regional carriers. This is most pronounced for Cingular and Verizon, while Nextel and Sprint's decision are less negatively correlated with regional carriers. The inverse correlation between national and regional carriers is consistent with the perception that regional carriers generally serve less populated markets. For example, Alltel, the largest regional carrier, maintains its business strategy of focusing on small to medium-sized cities. It provides services in parts of 35 states and has roaming agreement with Verizon and Sprint to achieve national coverage. The relationship between Sprint and regional carriers is the least negatively related.

Table 2.4: Correlation of Entry Decisions

	Cingular	Nextel	Sprint	T-mobile	Verizon
Cingular	1.00				
Nextel	0.45	1.00			
Sprint	0.48	0.58	1.00		
T-mobile	0.48	0.47	0.53	1.00	
Verizon	0.36	0.37	0.33	0.26	1.00
#Regional>0	-0.30	-0.16	-0.12	-0.21	-0.29

2.4 A Statistical Model

2.4.1 Model Setup

The entry decision of wireless carriers is modeled as equilibrium outcome of a two-stage game with complete information. There are six types of players in this game: Cingular, Sprint, Nextel, T-mobile, Verizon and homogeneous regional carriers. In the first stage, national carriers simultaneously determine whether to enter or not and in the second stage, symmetric regional carriers determine whether to enter or not after observing national carriers decision. Let NC ={cinglar, nextel, sprint, tmobile, verizon} denote the set of national carriers. Let NC_{-i} be the set of national carriers excluding i. The post entry profits for national carrier i in market m is:

$$\Pi_{im}(D_{-im}, N_{rm}|\Theta) = X_m\beta_i + \sum_{j \in NC_{-i}} \lambda_{ij} D_j + \theta_i \ln(N_{rm} + 1) + \rho u_{im} + \sqrt{1-\rho^2}\varepsilon_m$$

$$\forall i \in NC$$

National carrier i will enter the market if and only if entry generates positive profit, i.e. $\Pi_{im}(D_{-im}, N_{rm}|\Theta) \geq 0$. Let D_{im} be national carrier i's binary decision that takes value 1 if entry occurs and 0 otherwise and I be indicator function, $D_{im}(D_{-im}, N_{rm}|\Theta) = I\{\Pi_{im}(D_{-im}, N_{rm}|\Theta) \geq 0\}$. Ultimately, i's entry decision depends on all other national competitor's entry decision D_{-im}, and number of regional competitor N_{rm}. Regional carriers, on the other hand, are considered homogenous. They will keep entering until the profit is driven below zero.[35]

Let D_m be a 1 by 5 vector denotes all national carriers' decision, regional carrier's symmetric profit is (1)

$$\Pi_{rm}(D_m, N_{rm}|\Theta) = X_m\beta_r + \sum_{j \in NC} \lambda_{rj} D_j + \theta_r \ln(N_{rm}) + \rho u_{rm} + \sqrt{1-\rho^2}\varepsilon_m$$

All together, there are six reduced form profit equations, five for each national carrier respectively and one for symmetric regional carriers. The parameters to be estimated are $\Theta = \{\beta_i, \lambda_{ij}, \theta_i, \rho, \beta_r, \lambda_{rj}, \theta_r | \forall i \in NC, j \in NC_{-i}\}$.

[35] See next section for detail.

Several important determinants drive national carrier's entry decision. $X_m\beta_i$ measures the overall market attractiveness. All carriers will face the same market characteristics X_m, while β_i captures the player specific "preferences" over X_m. Element of X_m includes population, land area of the market, distance weighted population in distance band of 10, 15 and 20 miles, minutes transit to work, median age etc. Geographic dummy south is added to Cingular's profit function to account for its strength in this region. Similarly, west is added in T-mobile's profit function. $\sum_{j\in NC_{-i}}\lambda_{ij}D_j$ are influences from national competitor NC_{-i}. Again, different national competitors are allowed to have different impact on i' s profitability. For example, Verizon would have differential impact on T-mobile and Cingular. Presence of T-mobile and Verizon would have heterogeneous effects on Cingular. The regional carriers influence national carrier i through $\theta_i \ln(N_{rm}+1)$. The log transformation ensures that the marginal effect coming from an additional regional competitor decreases. Similar to national carriers, regional carrier's profit $\Pi_{rm}(D_m, N_{rm}|\Theta)$ consists of market demand $X_m\beta_r$, influence of national competitor $\sum_{j\in NC}\lambda_{rj}D_j$ and competitive pressure coming from other regional carrier in m, $\theta_r \ln(N_{rm})$. Again, national carriers' influences on regional carriers are identity specific.

Under the complete information framework, the players observe all components of every other player's payoff function including random shocks u and ε. ε captures the market level profit shock that's common to both regional and national players and u is firm and market specific. The common market level shock ε makes the entry decision of national carriers and regional carriers endogenous in each other. The correlation ϱ weights the importance of firm heterogeneity over the common market shock. I will assume both u and ε standard normal.[36] Conditional on true parameter Θ, the

[36] As in probit model, mean and variance of coefficients are not separately identified. Location and scale normalization are imposed.

random shocks allow model prediction deviates from the observed. The parameters to be estimated come from six equations, which are interdependent on each other through (D_m, N_{rm}), i.e. one player's decision endogenous to other players'. A crucial step in estimation is to solve for (D_m, N_{rm}) under an equilibrium framework.

2.4.2 Information Structure

Information structure is an important ingredient in modeling the game with strategic interactions. There are generally two types of modeling approaches: complete information and incomplete information. Under both schemes, the econometrician does not observe the realization of profitability shock but the distribution of the shock is known and all players observe the deterministic part of profit function (e.g. Xβ). The key differences between two different modeling schemes depend on whether or not the random shocks, which move the equilibrium outcome from perfect prediction, are observable to the players. Under the incomplete information approach, the random shocks are private information and everyone observes only the realization of his own shock. Analogously, the complete information presumes that the shocks are common knowledge to the all the players.

Implicitly, an important distinction between two schemes is whether the players know each other better than the econometrician. Incomplete information, as it is typically modeled, means that the players know each other exactly as much as the econometrician does. The complete information scenario presumes that players more informed than the econometrician and they know their competitors as much as their competitors know themselves. Both of these modeling schemes are an extreme abstraction of the real world phenomena. In the wireless telecom industry, wireless firms frequently interact, for example, in billing one another for roaming charges. Some of them descended from the same parent company and share a common background and history. Thus there is good reason to believe they know each other at least better than econometricians. In this sense, the complete information assumption is a more realistic approximation for the wireless telecom industry. The final estimates suggest that the common market level shock is much more important than firm/market shocks. Since the common market level shocks are more likely to be common knowledge, the estimation result cross-validates the complete information assumption.

2.4.3 Solution Concept

Firm's entry decision is modeled as equilibrium outcome a two stage game with complete information. In stage 1, five national firms simultaneously decide whether to enter or not. In stage 2, regional carriers observe national firm's entry decision and determine whether to enter or not.

The game is then solved through backward induction. In stage 2, given equilibrium strategy of national carriers there is a unique equilibrium number of regional carriers as long as $\theta_r < 0$. Namely, (2)

$$\Pi^{*}_{rm} = \max\{N \mid \Pi_{rm}(D_m, N \mid \Theta) \geq 0 \; and \mid \Pi_{rm}(D_m, N+1 \mid \Theta) < 0 \}$$

The existence and uniqueness is established by Berry (1992), Bresnahan and Reiss (1991) and Mazzeo (2002). The condition $\theta_r < 0$ guarantees that regional carrier's post-entry profit is decreasing in the number of regional carriers. The equilibrium number of regional carrier $N_{rm}\ (D_m \mid \Theta,\ u_{rm}, \varepsilon_m)$ is a function endogenous in national carriers' strategy D_m .

Back in stage 1, national carriers will account for the second stage regional entry when they make their own decisions. Given equilibrium number of regional carrier in the second stage $N^{*}_{rm}\ (D_m \mid \Theta, u_{rm}, \varepsilon_m)$ and $\{ u_{im} \mid \forall\ i \in NC \}$ national carrier's equilibrium strategy is (3)

$$D_m^* = I\ \{\Pi\ (D_m, N_{rm}^*(D_m)|\Theta, u, \varepsilon) \geq 0\}$$

i.e.

$$\begin{pmatrix} D_{1m} \\ D_{2m} \\ D_{3m} \\ D_{4m} \\ D_{5m} \end{pmatrix} = \begin{pmatrix} I\{\Pi(D_{2m}D_{3m}D_{4m}D_{5m}|N_{rm}^*(D_m), \Theta, u, \varepsilon\ \varepsilon) \geq 0\} \\ I\{\Pi\ (D_{1m}D_{3m}D_{4m}D_{5m}|N_{rm}^*(D_m), \Theta, u, \varepsilon\ \varepsilon) \geq 0\} \\ I\{\Pi\ (D_{1m}D_{2m}D_{4m}D_{5m}|N_{rm}^*(D_m), \Theta, u, \varepsilon\ \varepsilon) \geq 0\} \\ I\{\Pi\ (D_{1m}D_{2m}D_{3m}D_{5m}|N_{rm}^*(D_m), \Theta, u, \varepsilon\ \varepsilon) \geq 0\} \\ I\{\Pi\ (D_{1m}D_{2m}D_{3m}D_{4m}|N_{rm}^*(D_m), \Theta, u, \varepsilon\ \varepsilon) \geq 0\} \end{pmatrix}$$

Given parameters of the model, and (u, ε), there are five unknowns D_{1m} through D_{5m} and five equations. The solution to (3) could exist under some parameter values.[37]

Moreover, since D_m is a binary vector, the solution $D_m^* \in \{0, 1\}^5$, i.e. D_m^* must be one or several of the 32 possibilities ranging from (0 0 0 0 0)' to (1 1 1 1 1)'. In fact, the solution to (3) needs not be unique and multiple equilibria is highly likely to present.

As suggested by Bajari, Hong and Ryan (2004), the equilibrium that maximizes the industrial profit is more likely to occur. I impose the first rule that maximize sum of equilibrium profit generated by the national carriers. Alternatively, I re-estimate with a selection rule that favors more commonly observed market configuration. All market 32 configurations are ranked according to the aggregated observed frequency in the data. More frequently observed configuration has a lower rank (e.g. in the data the case all five national carrier enter is ranked number one). When multiple solutions to (3) presents, the solution with a lower rank is picked.

[37] The solution to (2) is the fixed point of the mapping $I\{\Pi(*) \geq 0\}$. Tarski fixed point theorem states: an increasing function on a complete lattice has fixed point. Since $D \in \{0,1\}^5$ is finite and all finite lattice is complete. The indicator function $I\{\Pi(D|\Theta) \geq 0\}$ is increasing in $\Pi(D|\Theta)$ and as long as $\Pi(D|\Theta)$ is increasing in D, $I\{\ \Pi(D|\Theta) \geq 0\}$ is increasing in D. Clearly, there are Θ s.t. $\Pi(D|\Theta)$ is increasing in D. For example, when all parameters are positive, $\Pi(D|\Theta)$ is increase in D.

The equilibrium outcome of the two stage game $\{D_m, N_{rm}|\Theta, u, \varepsilon\}$ is conditional on structural error $\{u, \varepsilon\}$. Given the complexity in analytically deriving the likelihood of equilibrium outcome, the estimation will be built on simulated estimator. The idea is to form unbiased estimator of equilibrium outcome using draws taken from the distribution of $\{u, \varepsilon\}$ and match the derived outcome with the data. Formally, the estimation proceeds with Simulated Method of moments (MSM).

2.4.4 Assumptions

Generally, there are three natural modeling approaches when lacking information about the sequence of move. I could assume regional carriers enter first, followed by national, or vice versa, or both regional and national enter simultaneously. Assuming regional carriers move first is non-favorable because regional carrier usually faces the residual demand of national carriers. Industrial evidence suggests that regional carriers typically serve the market segment that is under-served by national carriers. As noted in Berry (1992) and Berry and Reiss (2007), assuming an order of movement could lead to the outcome where the less efficient first movers preempt the more efficient subsequent movers. While this can happen in some markets, it's unlikely to happen in all markets. They suggest an alternative modeling approach where the most profitable firms always move first so that the inefficient outcome never happens. Furthermore, if we believe that national carriers could credibly commit entry, then the two stage entry game where national carriers enter first followed by regional carriers would yield the same equilibrium outcome as a simultaneous move game.

The identification of the model is analogous to the identification in discrete choice model. The scale of the parameter is generally not identified and the distribution of error terms is normalized. The coefficients on exogenous shifters are identified through the difference in players' "preference" over the market characteristics. The identification of strategic effects comes from the geographical distributional pattern of carrier's entry decision, i.e. the extents to which one carrier's entry is offset or imitated by its rival. The model, however, is not identified if the error terms are correlated as the moment conditions do not hold at true parameter values anymore.

Assumption 1 u_{im} and ε_m are distributed i.i.d standard normal across all markets and players.

Both the existence and uniqueness of solution to (1) could be established as long as $\theta_r < 0$.The solution to (3) could exist for some parameter values but might not be unique. When multiple solutions to (3) exist, the model cannot be identified.

In estimating empirical game of entry, the existence of multiple equilibria has posed formidable challenges to identification. When multiple equilibria presents, one set of parameters generates different equilibrium outcome prediction, which breaks down the one to one mapping between model prediction and data observations. One natural solution to this problem is to impose an equilibria selection rule that selects a particular type of equilibria. Along this line, Berry (1992) and Jia (2006) argue that more profitable firm moves first. They select the equilibrium that produces higher outcome for the first movers when multiplicity occurs. Alternatively, Ciliberto and Tamer (2006) develop a semi-parametric interval estimator to avoid the arbitrary equilibrium selection rule. More recently, Bajari, Hong and Ryan (2006) tries to formally estimate the equilibrium selection rule. Their result suggests that the equilibrium that maximizes players' joint profit is more likely to occur. This paper borrows their insights and imposes a selection rule that maximizes the joint profit of national carriers.

Assumption 2 The national carriers play pure strategy and there here exist a set of parameters s.t. the model is identified under the equilibrium selection rule that maximizes the profit of national carrier, i.e. $\exists\Theta,\ \text{s.t.} \forall\Theta^1 \neq \Theta^2 \ \in \Theta, \text{F}(\Theta^1) \neq \ \text{F}(\Theta^2),$ where F is the distribution that characterizes the equilibrium outcome.

The mixed-strategy equilibria is ruled out due to the computational burden of computing all equilibriums. m's entry decision is modeled

2.5 Empirical Method

The estimation proceeds with the simulated estimator as described in Pakes and Pollard (1989) and McFadden (1989). Let true parameter be Θ_0 and the moment condition S holds at Θ_0, i.e. $E\{\hat{S}(X_n \mid \Theta_0)\} = 0$. S will be computed with simulated draws.[38]

Let $S \in R^p$ and $\Theta \in R^q$, with $p \geq q$, an MSM estimator is (4)

$$\Theta^{MSM} = argmin \left(\sum_{m=1}^{\#obs} \hat{S}\,(X_m|\Theta)\right)' W \left(\sum_{m=1}^{\#obs} \hat{S}\,(X_m|\Theta)\right)$$

$$\sqrt{\#obs}(\Theta^{MSM} - \Theta_0) \rightarrow N\left(0, (1+\frac{1}{ns})A^{-1}BA^{-1}\right)$$

Where *#obs* denotes the number of observations, ns denotes the number of simulations, W is a positive definite matrix. Let $\hat{J} = E\{\nabla_\Theta \hat{S}(X_m|\Theta)\}'$and $V = E\{\hat{S}(X_m|\Theta)'\hat{S}(X_m|\Theta)\}$ then $A = J'WJ$ and $B = J'WVWJ$. If $W = E\{\hat{S}(X_m|\Theta)'\hat{S}(X_m|\Theta)\}^{-1}$, then Θ^{MSM} is efficient.

[38] An example of S could be predicted entry probability less observed entry decision.

I use the following sets of moment conditions: 1. Difference between predicted entry probability and observed entry decision for each of national carriers. 2. Difference between predicted probability of market configuration and observed market configuration for the top 10 most frequently observed configurations. 3. Difference between predicted and observed number of national carriers. 4. Difference between observed and predicted number of regional carriers. 5. All of above interact with demand shifter (lpop linc ltime medage larea rural dp10 dp15 dp20).[39]

The estimation procedure takes two steps. In step 1, an initial estimate $\widetilde{\Theta}$ is obtained to construct a consistent estimate of $W = E\{\hat{S}(X_m|\Theta)'\hat{S}(X_m|\Theta)\}^{-1}$and in step 2, I re-do the estimation inserting $\widetilde{W}$ as weighting matrix. The detailed procedure goes as follows: 1. Prepare draws: draw ns times $\{u_{im}, u_{\mathrm{rm}}, \varepsilon_{\mathrm{m}} | \forall \mathrm{i} \in NC\}$ from the distribution of $\{u, \varepsilon\}$, fix them throughout the estimation. 2. Start with a guess[40]of parameter Θ_1. 3. For each ns, compute equilibrium based on (2) and (3) using Θ_1 and draws of $\{u, \varepsilon\}$. If multiple solutions present in solving (3), choose one and only one solution using prescribed selection rule; form model prediction $\widehat{Pr}_m\{*\}, (\widehat{Pr}_{1m} \dots \widehat{Pr}_{5m}), \widehat{N}_{rm}$ and $\widehat{N}_{Nm}$, evaluate $\hat{S}$ and MSM objective $\hat{S}'W\hat{S}$. 4. Go back to 2, search over Θ to minimize MSM objective. The weighting matrix in step 1 is $W_1 = I(I_{17} \otimes \mathrm{IV}' * \mathrm{IV})^{-1}$, where IV=[1 lpop linc ltime medage larea rural dp10 dp15 dp20].[41]

[39] The first set gives 5 moment conditions, the second set gives 10, the third set gives 1, and the fourth set gives 1. Together, the first four set of moment conditions sum up to 17. In summary, p, the dimension of S, is $R^{17*(\#of\ demand\ shifters+1)} = R^{153}$

[40] The probit result is used as the initial guess.

[41] I_{17} is a 17 by 17 identity matrix and $\otimes$ is Kronecker product. W_1 is created by stacking $(\mathrm{IV}' * \mathrm{IV})^{-1}$ on the diagonal blocks of a big identity matrix. The form of W is introduced by Mike Cliff and it deals with possible problems arising from the scaling of data. Each of moment conditions is scaled down to a reasonable range by $(\mathrm{IV}' * \mathrm{IV})^{-1}$.

2.6 Result

2.6.1 Descriptive Result

Before presenting the final result, I consider a Probit analysis on wireless carriers' entry decision. The first specification describes how market characteristics affect each carrier's entry decision. The result is reported in Table 2.4. I try different combinations of geographical dummy like south, northeast, west, central, east etc, to account for possible incumbency of different wireless carriers in different regions. For example, Cingular is headquartered in Atlanta, Georgia and AT&T in San Antonio, Texas. Their mother company SBC and Bell South are both incumbent in the landline phone market especially in the southern U.S. It turns out that the geographical dummy south does positively contribute to Cingular's entry decision. Similarly, west positively contributes to T-mobile's decision. Most of the coefficients in Table 2.4 are significant with expected sign. Carriers' entry decision is positively correlated with income and travel time to work; it's negatively correlated with proportion of rural population and age of population. The population in the neighboring place is significantly positive correlated with their decision within all distance bands, suggesting that the spillover across cities is controlled to some degree. The population, however, is insignificant in Verizon's decision. It could be biased downward if, for example, more populated places are also more competitive.

Table 2.5:Binary Probit

	Cingular	Nextel	Sprint	T-mobile	Verizon
lpop	0.13***	0.18***	0.24***	0.22***	-0.00
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
linc	0.39***	0.90***	0.71***	0.57***	0.73***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
rural	-0.30***	-0.15***	-0.23***	-0.36***	-0.27***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
ltime	0.77***	0.31***	0.31***	0.60***	0.26***
	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)

medage	-0.02***	-0.04***	-0.04***	-0.03***	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
larea	0.04***	-0.00	-0.00	0.00	0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
dp1	0.02***	0.02***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
dp2	0.01***	0.02***	0.01***	0.01***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
dp3	0.01***	0.01***	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
msa	0.59***	0.54***	0.54***	0.48***	0.60***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
south	0.10***				
	(0.03)				
west				0.43***	
				(0.03)	
_cons	-6.67***	-9.93***	-7.89***	-8.57***	-7.39***
	(0.52)	(0.52)	(0.50)	(0.48)	(0.47)
R square	0.37	0.35	0.32	0.36	0.24

Table 5 shows the Probit estimate of individual carrier's entry decision incorporating the rival's entry decision as an exogenous explanatory variable. I directly regress each national carrier's entry decision on market characteristics, their rival's entry decision and the number of regional carriers. For symmetric regional carriers, the estimates solves (2), taken national carriers' decision exogenous. The effects of national competitors are mostly positive. It appears that most of the national carriers' decisions constitute strategic complements. However, the coefficients could suffer from an upward bias, if, for instance, there is a common market level shock that attracts all national carriers to enter. The regional carrier's effect on national carriers and the national carrier's effect on regional carriers could go either way. The raw correlation shows that the presence of one regional carrier is negatively correlated with any presence of a national carrier. The correlation is least negative for Sprint and Nextel. The Probit result on regional carriers suggests that after controlling for market demand, the presence of Nextel and Sprint is positively correlated with the entry of regional carriers; individually, looking at the two national carriers one by one, the presence of Sprint alone is also positively correlated with regional carriers, and likewise the presence of Nextel alone positively correlates with regional carriers.

Table 2.6:Binary Probit (with rival's decision)

	Cingular	Nextel	Sprint	T-mobile	Verizon	Regional
cingular	---	0.21***	0.52***	0.50***	0.04	-0.53***
		(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
nextel	0.32***	---	0.85***	0.46***	0.21***	0.10***
	(0.03)		(0.03)	(0.03)	(0.03)	(0.02)
sprint	0.42***	0.85***	---	1.02***	0.14***	0.40***
	(0.03)	(0.03)		(0.04)	(0.03)	(0.02)
tmobile	0.60***	0.4346***	0.98***	---	0.15***	-0.29***
	(0.03)	(0.03)	(0.03)		(0.03)	(0.02)
verizon	0.01	0.23***	0.17***	-0.03	---	-0.61***
	(0.03)	(0.03)	(0.03)	(0.03)		(0.02)
lreg	-1.00***	0.07**	0.54***	-0.27***	-0.96***	-2.36***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
lpop	0.08***	0.10***	0.1530***	0.17***	-0.01	0.07***
	(0.02)	(0.02)	(0.0177)	(0.02)	(0.02)	(0.01)
linc	0.07	0.71***	0.36***	0.32***	0.64***	-0.15***
	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.03)
rural	-0.21***	-0.00	-0.07***	-0.26***	-0.24***	-0.03
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)
ltime	0.65***	0.12**	-0.01***	0.42***	0.13***	-0.11***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.03)
medage	-0.01***	-0.02***	-0.03***	-0.02***	-0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
larea	0.02	-0.02	-0.02***	0.01	0.06***	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
dp1	0.01***	0.01***	0.00***	0.00***	0.01***	-0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
dp2	0.01***	0.01***	0.01***	0.00***	0.01***	0.04***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
dp3	0.00***	0.01***	0.00***	0.00***	0.00**	-0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
msa	0.44***	0.29***	0.21***	0.22***	0.57***	0.19***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)

south	1.09***	---	---	---	---	---
	(0.03)					
west	---	---	---	0.56***	---	---
				(0.03)		
_cons	-3.31***	-8.20***	-4.68***	-6.80***	-5.85***	2.17***
	(0.56)	(0.56)	(0.56)	(0.52)	(0.49)	(0.30)

Note: Standard error in parenthesis #obs: 19407;
***1%, **5%,*10%

One other point to notice in Table 2.6 is that the effect of population is still insignificant for Verizon. This, however, does not imply that population is biased downward through correlation with error terms. In a non-linear model, the estimated coefficients could be biased even if the omitted variable is not correlated with explanatory variables.[42]

2.6.2 Structural Result

The result reported in Table 2.7 is based on structural model. The parameter estimation employs 50 Halton draws,[43] per firm, per market. The standard error is derived through (4) where the Jacobian matrix is derived numerically using a finite difference approach.

Table 2.7: Structural Result

	Cingular	Nextel	Sprint	T-mobile	Verizon	Regional
cingular	-	1.04***	1.56***	0.54***	-0.30**	-0.05
		(0.17)	(0.26)	(0.10)	(0.13)	(0.13)
nextel	0.10	-	1.32	0.62	0.16	0.10
	(0.18)		(1.89)	(1.69)	(0.16)	(0.12)
sprint	0.00	0.31	-	0.82	0.04	1.31***
	(0.14)	(0.26)		(1.78)	(0.11)	(0.29)

42 This is because, in addition to the usual bias that could be found in the linear model, there is a rescaling effect that affects all coefficients. The direction of the biases depends critically on the sampling method and is not straightforward to speculate. For detail see Yatchew and Griliches (1985).

43 Halton draws provides a good sampling coverage of normal distribution. According to Train (2000), 100 Halton draws performs better than 1000 random draws in a mixed logit application. A Halton sequence is constructed from a prime number k, recursively through $H_{t+1} = \{H_t, H_t + \frac{1}{k^2}, H_t + \frac{2}{k^2}, \dots, H_t + \frac{k-1}{k^2}\}$ where $H_0=\{0\}$ and the length of such sequence is k^t. The Halton draws is generated by taking $\Phi^{-1}(H)$, where Φ^{-1} is inverse cumulative normal.

tmobile	1.46***	0.24	-0.32	-	0.03	-0.08
	(0.27)	(3.98)	(6.40)		(0.14)	(0.14)
verizon	0.00	0.25*	0.12	-0.03	-	-0.74***
	(0.06)	(0.15)	(0.16)	(0.16)		(0.16)
lreg	-3.14***	-0.06	0.29	-0.18	-2.85***	-1.66***
	(0.26)	(0.17)	(0.22)	(0.16)	(0.29)	(0.15)
rho	0.00					
	(0.31)					
lpop	0.16***	0.14***	0.22***	0.17***	0.05***	0.01
	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.01)
linc	0.14***	0.80***	0.66***	0.38***	0.78***	-0.16***
	(0.04)	(0.01)	(0.02)	(0.02)	(0.01)	(0.03)
rural	-0.28***	0.00	-0.10**	-0.33***	-0.14***	-0.00
	(0.06)	(0.03)	(0.05)	(0.05)	(0.04)	(0.03)
ltime	0.49***	-0.18***	0.03	0.36***	0.22***	-0.16***
	(0.08)	(0.05)	(0.06)	(0.06)	(0.05)	(0.04)
medage	-0.01***	-0.03***	-0.03***	-0.02***	-0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
larea	-0.04**	-0.03*	-0.03**	0.01	0.04**	-0.00
	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)
dp1	0.04***	0.02***	0.02***	0.011***	0.02***	-0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
dp2	0.05***	0.01	0.01	-0.00	0.06***	0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
dp3	0.06***	0.00	0.00	-0.00	-0.08***	-0.03***
	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)
msa	0.22	0.81***	-0.56	0.76***	2.23	0.15
	(0.19)	(0.11)	(1.45)	(0.14)	(2.02)	(0.11)
south	2.68***	-	-	-	-	-
	(0.29)					
west	-	-	-	0.00	-	-
				(0.08)		
_cons	-3.05***	-8.55***	-7.83***	-7.58***	-7.16***	1.11***
	(0.21)	(0.09)	(0.06)	(0.11)	(0.07)	(0.33)

GMM obj: 3065.7 #obs: 19407; ***1%, **5%,*10%

The results reveal that Cingular's entry negatively affects Verizon, but the relationship is not symmetric in that Verizon's entry has insignificant effect on Cingular. The negative effect of

Cingular on Verizon confirms the rivalry between them. It is also a projection of the raw correlation, where Cingular's entry decision is least positively correlated with Verizon's service decision amongst all national carriers. The effect of Verizon (the smaller firm) on Cingular (the larger firm) is both numerically and statistically close to zero. The estimated coefficient is consistent with the intuition that a bigger firm may have a significant impact on a smaller firm but the smaller firm does not necessarily have any significant impact on the bigger firm.

The effect of Cingular on T-mobile and the effect of T-mobile on Cingular are both positively significant. The symmetrical interaction between Cingular and T-mobile could stem from the collaborative relationship between the two. T-Mobile and Cingular use the same wireless technology and could learn to better feed off each other and mutually benefit in areas such as optimizing their wireless technology infrastructure and enhancing their current coverage strength. Consumers from both companies would also benefit from resources shared by Cingular and T-mobile, if, for instance, there are spots in a city where one of the two firms has weak signal strength but not both and consumers from either companies enjoy higher quality of service. This could also in turn re-enhance the demand for wireless services of both firms. In summary, supply side complementarities and demand side complementarities enforce each other.

It's not surprising to anticipate that Sprint positively affects the entry of regional carriers, since its strength lies in local exchange services in primarily in smaller places, where regional carriers are more likely to serve. The affiliation between regional carrier and Sprint could generate positive influence to other regional carriers as well. For instance, regional carriers might mimic this strategy in partnering with national carriers and in turn picking up expertise from the big players on operating wireless businesses and wireless technology development. The presence of Sprint thus facilitates the entry of other regional carriers by increasing the likelihood of new regional carriers entering the market. However, the converse can't be said; that is, the effect of regional carriers on Sprint is not significant, as the regional affiliates often focus on a confined geographic area and does not help Sprint enter the outside markets.[44]

Most of other strategic coefficients are imprecisely estimated. This could stem from the low variation of alternative market configurations. As there are five national carriers, the possible market configurations sums to 32. In the sample, the configuration where all national carriers enter accounts for 35% of the sample, followed by the configuration where all national carriers don't enter which is around 10%. The case where all national carriers but T-mobile enters accounts for another 10% and the case where only Verizon enters accounts for 8%. These top four configurations combined make up 63% of the total observations. If we assume the market configurations to be randomly distributed, then each configuration on average occurs about 3% of time. The distribution of market configurations is heavily skewed such that the top four configurations account for far more than 12%, leaving only limited variations for the rest.

The estimated correlation across firm market is insignificant and close to zero, suggesting that market level shocks common to all carriers is more important than firm-specific shocks. The magnitude of standard error does not change much for the market characteristics compared with Probit estimates. Most of the market characteristics have expected sign as well. Specifically, population positively and significantly affects Verizon's entry decision, suggesting that the structural model takes care of some of the bias.

The population in a neighboring city within 10 miles significantly affects the entry decision of all national carriers. Regional carriers generally target more isolated places and are less likely to serve a

[44] Not surprisingly, Sprint's merger proposal with Nextel faced opposition mostly from regional affiliates. These regional affiliates were afraid that the new company would not honor the non-compete agreements that Sprint had made. Sprint and Nextel acquire some of the regional affiliates after the merger.

city if it is close to another populated place. The effect of neighboring city attenuates when the distance grows from 10 to 15 and insignificantly affects Nextel, Sprint and T-mobile. When the distance goes from 15 to 20, a neighboring city positively and significantly affects only Cingular and no other carriers. This suggests that using city as a measure and examining its immediate neighbors are sufficient and best-suited for studying entry.

To understand the magnitude of these coefficients, I re-compute the equilibrium by perturbing each of the explanatory variables one standard deviation up, keeping everything else the same. The result is captured in Table 2.8. The baseline of comparison is the observed equilibrium outcome in the data; that is, the mean and standard deviation of observed entry decision for national carriers and observed number of regional carriers, which is shown in the first row. The column Cingular and row lpop, for example, illustrates when I resolve the equilibrium by setting the log of population one standard deviation above its mean for all markets and in the new equilibrium, Cingular enters 72% of the markets in the sample. Compared to the baseline of 68%, there is a 4% increase in market penetration. The effect of population on regional carriers is small (only 0.07 in terms of the number of regional carriers) and negligible. One noteworthy finding is the effect of population change on Verizon: when population increases, Verizon drops out of some markets. This is because Cingular has a more pronounced response to population increase and enters more aggressively. Verizon is subsequently driven out through its strategic interaction in response to Cingular. By contrast to these structural model predictions, Probit estimation would predict that as population increases, both Cingular and Verizon respond by entering to serve more markets.

Table 2.8: **Effect of Market Characteristics on Outcome**

	Cingular	Nextel	Sprint	T-mobile	Verizon	Regional
data mean	67.87%	67.50%	69.41%	45.84%	67.50%	0.93
lpop	3.92%	8.20%	19.31%	6.13%	-5.63%	0.09
linc	3.33%	12.04%	16.43%	1.33%	11.76%	0.01

rural	-4.48%	-3.19%	5.68%	-8.68%	-6.95%	0.04
ltime	4.08%	-2.17%	11.04%	1.76%	-1.80%	0.02
medage	-4.87%	-10.12%	0.32%	-6.37%	-10.63%	0.07
larea	-1.34%	-3.03%	6.68%	-2.22%	-2.40%	0.03

Notice: This table shows how equilibrium changes with one standard deviation in each input, while keeping all else the same. The baseline of comparison is sample mean. For example Cingular enters on average 67.87% cities in the sample. When lpop goes up one standard deviation, Cingular is predicted to enter 3.92% more cities.

I also compute measures of goodness of fit as shown in Table 2.9. I calculate the percentage of correctly predicted for national carriers. It ranges from 81% to 73%. The mean and variance of the predicted result is also shown in Table 2.9. For example, the model predicts that Cingular enters 66.6% of the markets, while the observed entry rate is 67.9% in the sample. There is no significant difference between predicted mean and observed mean in the case of Cingular. However, for Sprint the prediction is not as precise. The model predicts that Sprint enters 77.8% of the cities while the observed entry rate is 69.4%. Still the percentage of correctly predicted for Sprint is an acceptable 79.1%. The model seems to work poorly when it comes to predicting the number of regional carriers as the percentage correctly predicted is only 50%. As a matter of fact, the number of regional carriers is theoretically more difficult to predict. For example, the entry decision of national carrier is a binary number, 0 or 1, and flipping a coin would have a 50% chance of being right. The number of regional carriers ranges from 0 to 4 and a random prediction only has a 20% chance of getting it right.

Table 2.9: **Goodness of Fit**

	Cingular	**Nextel**	**Sprint**	**T-mobile**	**Verizon**	**Regional**
Pred mean	0.67	0.65	0.78	0.43	0.62	0.98
PredStdev	0.47	0.48	0.42	0.49	0.49	0.30

%pred	0.81	0.79	0.79	0.78	0.73	0.50
Data						
mean	0.68	0.68	0.69	0.46	0.68	0.93
Stdev	0.47	0.47	0.46	0.50	0.47	0.77

Pred mean: mean of the predicted entry choice; Pred Stdev: the standard deviation of predicted entry choice; %pred: percentage correctly predicted. The baseline for comparison is again data mean and standard deviation. For example, in panel a, Cingular enters 67.9% of cities in the sample while the model predicts Cingular enters 66.6% of cities.

The finding that estimates of strategic effects change when I modify selection rule suggests that multiple equilibria might be a substantive concern in this context. The result of the policy experiment presented below appeared to be robust to selection mechanism. How to best deal with the multiple equilibria in this context is a subject of ongoing research.

Finally I evaluate the average loss if a carrier enters cities with population of less than 500 and where it does not yet serve. The result is shown in Table 2.10. For example, there are 2764 cities in the sample, with population less than 500, which are not yet served by Cingular. I calculate the post-entry profit as implied by estimated parameters, taking the current market configuration as given. Then I average the profit out across 2764 cities. The model implies that Cingular on average earns -0.185 if they were to serve these cities. Amongst all the national carriers, Sprint seems to incur least profit loss. Of course these numbers may or may not reflect the true financial profitability. I have done several normalizations in order to pin down the estimate. For example, profit not entering is normalized to zero and the scale of the coefficient is one. The profit loss is actually the distance to entry cutoff. The market level financial data for the wireless carriers would help in understanding the mapping between the underlying entry propensity and the dollar value.

Table 2.10: Policy Experiment

	#cities	Average "Profit Loss"
Cingular	2764	-0.185
Nextel	2822	-0.132
Sprint	2848	-0.067
T-mobile	4157	-0.453
Verizon	2566	-0.174

This table demonstrates the average profit loss (average cost) if the carriers are required to serve the city that satisfies the following criterion: 1. Population <500; 2.the city is not are not served by this particular carrier yet

For comparison, I perform the same exercise as above using the Probit estimates and find that Probit and structural estimation yield different predictions. The Probit model implies that Verizon incurs the least profit loss. In the sample, there are a total of 5023 cities with population less than 500. Among these cities, the places where neither Verizon nor Sprint serves have similar demand characteristics; compared to Sprint, Verizon has slightly stronger preferences to serve these places. Cingular, on the other hand, appears in 893 cities that Verizon has not entered and in 850 cities that Sprint has not entered. The structural estimation predicts that Verizon has a much stronger aversion to Cingular than Probit predicts, while the entry of Cingular seems to actually encourage Sprint. As a result, the structural model predicts Sprint to be more likely to enter while Probit predicts Verizon to be more likely to enter. The contrasting predictions generated by different models underscore the importance of accounting for endogeneity.

2.7 Conclusion

This paper has examined strategic interactions as determinants of market structure. The results indicate that strategic interactions significantly affect a firm's entry decision. In particular, pair-wise entry decisions between firms could be either strategic substitutes or strategic complements depending on which firms are being considered. Therefore the commonly used assumption that post-entry profit decreases uniformly and equally with the entry of each rival is an inaccurate approximation of reality in wireless telecommunication industry. Though the empirical context here focuses on wireless telecommunications, the methods and findings of this paper may be applicable to examining other concentrated industries as well.

The findings of the paper have key ramifications for public policy and firm strategy in the wireless telecommunication industry. They show that Sprint is in fact more likely to serve small cities. This is contrary to the prediction generated when analyses fail to address endogeneity in firm's entry decision, as in that case the false prediction would point to Verizon as more likely to enter small cities. Additionally, the significance of identity-specific strategic interactions highlights the heterogeneity amongst firms. It suggests that the practice of counting the number of wireless carriers, which presumes that firms are identical, could be misleading in assessing the competitiveness of the market. The results are also helpful in guiding firms to make their decisions. For instance, when existing wireless carriers in a particular market have the option to affiliate with other carriers, the estimated equations help predict how the market outcome could change.

Currently, the paper focuses solely on wireless carriers' entry decisions. Interesting extensions could investigate the stage games where firms invest in spectrum capacity in stage one and provide wireless service in stage two. Are investments in capacity an effective form of preemptive commitment device, resulting in entry deterrence? Answering this question opens up avenues for future research.

3 When and How Does Wireless Firm Invest?

3.1 Introduction

Does a firm's willingness to invest in new capacity depend on the state of competition? Do the incumbents and entrants make different capacity decisions when they face different level of competitions? I investigate these questions under the context of the U.S. wireless telecommunication industry.

Understanding the relationship between market competition and firm's investment behavior is important because it informs a variety of policy questions. For instance, industrial policy makers might worry that too much competition undermines firm's incentive to invest, which could potentially reduce the rate of innovations and harm productivity growth. Lots of work analyzes market structure and conduct under different settings (e.g. Calem and Carlino (1991), Worthington (1989), Zellner (1989), Bresnahan and Reiss (1991), Symeonidis (2000), Mookherjee and Ray (1991), Panzer and Rosse (1977), Mazzeo (2003), Dranove and White (1994), Chevalier (1995)). This paper complements the literature by linking firm's investment behavior to market structure using a novel data set of the wireless telecommunication industry.

The data set consists of the wireless license holding information (both Cellular and PCS license) and details of Advanced Wireless Service auction from the FCC (Auction 66) in 2006. I extract the Cellular and PCS licensing from the FCC's Universal License System (ULS). It identifies the operating wireless company (i.e. incumbent) in any given geographical region across U.S. It also contains information such as whether the wireless company is affiliated with other existing wireless firm, when the license was granted, and the location of wireless facility etc. In addition to the ULS data, I recover how much firm invested in new spectrum capacities from the AWS auction and use the winning bid and the second highest bid to approximate firm's willingness to invest. I also retrieve the identity of competitive service providers in each geographical region which helps in identifying the potential entrant. Using this data set, I investigate how the number of existing wireless firms (i.e. the Cellular and PCS licensee) and their geographical coverage affects the number of potential entrants and amount of investment in each market.

The U.S. wireless telecommunication industry contributes $138.9 billion in revenue in 2007 and the Advanced Wireless Service auction collects $13.8 billion in net bids. Despite the bloom in the wireless industry in the past a few years, the literature mostly focuses on its early age when wireless firms face substantial uncertainties in financial performances. This paper complements the literature by documenting the firms' investment pattern in its maturing age.

The main finding of the paper can be summarized as follows. First, I find that that the presence of an entrant bidder drives up the winning bid much greater than the presence of an incumbent. This suggests that the extent of winner's curse might be greater for entrant. I also find that the incumbent's investment in advanced capacity (as measured by bids in the spectrum auction) does not differ from that of an entrant; therefore, there is little direct evidence of investment motivated by entry preemption. Finally, the incumbent invest more when he faces intense competitions from competitors both with full coverage and with moderate coverage. The entrants invest more only when they face moderate competition from the firm with moderate coverage. This suggests that an entrant firm targets different market segments than an incumbent firm.

3.2 Background

Wireless spectrum is the one of the most important inputs in producing wireless telecommunication service. The wireless carriers enter the markets either through acquiring Cellular spectrum in early 80's or procuring PCS spectrum in mid-90. Over the past several years, the industry has experienced explosive growth in the demand for both voice and data services. Carriers have been upgrading their networks with advanced technologies in order to deploy both high-quality voice services and data services. To keep pace with the industry growth, the FCC auctioned off AWS spectrum licenses in 2006.

Similar to past FCC auctions, AWS auction adopted a Simultaneous Multiple Round (SMR) format. It has discrete, successive rounds, with each round announced in advance by the commission. After each round closed, round results were processed and made public. In such auctions, there is no present number of rounds and bidding continues until all bidders activity ceases. All licenses were available for bidding throughout the entire auction. However, in an AWS auction, the identity of bidders is not disclosed in each round (unless a competitive threshold was met) to prevent collusive or retaliation bids.

The AWS licenses are designated based on three types of geographical regions and six frequency blocks: block A of 20 MHz is assigned based on Cellular Market Areas (i.e. MSA/RSA); block B of 20 MHz and block C of 10 MHz is assigned based on Basic Economic Areas (BEA); block D, E and F of 10, 10 and 20 MHz is assigned based on Regional Economic Areas (REA). The continental U.S. can be divided into 695 CMA, 119 BEA and 6 REA. Their boundaries do not coincide with each other. The land area and population in a REA is much greater than those in CMA and BEA.

The AWS auction ended in September 2006. In this auction, 104 of 168 bidders won 1087 licenses and the net winning bids sum up to $13,700,267,150. The reserves for 35 licenses were not met, and these licenses were retained by the FCC. The unsold licenses are usually for rural areas with low population density or in non-contiguous parts of U.S. In my analysis, I exclude all the unsold licenses, and licenses for Gulf of Mexico, Puerto Rico, American Samoa, Virgin Islands, Guam, Alaska and Hawaii.

3.3 Data

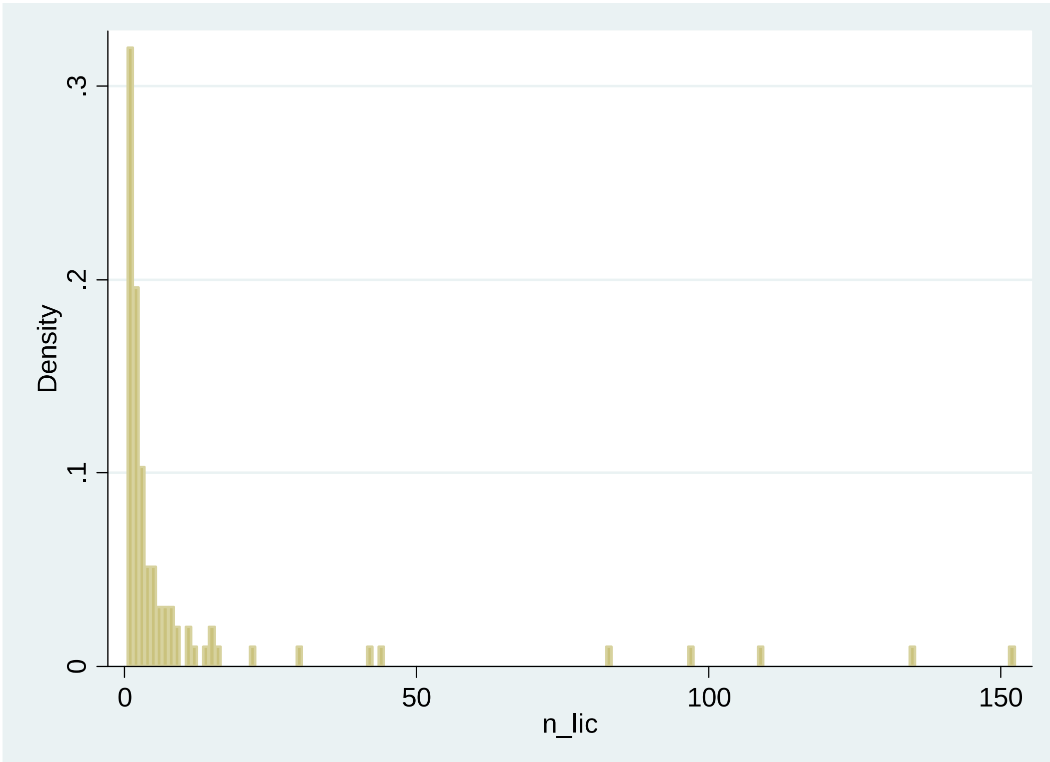
3.3.1 Data Sources

The sample is built from the FCC's Advanced Wireless Services auction (Auction 66) and the FCC's Universal License System (ULS). From auction data, I identify the investment amount in AWS spectrum while I use USL data to recover the market status and incumbent information in each AWS license covered area. The market demographics are downloaded from the U.S. Census Bureau web site.

3.3.2 The AWS auction

The AWS auction began in August 2006 and ended in September. The FCC released all the information on the identity of all bidders, the winning bids, bids in each round and upfront payments etc. There were 169 qualified bidders participating in the auction and 97 (after adjusting for ownership status) winners split 1051 licenses. The name and aggregate winning bids of each winner is listed in Table 3.1. Each winner took 10 licenses on average however the distribution is quite skewed. 50 firms (out of a total of 97) won less than 2 licenses. The full distribution on the counts of license is displayed in Figure 1.

Figure 1: Distribution of winning license counts for each winner



n_lic: number of licenses each winner won

The incumbency status of each AWS auction participant is recovered using the FCC's ULS data. The ULS database contains information on all existing wireless service providers (i.e. Cellular and PCS license holders) including their ownership status (i.e. whether the licensee is affiliated with other firms under FCC's disclosure rules)[45]. It also includes the detail wireless licenses characteristics such as the geographical range, the frequency blocks and when the license is issued. The ULS data helps to identify whether an AWS licensee is an incumbent in a particular geographical range and its penetration rate. Among the AWS license winners, 35 of them held either Cellular or PCS license in some region in the U.S. and are considered as incumbent.

[45] I adjust ownership status for the whole sample. Two firms are considered as identical to each other if one hold more than 50% share of the other.

Table 3.1: List of AWS licensees

Bidder	# license	net bids ($)	PCS Incumbent	Cell Incumbent	% Bid Credit
T-Mobile License LLC	116	4,170,000,000	1	0	0
Cellco Partnership d/b/a Verizon Wireless	12	2,800,000,000	1	1	0
SpectrumCo LLC	135	2,370,000,000	0	0	0
MetroPCS AWS, LLC	8	1,390,000,000	1	0	0
Cingular AWS, LLC	46	1,330,000,000	1	1	0
Cricket Licensee (Reauction), Inc.	99	1,080,000,000	1	0	0
Barat Wireless, L.P.	17	170,000,000	1	1	25
AWS Wireless Inc.	152	111,000,000	0	0	0
Atlantic Wireless, L.P.	15	100,000,000	0	0	25
American Cellular Corporation	83	63,700,000	1	1	0
Cincinnati Bell Wireless LLC	9	37,100,000	1	0	0
Cellular South Licenses, Inc.	12	33,000,000	1	1	0
Cable One, Inc.	30	22,100,000	0	0	0
Cavalier Wireless, LLC	22	16,200,000	0	0	25
Daredevil Communications LLC	14	13,400,000	0	0	25
Iowa Telecommunications Services, Inc.	15	11,500,000	0	0	0
Centennial Michiana License Company LLC	2	9,134,000	1	1	0
Red Rock Spectrum Holdings, LLC	42	7,466,000	0	0	0
Public Service Wireless Services, Inc.	7	5,480,000	0	0	0
Central Texas Telephone Investments	5	4,940,000	1	1	0
Hill Country Telephone Cooperative, Inc.	2	4,700,000	0	0	15
Carolina West Wireless, Inc.	9	4,621,000	0	0	0
Palmetto Rural Telephone Cooperative, Inc.	2	4,483,000	0	0	15
Plateau Telecommunications, Inc.	4	4,200,000	1	1	0
LL License Holdings II, LLC	8	3,435,000	1	0	15
KTC AWS Limited Partnership	11	3,108,000	0	0	25
Vermont Telephone Company, Inc.	3	2,911,000	1	0	15
Cross Telephone Company	3	2,450,000	1	1	15
Manti Telephone Company	5	2,421,000	0	0	25
Chequamegon Communications Cooperative, Inc.	3	2,419,000	0	0	15
Mediapolis Telephone Company	2	2,392,000	0	0	25
MTPCS License Co., LLC	4	2,348,000	1	0	0
NTELOS Inc.	7	2,295,000	1	0	0
Command Connect, LLC	5	2,210,000	1	0	15
FMTC Wireless, Inc.	2	2,197,000	0	0	15

Spotlight Media Corp	2	2,192,000	1	0	25
NSIGHTTEL Wireless, LLC	5	2,099,000	1	1	0
Smithville Spectrum, LLC	2	2,011,000	0	0	0
Union Telephone Company	8	1,948,200	1	1	0
Blackfoot Telephone Cooperative, Inc.	4	1,798,000	0	0	15
Hemingford Cooperative Telephone Company	11	1,660,000	0	0	25
West Carolina Piedmont Bidding Consortium	3	1,642,000	0	0	15
Wittenberg Telephone Company	3	1,519,000	0	0	25
Fidelity Communications Company	7	1,501,000	1	1	15
Atlantic Seawinds Communications, LLC	1	1,477,000	1	0	0
CTC Telcom, Inc.	1	1,407,000	0	0	15
FTC Management Group, Inc.	2	1,380,000	1	0	0
NEIT Wireless, LLC	3	1,315,000	1	0	25
Sandhill Communications, LLC	1	1,179,000	0	0	15
Chester Telephone Company	1	1,100,000	0	0	15
3 Rivers Telephone Cooperative, Inc.	4	1,066,000	0	0	0
Agri-Valley Communications, Inc.	5	1,045,000	0	1	15
Horry Telephone Cooperative, Inc.	1	925,000	1	0	0
SKT, Inc.	1	774,000	1	0	0
18th Street Spectrum, LLC	4	751,000	1	0	15
Blue Valley Tele-Communications, Inc.	2	711,000	0	0	25
Southeastern Indiana Rural Telephone Coop., Inc.	1	658,000	0	0	25
Hancock Rural Telephone Corporation	1	629,000	0	0	25
Triad AWS, Inc.	3	605,000	0	0	25
Pine Cellular Phones, Inc.	2	601,000	1	1	0
Telephone Electronics Coporation	3	559,000	0	0	0
Bend Cable Communications, LLC	2	528,000	0	0	0
LCDW Wireless Limited Partnership	1	514,000	0	0	25
Midwest AWS Limited Partnership	1	489,000	0	0	25
Lynch AWS Corporation	1	485,000	1	0	0
CenturyTel Broadband Wireless LLC	6	468,000	1	0	0
Alenco Communications, Inc.	1	437,000	0	0	25
Stayton Cooperative Telephone Company	1	391,000	0	0	25
James Valley	1	373,000	1	0	25
Paul Bunyan Rural Telephone Cooperative	3	329,000	0	0	0
Ligtel Communications, Inc.	2	319,000	0	0	15
Bek Communications Cooperative	2	312,000	1	0	25
Mutual Telephone Company	1	312,000	0	0	0

Comporium Wireless, LLC	1	295,000	0	0	0
ETCOM, LLC	1	283,000	0	0	25
La Ward Cellular Telephone Company, Inc.	1	273,000	0	0	25
Chariton Valley Communication Corporation, Inc.	2	268,000	1	1	15
Big River Telephone Company, LLC	2	243,000	0	0	25
BPS Telephone Company	1	228,000	0	0	15
CCTN Bidding Consortium	6	228,000	0	0	15
Mt. Vernon. Net, Inc.	1	227,000	0	0	25
C&W Enterprises INC.	1	226,000	0	0	15
Dakota Wireless Group, LLC	2	222,000	0	0	15
Green Hills Area Cellular Telephone, Inc.	1	213,000	0	0	15
North Dakota Network Company	3	177,000	1	0	0
Big Bend Telecom, LTD	2	129,000	0	0	0
Volcano Internet Provider	1	105,000	0	0	0
Grand River Communications, Inc.	1	103,000	0	1	0
Reservation Telephone Cooperative, Inc.	1	92,000	0	0	25
Farmers Telecommunications Cooperative, Inc.	1	85,000	1	1	15
Three River Telco	1	72,000	0	0	25
The S&T Telephone Cooperative Association, Inc.	2	72,000	0	0	15
Route 66 Wireless, LLC	1	72,000	0	0	25
Churchill County Telephone d/b/a CC Communications	2	60,000	0	1	0
Northeast Missouri Rural Telephone Company	1	28,000	0	0	15
Northwest Missouri Cellular Limited Partnership	1	26,000	0	1	0
WUE INC	1	8,000	0	1	25
Total	1,051	13,832,454,200	36	20	

The AWS license is auctioned at CMA, BEA and REA level, none of which is a standard geographical designation (such as county or state) used by the Census. Nevertheless, CMA, BEA and REA could be effectively decomposed into counties and I aggregate the county level demographics to CMA/BEA and REA level for my analysis.

The unit of observation in my analysis is license (i.e. market/frequency block).

The dependant variable (price) is generated by dividing winning bid of each license by population in the license covered area and bandwidth. I use log price in later analysis to reduce the abnormal variations. The average price of the AWS license is 19 cents per pop MHz. The price is lower (16 cents) in CMA, and is much higher in REA (63 cents). The summary statistics of log price (lprice) is displayed in Table 3.2. Compare across different geographical level, the average price of a REA license (0.63 cents per pop per MHz) is much more expensive than CMA/BEA license (0.16/0.23 cents). The geographical range and population in a REA is quite different from both BEA and CMA. For instance, the average population in REA is 46,600,000 while it is 1,652,627 in BEA and 399,359 in CMA. The winners of all 18 REA licenses are six bidders, including Cingular, T-mobile, Verizon, Metro PCS, U.S. Cellular (Barat) and Cricket (Denali). They generated 7.6 billion in net bids, which accounts for more than half of total AWS auction revenue. All suggests that REA differ substantially from the rest of licenses and I exclude all observation based on REA (18 observations) from my analysis.

Table 3.2: Summary Statistics (Dependant Variables)

	#obs	Mean	Std. dev	Min	Max
			All		
price	1051	0.19	0.21	0.02	1.59
log (price)	1051	-2.15	0.98	-3.82	0.46
			CMA		
price	695	0.16	0.18	0.02	1.59
log (price)	695	-2.33	0.96	-3.82	0.46
			BEA		
price	338	0.23	0.21	0.02	1.57
log (price)	338	-1.87	0.90	-3.80	0.45
			REA		
price	18	0.63	0.29	0.25	1.33
log (price)	18	-0.56	0.45	-1.37	0.29
			CMA and BEA		
price	1033	0.18	0.20	0.02	1.59
log (price)	1033	-2.18	0.96	-3.82	0.46

Note: price = winning bid/pop

The key explanatory variable is the number of existing wireless firms in each market. Table 3.3 displays the summary statistics. I group existing wireless firms serving each market based on their geographical penetration rate. The penetration rate for an existing wireless firm is constructed by summing up the population it's licensed to cover (under either Cellular or PCS license) and then dividing the sum population by the total population in that area. compH is the number of competitors who achieves full penetration, compM is the count of wireless competitor that covers more than 32% of population, compL is the number of the competitor that covers less than 32% of population. The division of compH, compM and compL are based on the distribution of penetration rate of all Cellular and PCS firms in each market across the sample. A penetration rate of 32% is the 25% quartile while a penetration rate of 100% is the 50% quintile. When computing competitive measures, the commonly owned firms are treated as a single firm. In this paper, two firms are considered as a commonly owned firm if more than 50% of interest is held by the same entity.

Table 3.3 : Summary Statistics (Other Key variables, N=1033)

	Mean	Std. dev	Min	Max
$\#\ competitorH$	5.00	1.52	0	10
$\#\ competitorM$	1.50	1.74	0	10
$\#\ competitorL$	2.38	3.83	0	28
$I(competitor\ H_0)$	0.04	0.20	0	1
$I(competitor\ H_1)$	0.91	0.29	0	1
$I(competitor\ H_2)$	0.05	0.22	0	1
$I(competitor\ M_0)$	0.44	0.50	0	1
$I(competitor\ M_1)$	0.43	0.50	0	1
$I(competitor\ M_2)$	0.13	0.34	0	1

Note: compH_i and compM_i are binary indicators for categories in compH and and compM.

On average, each AWS license winner faces 5 strong competitors who have licenses fully covering the market while there are 1.5 competitors who have moderate coverage and 2.4 competitors who have little coverage. Looking into the distribution on each type of competitor compH, compM, and compL, a firm is defined as facing little competition from strong competitors if compH<3 and let binary indicator compH0 equals 1. Similarly, compH1 = 1 if a firm face moderate competition from strong competitor when 2≤ compH ≤7 and compH2=1 if compH>7. For moderate competitors, compM0 = 1 if compM=0, compM1 = 1 if 1≤ compM ≤3 and compM2=1 if compM > 3. In the whole sample, 91% of the markets are occupied by moderate number of strong competitors while 43% are occupied by moderate number of intermediate competitors.

We realize the endogeneity using the counts of firms to proxy the level of competition. If existing firms and bidders are attracted to the market for some unobserved market condition, then effect of competition measured by firm counts may be biased upward. Separating the effect of competition and market condition is a difficult econometric problem. When estimating the main specification, I use firm counts based binary indicators H_1, H_2, M_1 *and* M_2 as oppose to including the firm counts in the estimation, to minimize the impact of possible endogenous regressors. Furthermore, including the *n_ab* the number of actual bidders in each license helps to control for the unobserved market conditions that might bias the estimates. The detailed discussion on endogeneity is presented in section 3.4.2.

The firm level explanatory variable includes clpcs indicator, which equal 1 if the firm holds Cellular or PCS license somewhere in the U.S. In other words, clpcs equals 1 if the firm is the incumbent if the industry. About 47% of the AWS licenses are held by an incumbent who previous held some wireless licenses. An AWS licensee's penetration rate is constructed by summing up the population covered by its PCS (or Cellular) licenses and then dividing by the total population in that area. Nevertheless, the PCS and Cellular license are auctioned off at different geographical units from AWS license. I decompose the PCS or Cellular license covered areas into counties and then aggregate them to the AWS unit accordingly. In contrast to clpcs, penrate > 0 if a firm is the incumbent of a particular market. On average, each AWS licensee holds the wireless spectrum that covers 25% of population in the AWS licensed areas. However, the distribution of penetration is skewed. If looking only at companies with non-zero penetration rate, the average penetration rate jumps to 90%. credit15 equals 1 if the firm receives 15% bidding credit in the AWS auction and 0 otherwise. credit25 is an indicator for 25% bidding credit defined similarly.

Several variables are useful in explaining the prices pattern in AWS auction. The market level variables determine the inherent value of the licenses to bidders. Each of the explanatory variables is displayed in Table 3.4. Some variables vary enormously (e.g. population and average household income), suggesting a non-linear relationship, and I logarithm them for the subsequent analysis. One important market level explanatory variable is the number of competitor (#competitor) faced by each AWS licensee in the auction. On average, one winner competes with 2.15 bidders in the auction, and the actual number of competitor in the auction ranges from 0 to 9. When decomposing #competitors into entrant and incumbent, each license attracts 1.67 incumbent and 0.49 entrants to bid on. It's easy to show that entrants have a higher probability to win ex-post. Generally, entrants bid more aggressively than incumbent, and the presence of an entrant raises the winning bid greater for an incumbent.

In the sample, the average population of each AWS license covered area is 809,431. BEA with average population 1,651,429 is generally more populated than CMA, whose average population is

399,359. As in previous chapters, income, time commute to work etc. are used as explanatory variable. I use average household income as opposed to per capita income because the census have the information on aggregated household income for each county, which allows me to aggregate and average out at BEA/CMA level. Binary indicator bea1=1 if the license based on BEA and frequency block is B, bea2=1 if the license is based on BEA and frequency block is C. If neither bea1 nor bea2 equals 1, the observation is based on CMA (i.e. block A).

Table 3.4 : Summary Statistics (Other variables, N=1033)

	Mean	Std dev	Min	Max
	Firm Level			
cl/pcs incumbent	0.47	0.50	0	1
penetration rate	0.26	0.43	0	1
penetration rate>0*	0.90	0.24	0.00	1
credit15	0.07	0.26	0	1
credit25	0.12	0.33	0	1
	Market Level			
#competitors	2.15	1.65	0	9
#entrant	1.66	1.28	0	8
#incumbent	0.49	0.75	0	3
log (population)	12.66	1.24	9.40	17.06
rural population %	0.40	0.22	0.00	0.95
log(average household income)	10.76	0.17	10.26	11.55
log (land area)	8.38	1.16	4.64	11.38
car occupation rate	0.91	0.04	0.58	0.96
log (average time commute to work)	3.06	0.18	2.46	3.61
cma	0.67	0.47	0	1
bea1	0.16	0.37	0	1
bea2	0.16	0.37	0	1

*Notice: * the number of observation is 298. car is private vehicle occupation rate for works over 16 years old, cma=1 if the license is based on CMA, bea1=1 if the license based on BEA and frequency block is B, bea2=1 if the license is based on BEA and frequency block is C*

3.4 Results

3.4.1 Main Specification and Results

In this section, I will first present some empirical regularity of the FCC auction and then estimate the main specification.

Determinant of entry Though the average number of bidders in the AWS auction is 3.15 (excluding REA licenses), there is a wide variation. I investigate the determinant of entry in Table 3.5. In this specification, a bidder is considered as entrant if its penetration rate is less than 32% in the market. The number of existing wireless firms seems to matter only when there is the moderate number of firms with intermediate coverage. When I decompose the total number of bidders into the entrant and incumbent and look at them separately, the number of competitors with full coverage does not matter at all to the entrant while the number of competitors with limited coverage negatively affects the number incumbent firm who enters the auction.

Table 3.5: Determinant of Entry (N=1033)

	Dependent Variable		
	# bidder (total)	# bidder (entrant only)	#bidder (incumbent only)
# competitors H_1	-0.01 (0.21)	0.09 (0.20)	-0.10 (0.13)
# competitors H_2	0.15 (0.26)	0.03 (0.25)	0.12 (0.15)
# competitors M_1	-0.22** (0.11)	-0.06 (0.10)	-0.17*** (0.06)
# competitors M_2	-0.40*** (0.15)	-0.21 (0.14)	-0.20** (0.09)
log (population)	0.67*** (0.06)	0.31*** (0.06)	0.36*** (0.04)
rural population %	-0.79*** (0.29)	-0.38 (0.28)	-0.41** (0.17)
log(average household income)	0.58* (0.35)	-0.17 (0.33)	0.75*** (0.20)
log (land area)	0.39*** (0.05)	0.30*** (0.05)	0.08*** (0.03)

car occupation rate	-3.32*** (1.20)	-3.17*** (1.13)	-0.14 (0.70)
log(time commute to work)	0.18 (0.29)	0.43 (0.27)	-0.25 (0.17)
bea1	-0.23* (0.14)	0.12 (0.13)	-0.35*** (0.08)
bea2	-0.05 (0.14)	0.20 (0.13)	-0.25*** (0.08)
Constant	-11.82*** (4.20)	-0.60 (3.96)	-11.22*** (2.46)

Who bid more aggressively? Perhaps one of the most interesting empirical questions to ask about the FCC's auction is who's willing to pay more, the incumbent or the entrant? I estimate the determinant of final bid price focusing on the presence of entrant and incumbent bidders.

I estimate the following specification:

$$log(price_{im}) = \sum_{j=1}^{4} \gamma_j \left(I_{bidder\_entrant\,jm}\right) + \sum_{k=1}^{3} \delta_j \left(I_{bidder\_incumbent\,km}\right) +$$

$$\alpha X_m + \lambda Z_j + \varepsilon_{im}$$

The dependent variable is log per population investment of each AWS licensee. $I_{bidder_entrant\,jm}$is the number of entrant bidder indicator. $I_{bidder_entrant\,jm}$equals one if there are j entrants in market m and equals zero otherwise. The omitted category is zero entrants. Similarly, $I_{bidder_entrant\,jm}$is the number of entrant bidder indicator. The omitted category is zero incumbent bidders. The summary statistics for these variables are displayed in Table 3.6. For instance, on average, 18% of final auction winners face zero entrant bidders and 65% of the winners face zero incumbent bidder. X_m and Z_j is a set of control variables.

Table 3.6: Summary Statistics (Competitors, N=1033)

	Mean	Std dev	Min	Max

# competitor (entrant bidders)				
0	0.18	0.38	0	1
1	0.33	0.47	0	1
2	0.27	0.44	0	1
3	0.15	0.35	0	1
4+	0.08	0.27	0	1
#competitor (incumbent bidder)				
0	0.65	0.48	0	1
1	0.25	0.43	0	1
2	0.08	0.27	0	1
3	0.03	0.16	0	1

In Table 3.7, I regress the winning price on the different types of bidders and a set of controls (both market level and firm level). The presence of any entrant raises the winning price much greater than the presence of competitor. The presence of an additional bidder raises the winning bid by 38%. The presence of the first entrant bidder increases the final price by 76% while an incumbent only by 45%. However, conditional on the presence of competitor bidder, being an incumbent (cl/pcs =1 or penetration rate > 1) does not help to raise the final price.

One causes of this pattern could be the information asymmetry between incumbent and entrant and the winner's curse. The incumbent firm has better information about the market and thus their valuation is lower than the entrants'. The presence of an entrant increases the price much steeper than an incumbent.

Table 3.7: **Determinant of Price (Entrant v.s. Incumbent)**

	Dependent variable: winning price
# competitors (bidder all)	0.38*** (0.02)

# competitors (bidder entrant)		
1		0.76*** (0.06)
2		1.13*** (0.06)
3		1.40*** (0.07)
4+		1.58*** (0.10)
# competitors (bidder incumbent)		
1		0.45*** (0.05)
2		0.82*** (0.08)
3		0.98*** (0.13)
cl/pcs incumbent	0.08 (0.05)	0.08 (0.05)
penetration rate	-0.01 (0.06)	0.05 (0.06)
log (population)	0.09*** (0.04)	0.11*** (0.03)
rural population %	-0.06 (0.15)	-0.01 (0.15)
log (average household income)	0.54*** (0.19)	0.57*** (0.18)
log (land area)	-0.07*** (0.03)	-0.07** (0.03)
car occupancy rate	-0.27 (0.64)	-1.13* (0.62)
log (time commute to work)	-0.37** (0.16)	-0.15 (0.15)
bea1	-0.08 (0.07)	-0.11 (0.07)
bea2	-0.12* (0.07)	-0.09 (0.07)
credit15	-0.03 (0.08)	-0.06 (0.08)
credit25	-0.37*** (0.06)	-0.33*** (0.06)
constant	-8.37*** (2.24)	-8.72*** (2.17)

To look at determinant of firm's willingness to invest, I estimate the following specification:

$$log(price_{im}) = \sum_{j=1}^{2} \gamma_j I(competitor\ H_j) + \sum_{k=1}^{2} \delta_k I(competitor\ M_k) + \alpha X_m + \lambda Z_j + \varepsilon_{im}$$

The dependent variable is log per population investment of each AWS licensee. $I(competitor\ H_j)$ and $I(competitor\ M_k)$ are both binary indicators on how intense the completion is from strong competitors and weak competitors. There are two omitted categories: when competition is weak from strong competitors $I(competitor\ H_0)$ and when the competition is weak from moderately strong competitor $I(competitor\ H_0)$ one entrant. If the competition among existing firms matters, γ_j and δ_k should be significant. X_m and Z_j is a set of control variables.

The competitive determinant of firm's willingness to invest is displayed in Table 3.8. Competition does not seem to matter in the full sample (the last column), however, incumbent firm and entrant firm have differential responses to rival's presence in the product market and the result is robust when I try different definition of incumbent. When the incumbent is defined as firm who provides full coverage in a particular market (penrate=1), the presence of strong competitor who also provide full coverage will drive up the willingness to invest. For instance, presence of moderate number of strong competitors drives up the spectrum price by 36%, while the presence of a large number of strong competitors raises the price by 86%. At the same time, they don't seem to affect entrant's willingness to bid (the estimated coefficients are -0.11 and -0.06 and they are not significant). Alternatively, the same pattern could be found when I define the incumbent as firms who previously held any Cellular or PCS licenses (cl/pcs=1). However, the presence of moderate number of firm with limited coverage does increase the bidding price of entrant firm. In the specification where entrant is defined as firm with zero penetration into a particular market, presence of moderate number of limited coverage firm increases the winning bid by 15% while it increases the winning bids by 20% in an alternative definition.

Table 3.8: Effect of Market Competition on Willingness to Invest

	Incumbent		Entrant		Both
	penrate=1	cl/pcs=1	penrate =0	cl/pcs=0	
# competitors H_1	0.36* (0.22)	0.23* (0.13)	-0.11 (0.13)	-0.10 (0.14)	0.05 (0.10)
# competitors H_2	0.86*** (0.22)	0.44** (0.20)	-0.06 (0.17)	-0.03 (0.18)	0.14 (0.14)
# competitors M_1	0.04 (0.15)	0.01 (0.09)	0.15** (0.07)	0.20** (0.08)	0.12** (0.06)
# competitors M_2	0.67** (0.28)	0.12 (0.15)	0.09 (0.09)	0.13 (0.11)	0.11 (0.08)
cl/pcs incumbent			0.06 (0.06)		0.09 (0.06)
penetration rate		-0.03 (0.07)			0.00 (0.06)
# competitor (all bidders)	0.35*** (0.04)	0.37*** (0.03)	0.40*** (0.02)	0.39*** (0.02)	0.38*** (0.02)
log (population)	0.04 (0.07)	0.04 (0.05)	0.12*** (0.04)	0.15*** (0.05)	0.09*** (0.03)
rural population %	-0.45 (0.37)	-0.28 (0.23)	-0.06 (0.19)	0.06 (0.23)	-0.15 (0.16)
log (average house income)	0.28 (0.32)	0.64** (0.25)	0.59** (0.24)	0.51* (0.29)	0.57*** (0.19)
log(land area)	-0.09 (0.06)	-0.07 (0.05)	-0.11*** (0.04)	-0.11** (0.05)	-0.09*** (0.03)
car occupation rate	-0.79 (1.04)	0.00 (0.85)	-0.41 (0.85)	-0.60 (1.08)	-0.29 (0.66)
log (time commute to work)	0.08 (0.35)	-0.18 (0.23)	-0.50*** (0.18)	-0.51** (0.22)	-0.36** (0.16)
bea1	-0.07 (0.27)	0.00 (0.14)	-0.18** (0.09)	-0.18* (0.10)	-0.11 (0.08)
bea2	0.19 (0.17)	0.08 (0.11)	-0.28*** (0.09)	-0.30*** (0.10)	-0.15** (0.07)
credit15	-0.07 (0.27)	-0.16 (0.12)	-0.08 (0.11)	0.11 (0.16)	-0.02 (0.10)
credit25	-0.41*** (0.13)	-0.43*** (0.10)	-0.34*** (0.07)	-0.33*** (0.08)	-0.37*** (0.06)
Constant	-5.73 (3.78)	-9.62*** (3.07)	-8.31*** (2.94)	-7.65** (3.58)	-8.57*** (2.31)
#observations	227	487	735	546	1033

3.4.2 Robustness Checks

Heterogeneous Bidders To insure that the result is not driven by strong incumbent who won a large set of AWS licenses, I re-run the specification in Table 3.8 in a sub-sample, where the firms who won more than 50 licenses dropped out[46]. The result does not change. Weak competition among weak competitors drives up the sale price for entrant ($\beta_{\#competitors\mathrm{M}_1} = 0.27\ and\ 0.36$). Strong competition among strong competitors increases the price for incumbent ($\beta_{\#competitors\mathrm{H}_2} = 0.59$). However, the effect of weak competitors on incumbent became more pronounced after dropping top five bidders, and the same trend could be found in the main specification as well.

Table 3.9: Effect of Market Competition on Willingness to Invest (Sub-sample of medium and small firm)

	Incumbent		Entrant		Both
	penrate==1	clpcs==1	penrate==0	clpcs==0	
# competitors H_1	0.13 (0.35)	0.18 (0.20)	-0.15 (0.49)	-0.10 (0.63)	0.09 (0.20)
# competitors H_2	0.59* (0.35)	0.41 (0.27)	-0.23 (0.50)	-0.19 (0.65)	0.03 (0.24)
# competitors M_1	0.39* (0.23)	0.08 (0.14)	0.27** (0.11)	0.36*** (0.12)	0.24*** (0.09)
# competitors M_2	1.29*** (0.35)	0.25 (0.21)	0.22 (0.14)	0.28* (0.15)	0.30** (0.12)
cl/pcs incumbent			-0.25** (0.12)		-0.13 (0.11)
penetration rate		0.14 (0.12)			0.13 (0.11)
# competitor (all bidders)	0.38*** (0.06)	0.36*** (0.04)	0.41*** (0.04)	0.42*** (0.04)	0.39*** (0.03)
log (population)	0.04 (0.09)	0.07 (0.07)	0.10 (0.07)	0.06 (0.08)	0.06 (0.06)
rural population %	-0.84* (0.49)	-0.73* (0.38)	0.18 (0.30)	0.23 (0.34)	-0.07 (0.26)
log (average house income)	-0.46 (0.68)	-0.03 (0.51)	1.21*** (0.40)	1.40*** (0.43)	0.93*** (0.36)
log(land area)	-0.23** (0.09)	-0.12* (0.07)	-0.23*** (0.07)	-0.23*** (0.07)	-0.17*** (0.05)
car occupation rate	-3.01 (2.72)	-1.63 (1.45)	-2.18 (1.48)	-2.14 (1.91)	-1.40 (1.24)
log (time commute to work)	-0.36 (0.51)	-0.58 (0.37)	-0.38 (0.29)	-0.14 (0.33)	-0.32 (0.24)
bea1	-0.48 (0.33)	-0.03 (0.18)	-0.31 (0.19)	-0.35* (0.21)	-0.15 (0.14)
bea2	-0.05 (0.30)	0.04 (0.19)	-0.28* (0.16)	-0.35** (0.17)	-0.15 (0.13)
credit15	-0.27 (0.29)	-0.15 (0.15)	-0.19 (0.13)	-0.14 (0.16)	-0.17 (0.11)

[46] Five firms bid more than 50 licenses: T-mobile, American Cellular, Cricket, AWS and Spectrum.

credit25	-0.63*** (0.17)	-0.58*** (0.12)	-0.52*** (0.10)	-0.51*** (0.11)	-0.58*** (0.08)
Constant	6.97 (9.09)	0.48 (6.09)	-12.47** (4.87)	-14.95*** (5.21)	-10.46** (4.28)
#observations	99	198	314	259	457

Alternative Representation of Willingness to Invest There is a concern that whether the winning price truly represents the firm's willingness to invest, especially for licenses that are sold in one round. In other words, the highest bids are the lower bound for winning firms' willingness to pay. To investigate this possibility, I ran the same set of specification on the second highest bid for each license. Arguably the second highest bid proximate the amount the winner firm is willing to pay. The intuition is similar to the intuition in English auction. I re-estimate the specification replace the dependant variable with the 2nd highest bid. The result is displayed in Table 3.10. The auction for 145 licenses ended after only one round, thus the 2nd highest bid does not exist for them and dropped out from the analysis. The main result of the paper is very robust when using alternative definition of investment. The incumbent firm is more likely to invest when intense competition from strong competitors exists ($\beta_{\#competitors\mathrm{H}_2} = 0.66\ and\ 0.44$) while the entrants are more likely to invest when there is moderate competition from weak competitors ($\beta_{\#competitors\mathrm{M}_1} = 0.14\ and\ 0.19$).

Table 3.10: Effect of Market Competition on Willingness to Invest (Dependant Variable: 2nd highest bid.)

	Incumbent		Entrant		All
	penrate==1	clpcs==1	penrate==0	clpcs==0	
# competitors H_1	0.18 (0.21)	0.17 (0.14)	-0.13 (0.12)	-0.12 (0.13)	0.00 (0.09)
# competitors H_2	0.66*** (0.22)	0.44** (0.21)	-0.11 (0.17)	-0.09 (0.18)	0.07 (0.15)
# competitors M_1	0.02 (0.18)	-0.04 (0.11)	0.14* (0.08)	0.19** (0.10)	0.11 (0.07)
# competitors M_2	0.47 (0.31)	0.05 (0.16)	0.05 (0.11)	0.09 (0.12)	0.06 (0.09)
cl/pcs incumbent			0.07 (0.07)		0.10 (0.06)

penetration rate		0.00 (0.07)			0.02 (0.07)
# competitor (all bidders)	0.26*** (0.04)	0.27*** (0.03)	0.32*** (0.02)	0.32*** (0.03)	0.30*** (0.02)
log (population)	0.00 (0.10)	0.02 (0.07)	0.14*** (0.05)	0.16*** (0.06)	0.10** (0.04)
rural population %	-0.26 (0.45)	-0.32 (0.27)	0.02 (0.22)	0.22 (0.27)	-0.08 (0.19)
log (average house income)	0.55 (0.35)	0.83*** (0.28)	0.85*** (0.27)	0.82** (0.33)	0.80*** (0.21)
log(land area)	-0.08 (0.08)	-0.03 (0.05)	-0.09** (0.04)	-0.11** (0.05)	-0.07** (0.03)
car occupation rate	-0.76 (1.04)	-0.09 (0.89)	-0.37 (0.94)	-0.59 (1.19)	-0.29 (0.70)
log (time commute to work)	0.60 (0.44)	0.08 (0.28)	-0.41* (0.21)	-0.39 (0.25)	-0.21 (0.19)
bea1	0.04 (0.30)	0.01 (0.15)	-0.22** (0.10)	-0.21* (0.11)	-0.13 (0.08)
bea2	-0.47** (0.18)	-0.56*** (0.12)	-0.99*** (0.09)	-1.01*** (0.11)	-0.84*** (0.08)
credit15	-0.14 (0.34)	0.00 (0.15)	0.08 (0.12)	0.21 (0.16)	0.13 (0.11)
credit25	-0.12 (0.16)	-0.18 (0.11)	-0.05 (0.08)	-0.03 (0.09)	-0.09 (0.07)
Constant	-6.49 (4.00)	-9.11*** (3.37)	-8.50*** (3.27)	-8.35** (3.98)	-8.44*** (2.56)
#observations	189	411	636	477	888

Substitutability among Licenses One of the greatest concerns of the paper is the interdependence across unit of observations. That is firms are allowed to submit bids for multiple licenses and assemble their own package of licenses. I look at the possible substitution between BEA licenses since the two types of BEA licenses are almost perfect substitute to each other. Both BEA_B and BEA_C licenses are auctioned at the same time. They cover identical geographical range and the only difference between them is the frequency blocks at which the radio signal will be transmitted.

I first look at whether winner firms win both BEA licenses that covers the same geographical region. If a firm bid and win both BEA licenses, then the concern for substitution between licenses should be lessened. In the subsample, 171 BEA are included and there subsequently 342 licenses auctioned (two for each BEA). In 92 out of 171 BEA, both licenses are won by the same firm. I then look at whether the winner of BEA_B also participates in BEA_C auction and vice versa, among the rest of 79 BEA. The data suggests that the winner of the rest of licenses bid on only one of the two auctions as opposed to both. Moreover, in 54 of 79 BEAs, we observe at least one firm bid for both licenses but none of them wins either license. All these suggest that substitution between BEA licenses does not exist.

The concern that firms substitute among licenses can be further mitigated since the main result is robust when the firms who bid on and win a large set of licenses are deleted. Ideally, I should only include the observation where the winner firm bids on only one licenses. However, this eliminates too much variation (or most of observations) and the effect of competition is poorly identified. Nevertheless, there is no good way to investigate substitution between BEA and CMA licenses.

Endogeneity on the Firm Counts We realize the endogeneity using the counts of firms to proxy the level of competition. In the main specification, I use firm counts based binary indicators H_1, H_2, M_1 *and* M_2 as oppose to including firm counts in the estimation, to minimize the impact of possible endogenous regressors. Including the number of actual bidders helps to control unobserved market condition as well.

To further investigate the direction of bias, I estimate the specification omitting population. If the firm count is positively related with unobservable market condition, which is also positively related with population, then omitting population will further bias the estimated coefficients of H_1, H_2, M_1 *and* M_2 upwardly. Table 3.11 compares the estimates without *lpop* with that in the main specification. The magnitude and significance level of the estimates remains quite similar with or without *lpop*. For entrants (column 3 and column 4), I find however, this statement is true only for incumbent. When omitting population, the coefficients on M_2 increase when omitting *lpop*, suggesting positive bias as expected. Coefficients on H_1, H_2 *and* M_1 for the entrant are imprecisely estimated, though there is a tendency that when omitting *lpop* the estimate that is negative becomes more negative and the estimate that is positive becomes more positive. The effect of omitting *lpop* for incumbent is different. The estimated coefficients decrease when omitting *lpop,* suggesting negative bias. This reinforces the results for incumbent in the main specification for entrants, i.e. the estimated coefficients on H_1 *and* H_2 are positive and is a lower bound for the effect competition on incumbent's willingness to invest.

Table 3.11: Bias when omitting *lpop*

	Incumbent		Entrant		All
	penrate==1	clpcs==1	penrate==0	clpcs==0	
	Estimates when omitting *lpop*				
# competitors H_1	0.35 (0.22)	0.22* (0.13)	-0.16 (0.14)	-0.17 (0.15)	0.02 (0.10)
# competitors H_2	0.85*** (0.22)	0.43** (0.20)	-0.11 (0.17)	-0.09 (0.19)	0.11 (0.14)
# competitors M_1	0.04 (0.15)	0.01 (0.09)	0.18** (0.07)	0.23*** (0.09)	0.13** (0.06)
# competitors M_2	0.68** (0.28)	0.13 (0.15)	0.13 (0.10)	0.18 (0.11)	0.14 (0.08)
	Estimates in Main Specification				
# competitors H_1	0.36* (0.22)	0.23* (0.13)	-0.11 (0.13)	-0.10 (0.14)	0.05 (0.10)
# competitors H_2	0.86*** (0.22)	0.44** (0.20)	-0.06 (0.17)	-0.03 (0.18)	0.14 (0.14)
# competitors M_1	0.04 (0.15)	0.01 (0.09)	0.15** (0.07)	0.20** (0.08)	0.12** (0.06)
# competitors M_2	0.67** (0.28)	0.12 (0.15)	0.09 (0.09)	0.13 (0.11)	0.11 (0.08)

3.5 Conclusion

In this paper, I look at the FCC's Advance Wireless Service auctions. I document several empirical regularities on incumbent and entrant's firm's behavior that might generate policy implications.

First, I find that presence of an entrant bidder drives up the winning bid much greater than the presence of an incumbent. Secondly, the investment winning bids are monotonic in the number of entrant bidder and in the number of incumbent bidder. The investment pattern of an incumbent winner does not differ significantly from entrant. Thus little evidence of entry preemption could be found.

Finally, I construct measures of competition based on the number of the firm and their geographical penetration rate and look at how a firm's willingness to invest varies as the market becomes more competitive. I find that the incumbent invest more when they face intense competitions from competitors with both full coverage and limited coverage. The entrants invest more only when they face moderate competition from the firm with limited coverage. This finding suggests that incumbent and entrant firm compete in different market segments. In the robustness analysis, I check the sign of the possible bias and find out that it positively affects the entrant while negatively affects the incumbent. This is a suggestive evidence that information asymmetry exists between incumbent and entrant firms.

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