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Empirical Studies of the Market for Broadband Personal Communications Service Spectrum in the US

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Empirical Studies of the Market for Broadband Personal Communications Service Spectrum in the US

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by

Andraz Kavalar

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Abstract of the Dissertation

Empirical Studies of the Market for Broadband Personal Communications Service Spectrum in the US

by

Andraz Kavalar

Doctor of Philosophy in Economics

University of California, Los Angeles, 2014

Professor Connan A. Snider, Chair

Recent proposals to limit the participation of Verizon Wireless and AT&T in the upcoming broadcast TV spectrum incentive auction have rekindled the debate on the interactions between auction design and competition policy. Existing literature analyzes the efficiency of spectrum auctions by focusing on auction outcomes, noticing that there is little immediate post-auction resale in the secondary market for spectrum. However, the effects of specific pro-competitive auction policies on the market structure can only be fully understood by considering long-run market outcomes.

This dissertation provides a historical overview of the market for broadband PCS spectrum and then documents the construction of a unique and first comprehensive dataset of firms' spectrum licenses holdings. I then use this dataset to investigate the long-term effects of auction restrictions similar to the ones recently proposed.

I document how eligibility restrictions for entrepreneurs in the early years of the market for broadband PCS spectrum initially create two separate markets, the gradual opening of the restricted market, and its eventual convergence with the unrestricted one. Second, and con-

trary to the existing literature, the detailed nature of my data shows there was a significant level of market activity immediately following the auctions, a portion of which can be attributed to specific preferential treatment policies used. To investigate the actual transition of restricted spectrum from entrepreneurs to large companies, my identification strategy uses the institutional design of eligibility restrictions, resulting in considerable differences in the observed build-out behavior of entrepreneurs and large companies. While the latter have no incentive to meet the construction requirements ahead of time, doing so allows entrepreneurs to potentially sell their licenses to large companies. Results show a consistent pattern of entrepreneurs building out their licenses early only to immediately sell them to large companies.

By first constructing a unique spectrum license dataset and then exploring the effects of preferential treatment provisions used in spectrum auctions for PCS licenses, this dissertation provides evidence that these provisions did not achieve their long-run goal in terms of the desired market structure. Instead, there is strong evidence of opportunistic behavior of entrepreneurs, who get pulled in because of eligibility restrictions and then quickly resell their licenses to large companies. In general, it appears the presence of secondary markets undoes the outcomes generated in auctions (and desired by the policymaker). Because of this, FCC should consider regulating secondary markets in line with their existing regulatory practices rather than imposing auction restrictions, i.e. regulating auctions.

The dissertation of Andraz Kavalar is approved.

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2014

This dissertation is dedicated to my parents, Maja and Rajko; sister Manca; and best friend and fiancée Vedrana. Without their unconditional love and support I would not be where I am today.

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Glossary

ABDE market	The market for 80 MHz of PCS spectrum in the A, B, D and E frequency blocks. This definition is time-invariant.
CF market	The entire market for C and F block spectrum, i.e. for 40 MHz of nationwide (restricted and unrestricted) CF spectrum. This definition is time-invariant.
Complete sale	A sale of the license in which the entire spectrum associated with the license changes hands.
Derivative license	Licenses issued as a result of a market transaction (regardless of whether the first license was an original or a derivative license).
Disaggregation	Splitting of the quantity of spectrum associated with each license, retaining the geographical coverage of the license.
Entrepreneur	Collective term for what FCC calls designated entities, entrepreneurs, small enterprises, i.e. entities eligible to bidding on restricted licenses. Entrepreneurs must have average annual gross revenues of less than $125 million.
Initial auction	One of the first 3 (planned) PCS auctions.
Original license	License won in an auction.
Partial sale	A sale of the license where the existing license is partitioned or disaggregated.
Partitioning	Geographical splitting of an existing license, retaining the quantity of spectrum in each geographical area.
Quantity	Bandwidth, i.e. frequency range of spectrum associated of the license.

Re-auction	One of the 6 additional (unplanned) PCS auctions.
Regular entrepreneur	Entrepreneur that does not qualify for bidding credits and installment payment plans. Regular entrepreneurs must have average annual gross revenues of less than $125 million, but more than $40 million.
Restricted CF license	CF license won in the so-called closed bidding, that is in an auction with eligibility restrictions that was open only to entrepreneurs. All CF licenses were initially restricted; under certain conditions these restricted CF licenses could however be converted to unrestricted ones. The total volume of restricted CF spectrum is therefore decreasing over time.
Small entrepreneur	Entrepreneur that also qualifies for bidding credits and installment payment plans. Small entrepreneurs must have average annual gross revenues of less than $40 million, but more than $15 million.
Unrestricted license	License won in so-called open bidding where all firms could participate. These licenses could be either ABDE or CF licenses.
Very small entrepreneur	Entrepreneur that also qualifies for bidding credits and installment payment plans. Very small entrepreneurs must have average annual gross revenues of less than $15 million.
Volume	MHzPop, i.e. the potential coverage of the license, calculated as the population of the license area multiplied by the quantity of the spectrum associated with a particular license.

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CHAPTER 1

Construction of Spectrum License Dataset

1.1 Introduction

This chapter documents the construction of a unique dataset tracking the evolution of the markets for spectrum and spectrum licenses in the US since early 1990s. In line with the title of the dissertation, the discussion below will focus on the market for a specific type of spectrum called Broadband Personal Communication Services (PCS) spectrum. However, same principles and logic apply to markets of other types of spectrum licenses used in the provision of commercial mobile wireless services.

1.2 Historical Background

Spectrum refers to the part of the electromagnetic spectrum corresponding to radio frequencies used to transmit information. These frequencies support a wide array of uses including astronomy, meteorological satellites, amateur radio, TV broadcasting, and other commercial services. There is only a limited supply of spectrum available for these uses though; the laws of physics dictate how much spectrum can be used, resulting in its fixed supply. Additionally, different uses can often cause radio interference, and in order to prevent these negative externalities a strict regulation is required. Most often, the latter takes the form of exclusive licensing[1].

[1]To keep things simple, I ignore the possibility of spectrum sharing (see e.g. Bazelon and McHenry [2014]) and of unlicensed spectrum (see e.g. Milgrom et al. [2011]).

A spectrum license gives its holder, i.e. the licensee, the exclusive right (but not the obligation) to use a certain range of frequencies in a certain well-defined geographic area. That is, each license grants the licensee the right to a maximum quantity of spectrum that licensee can use. In the US, the two agencies responsible for the regulation of spectrum are the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA).

Historically, spectrum licenses have been first awarded using comparative hearings ("beauty contests") and later lotteries. Recognizing the need for a superior way of allocating spectrum, FCC turned to an idea first proposed by Ronald Coase in 1959, who advocated price-based mechanisms (see Coase [1959]). In the early '90s FCC finally started auctioning licenses in spectrum auctions after the US Congress passed the Omnibus Budget Reconciliation Act in 1993. These spectrum auctions have in essence changed very little since then. For a general summary of the historical development of both the wired and the wireless telecommunications industry in the US, see Irwin and McConnaughey [2000], Corr [2000], Galambos and Abrahamson [2002], Murray et al. [2002], McConnaughey [2004], Crandall [2005], Sterling et al. [2005], McConnaughey [2008], and DeGraba and Rosston [2013].

A common feature of all commercial spectrum is that it has no substitutes. Together with its scarcity this makes it the key resource in the facilities-based mobile industry[2]. Firms that hold spectrum licenses, i.e. licensees, provide access to spectrum to mobile carriers, which use it as an input in the production of mobile wireless services. However, the market for spectrum represents just one of several upstream segments of the mobile wireless ecosystem; in order to provide wireless services, mobile carriers also need cell sites (towers), network equipment and access to backhaul (intermediate links connecting different wired networks). In the downstream (product) market mobile carriers then sell their services to their end users (see FCC [2013c]).

[2]This dissertation ignores mobile virtual network operators (MVNOs) that lease spectrum from facilities-based mobile carriers. For the analysis of MVNOs, see e.g. Kalmus and Wiethaus [2010].

This dissertation focuses on the frequencies used in the provision of commercial mobile wireless services, specifically on the frequencies in the 1900 MHz range. These frequencies are used by the Broadband Personal Communication Services (PCS) technology, lending its name to the 1900 MHz spectrum band[3]. The technology is sometimes also called the 3G technology as it superseded the inferior cellular, i.e. 2G technology. See Figure 1.1 for an illustration of all spectrum available in the US, and Figure 1.2 for a zoomed-in view of the PCS frequency band.

[3]I do not consider a similarly named (but substantively different) narrowband PCS spectrum in the 900 MHz range, which is used by the paging technology. Because of that I will refer to broadband PCS spectrum as simply PCS spectrum.

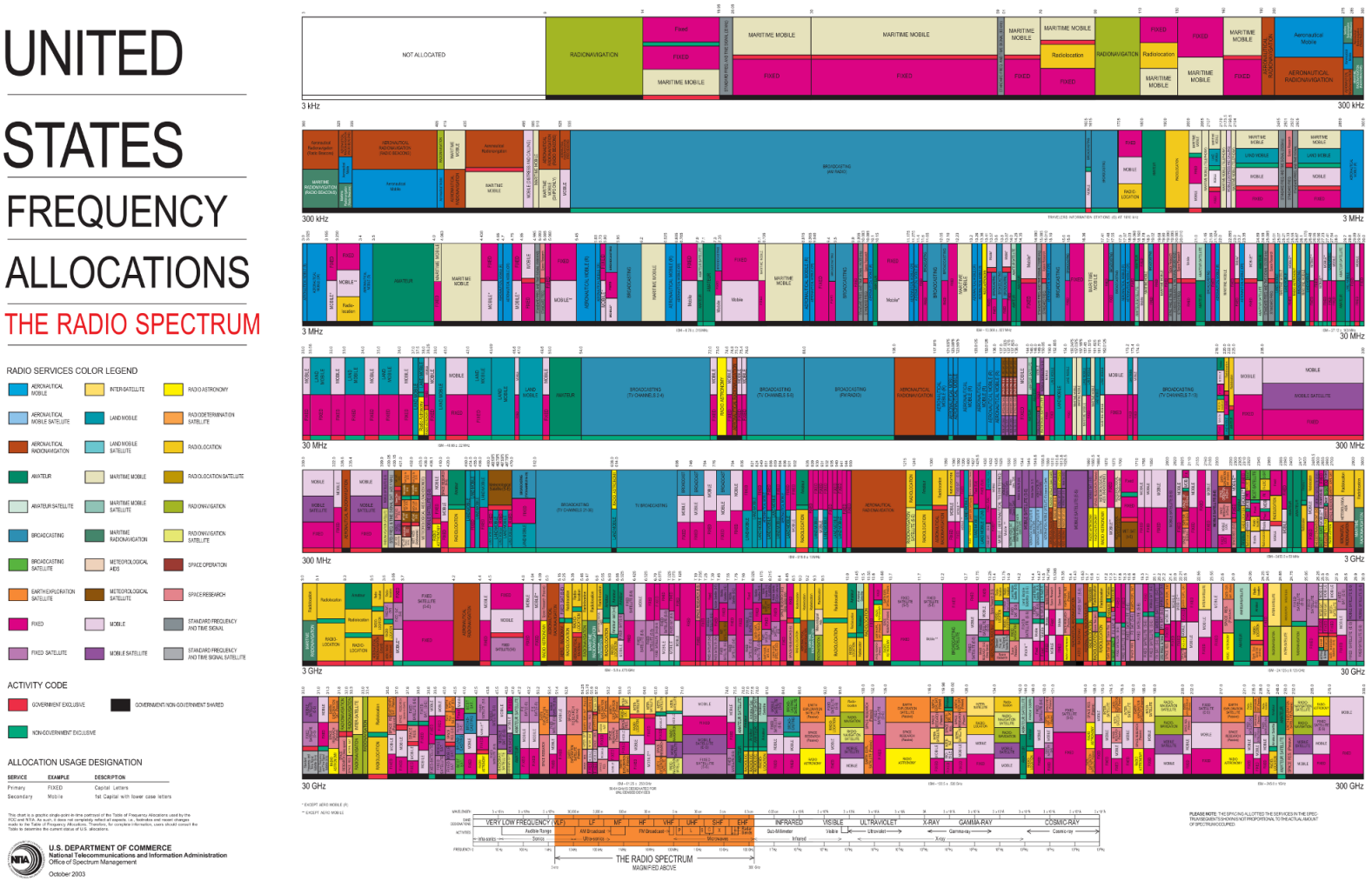

Figure 1.1: Spectrum available in US. [NTIA]

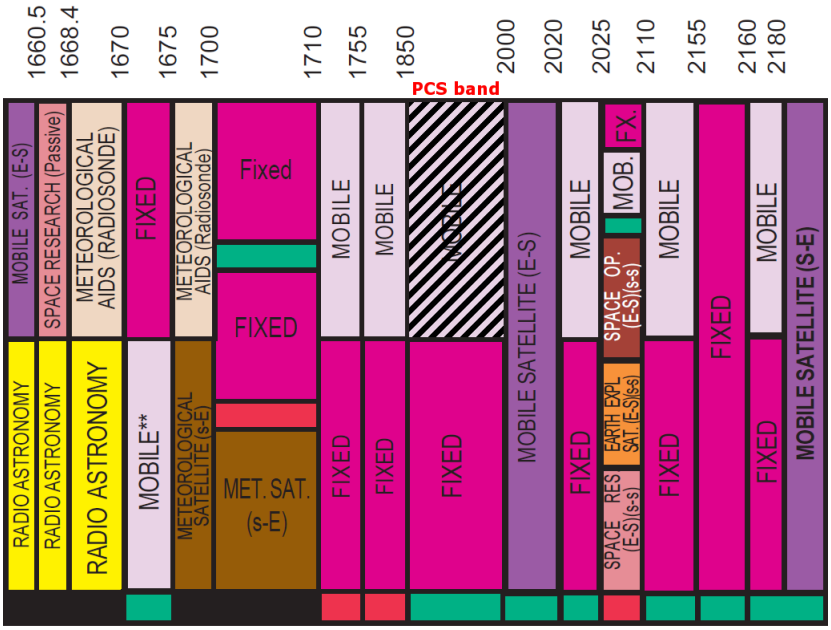

Figure 1.2: Zoomed-in view of the 1900 MHz band, i.e. PCS spectrum band (shaded area). [NTIA]

There are several other types (bands) of commercial spectrum that can be used for the provision of mobile wireless services. Ignoring the rather unconventional and outdated 800/900 MHz spectrum band, which has in the past been used predominantly by Nextel (later acquired by Sprint) for its voice-like iDEN ("push-to-talk") service, the other main spectrum bands used by mobile carriers so far have been the cellular (850 MHz), AWS-1 (1700/2100 MHz) and the 700 MHz ("LTE") bands[4]. However, there are also other bands that are suitable for commercial deployment but have yet to be used on a larger, i.e. nationwide scale (WCS band, BRS/EBS band, etc.). This includes the 600 MHz band, which will be auctioned in the upcoming reverse incentive auction in mid-2015.

With the exception of the cellular spectrum, which has been completely allocated even before spectrum auctions were used for the first time, all other spectrum licenses have been sold in spectrum auctions after the US Congress passed the Omnibus Budget Reconciliation Act

[4]Sprint is currently repurposing its 800/900 MHz spectrum, which it intends to use for its 4th generation mobile broadband network.

in 1993. Of all such auctions, auctions of PCS licenses have been the first and historically the most interesting ones. Instead of running just 3 PCS auctions, it took FCC more than 10 years and 9 auctions to allocate all PCS licenses. Additionally, each PCS auction had a slightly different set of rules, making them interesting from the economic (and the econometric) perspective.

A thorough analysis of PCS spectrum auctions is beyond the scope of this dissertation. However, the following section details some of the characteristics of PCS spectrum and the timeline of its auctions and other events, which are important for the subsequent construction of the spectrum license dataset. For another view of spectrum auctions, the interested reader should see Hazlett [1998] and Mobile Future [2013b]. Auctions for other types of commercial spectrum used in the provision of mobile wireless services are briefly summarized as well.

1.3 PCS Spectrum and the Timeline of PCS Spectrum Auctions

The PCS band was initially composed of 6 frequency blocks (A to F) totaling 120 MHz, which represented the total quantity of PCS spectrum available in each geographic area as shown in Figure 1.3. In 2005, a nationwide block of additional 10 MHz (block G) was added and given exclusively to Sprint in exchange for a part of its 800 MHz spectrum[5].

[5]Also, 10 MHz of additional nationwide PCS spectrum was offered in a recent spectrum auction in January 2014, in which all licenses that were auctioned off were won by Dish.

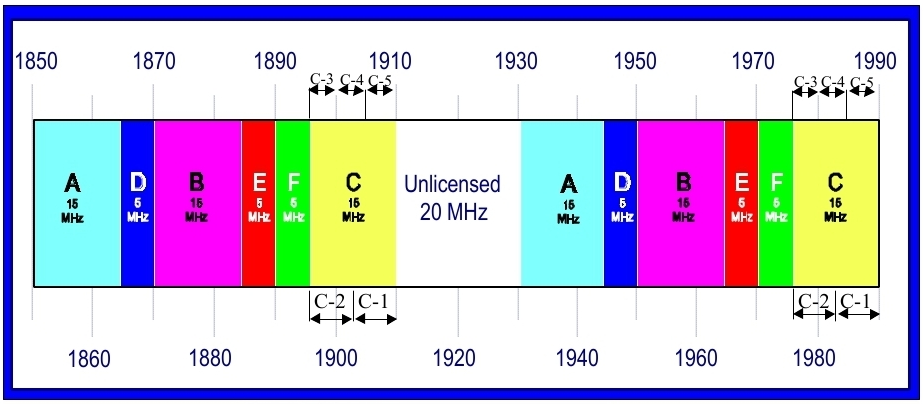

Figure 1.3: PCS band plan. Bands G and H are not pictured. [FCC]

All PCS auctions were simultaneous multi-round ascending auctions (see Goeree and Lien [2009a] for a theoretical model). In such an auction several items are auctioned at the same time and the bidders then bid on individual items. The auction ends when bidding on every single item stops. In the context of spectrum, these items were licenses covering specific geographic areas and specific frequency block, i.e. frequency ranges.

Initially, the geographic areas that licenses covered were defined in terms of Major Trading Areas (MTAs) and Basic Trading Areas (BTAs). These are different methodologies of aggregating individual counties and county-equivalents, e.g. parishes in Louisiana. There are 51 MTAs and 493 BTAs, with several BTAs making up one MTA. See Figures 1.4 and 1.5 for the maps of MTAs and BTAs.

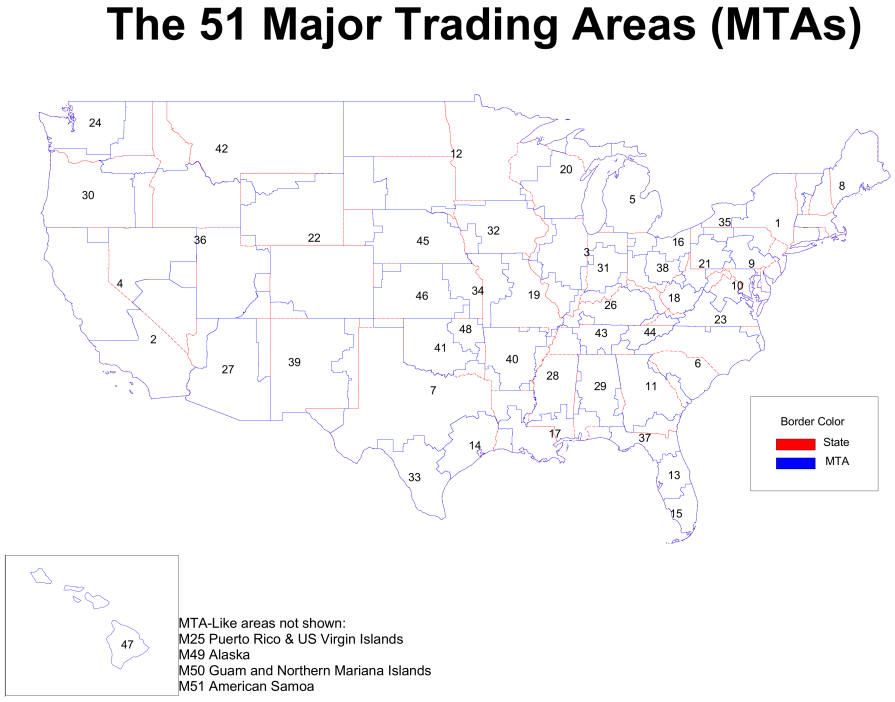

Figure 1.4: Major Trading Areas (MTAs). [FCC]

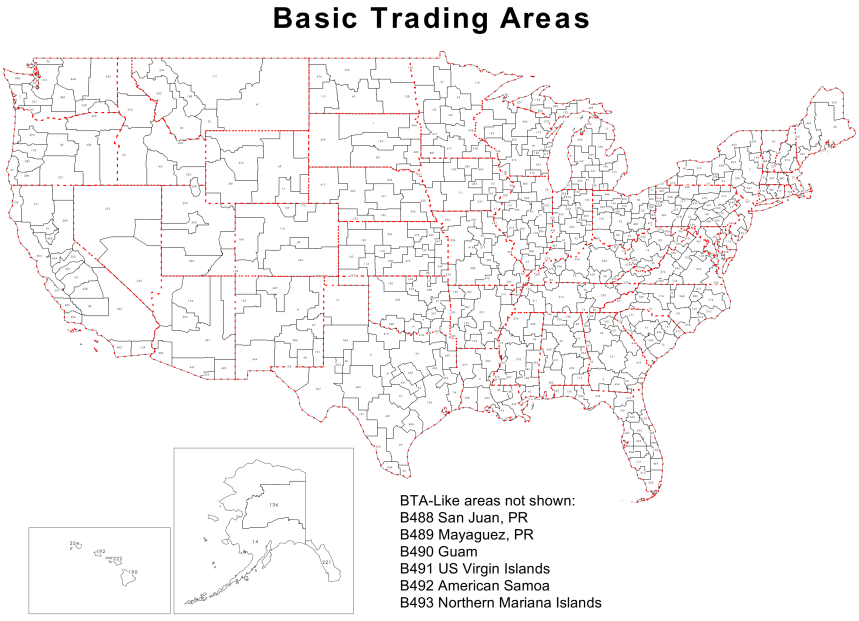

Figure 1.5: Basic Trading Areas (BTAs). [FCC]

FCC was planning to run a total of 3 PCS auctions, which should have been completed in 3 years. In these 3 auctions it wanted to allocate all 120 MHz of nationwide PCS spectrum (see Chakravorti et al. [1995]). However, as many licenses were later terminated by the FCC or returned by the licensees, FCC had to run 6 additional re-auctions to allocate the entire available quantity of PCS spectrum. Altogether, this process took more than 10 years.

1.3.1 Auction 4 – First Initial Auction

Beginning in 1994 and ending in 1995 FCC held its first initial auction for PCS spectrum (so-called Auction 4[6]), which marked the beginning of the market-based approach to licensing spectrum for mobile wireless services[7]. Prior to auctioning off PCS spectrum, cellular spectrum licenses were site-based, meaning they were tied to particular cell sites within each broadly-defined geographic area (such as BTA or MTA). With PCS auctions, FCC transitioned to a market-based approach, meaning that licensees could now use their spectrum in their entire respective geographic areas (and not only where they had cell sites that had to be registered with FCC).

In Auction 4, all firms that met the minimum eligibility requirements were eligible to bid. 2 licenses per MTA in A and B frequency blocks were awarded, with each license covering 30 MHz; therefore, a total of 60 MHz of spectrum was allocated in each market area. 3 licenses were allocated even before the auction started to firms participating in the Pioneer's Preference program. FCC offered no installment payment plans or bidding credits, and set no licenses aside for special groups of bidders. However, FCC did use the PCS/cellular cross-ownership restriction for bidders which already owned significant portions of the cellular spectrum. The would prohibited a cellular licensee from holding a broadband PCS license of more than 10 MHz if 10% or more of the PCS service area's population overlapped with

[6] http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 4$

[7] In Auctions 1 and 3 FCC sold narrowband PCS spectrum licenses meant for the paging service; in Auction 2 it sold IVDS (Interactive Video and Data Services) licenses. None of these two services can be considered a mobile wireless service in its true sense.

the cellular licensee's geographic service area.

The auction was considered a huge success although the winning bids have been lower than expected, a possible artifact of the cross-ownership restriction. Salant [1997] offers a first-hand perspective of Auction 4, in which he helped GTE (now Verizon) bid for PCS licenses.

1.3.2 Auction 5 – Second Initial Auction

In 1996 FCC concluded its second initial PCS auction (so-called Auction 5[8]). This time only firms that qualified as entrepreneurs were eligible to bid. The definition of an entrepreneur can be found in the Code of Federal Regulations of the United States of America (CFR):

> "No application is acceptable for filing and no license shall be granted to a winning bidder in closed bidding for frequency block C or frequency block F, unless the applicant, together with its affiliates and persons or entities that hold interests in the applicant and their affiliates, have had gross revenues of less than $125 million in each of the last two years and total assets of less than $500 million at the time the applicant's short-form application (Form 175) is filed." [47 CFR 24.709]

Additional 25% bidding credits were available those entrepreneurs that also qualified as small or very small businesses, as were generous 10-year installment payment plans with government-subsidized interest rates. Small and very small businesses are again defined in CFR:

> "(1) A small business is an entity that, together with its affiliates and persons or entities that hold interest in such entity and their affiliates, has average annual gross revenues that are not more than $40 million for the preceding three years. (2) A very small business is an entity that, together with its affiliates and persons

[8] http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 5$

or entities that hold interests in such entity and their affiliates, has average annual gross revenues that are not more than $15 million for the preceding three years." [47 CFR 24.720]

99% of all eligible bidders qualified for bidding credits and installment payment plans.

In Auction 5, FCC auctioned 1 license per BTA that authorized the winning bidder to 30 MHz in frequency block C. There was no overlap between bidders in Auction 4 and bidders in Auction 5except for Omnipoint, which was an entrepreneur but also one of the three licensees that received an A license under the Pioneer's Preference program. Together with licenses issued in Auction 4, the total quantity of spectrum available in each geographic area was now 90 MHz.

The financing terms offered by the FCC, especially the installment payment plans were very generous, which led many bidders to bid substantially more than what firms were bidding in Auction 4. By far the biggest winner, both in terms of the number of licenses and in terms of the volume of spectrum won was NextWave.

1.3.3 Auction 10 – First Re-auction

Shortly after Auction 5 was over FCC held its first initially unplanned re-auction (so-called Auction 10[9]). It re-auctioned 18 C block licenses, which have been terminated after the respective winning bidders from Auction 5 did not provide the required down-payment. No A or B block licenses from Auction 4 were re-auctioned. Since only C block licenses were offered in Auction 10, only entrepreneurs were qualified to bid on them. Also, same rules on bidding credits and installment payment plans as in Auction 5 applied. NextWave again won a substantial share of available licenses.

[9] http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 10$

1.3.4 Auction 11 – Third Initial Auction

In 1997 FCC concluded its third initial and what should have been the final auction for PCS spectrum licenses (so-called Auction 11[10]). 3 licenses of 10 MHz each in the remaining 3 frequency blocks (D, E & F) were sold in each BTA. These additional 30 MHz together with 90 MHz auctioned before Auction 11 meant all 120 MHz of PCS spectrum in each geographic area were allocated. Bidding on D and E block licenses was open to all bidders; however, only entrepreneurs were eligible to bid on F block licenses. As such, this was the first auction to feature parallel bidding of bidders with different bidding eligibilities.

FCC offered two types of bidding credits for qualified entrepreneurs bidding on F block licenses: those that qualified as small businesses received a 15% bidding credit, whereas those that qualified as very small businesses received a 25% bidding credit.

Bidder participation in Auction 11 was below expectations partly because of aggressive and speculative bidding in Auction 5. However, NextWave was again one of the most important bidders: at the end of Auction 11 it had close to the maximum number of licenses reserved for entrepreneurs (as determined by FCC). Not only did it own more than 35% of the spectrum reserved for entrepreneurs, its spectrum portfolio also gave it what was effectively a nationwide footprint.

1.3.5 C Block Election

Soon after Auctions 5 and 10 it became apparent that many entrepreneurs overbid for their C block spectrum licenses. They took advantage of installment payment plans offered by the government hoping that they will be able to secure additional financing before payments will be due. However, many faced difficulties in obtaining additional capital and consequently defaulted on their payments. This problem was so widespread and systemic that FCC of-

[10] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary\&id = 11$

fered to these C block licensees the so-called "C block election" (see e.g. CBO [2005]); to resolve their financial problems, licensees were offered several possible alternative possibilities of keeping, splitting and/or returning their licenses. Many chose to return their licenses to FCC causing a de facto exodus of entrepreneurs from the PCS spectrum market in mid-1998. Many licensees also chose to have the bandwidth of their licenses, that is the quantity of spectrum associated with their licenses, split in half. Quantity-wise, they kept one half of each license and returned the other half to FCC; they retained their geographic presence but were now only authorized to use 15 MHz of C block spectrum (instead of 30 MHz).

NextWave, after defaulting on a $500 million down payment (out of almost $5 billion it owed to the government) was one of those companies whose licenses were terminated by FCC. Instead of complying it sued FCC in court saying bankruptcy law should prevail over the telecommunications law. Simply put, NextWave argued that FCC should be treated like all its other creditors and that NextWave's spectrum licenses should be treated like all other assets in its bankruptcy proceeding (see Kurtin [2003]).

1.3.6 Auction 22 – Second Re-auction

After more than 55% of C block licenses were terminated (this does not include NextWave's licenses as its lawsuit was still pending at the time), the associated spectrum had to be a allocated again. FCC held its second re-auction in 1999 (so-called Auction 22[11]), offering C block licenses in both 30 and 15 MHz configurations, and a few E and F block licenses. 15 MHz C block licenses were the result of halving the quantity of spectrum associated with licenses in certain market areas due to the C block election.

Only entrepreneurs were eligible for licenses in C and F blocks. Realizing that installment payment plans introduced anomalous financial incentives, FCC decided against offering them again. Bidders that qualified as entrepreneurs in either Auction 5 or 10 automatically qual-

[11] http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 22$

ified as entrepreneurs in Auction 22. Somewhat surprisingly many licenses, especially 30 MHz C block licenses remained unsold.

1.3.7 Auction 35 – Third Re-auction

As NextWave's legal battle with FCC dragged on, the latter decided to terminate NextWave's licenses and to re-auction them. The third re-auction was concluded in 2001 (so-called Auction 35[12]). Realizing that the reason so many 30 MHz licenses remained unsold in Auction 22 was that entrepreneurs did not desire that much spectrum, FCC reconfigured each 30 MHz C block license into three 10 MHz licenses.

This time the eligibility criteria for some C block licenses were modified; some of the licenses that were before reserved for entrepreneurs only and that remained unsold in Auction 22 became available to all bidders. In contrast with previous auctions, bidding credits were offered to firms bidding on licenses that were not specifically reserved for entrepreneurs as long as they met the size criteria. This was a departure from FCC's previous policy of awarding bidding credits to bidders bidding on reserved licenses only.

1.3.8 FCC v. NextWave

In 2003 the Supreme Court decided the NextWave case in its favor leading to its settlement with FCC (see Kurtin [2003]). As part of the settlement NextWave returned several of its licenses, which have since greatly appreciated in value, to FCC as the payment for its debt. Because of this, FCC had to cancel the majority of Auction 35 licenses, meaning that less than 40% of licenses sold in Auction 35 were eventually issued to winning bidders. NextWave kept the remaining licenses. In 2004 it then reached another agreement with FCC and returned several more (but not all) of its licenses.

[12] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary\&id = 35$

1.3.9 Spectrum Aggregation Cap & Spectrum Screen

Starting in 2001 FCC introduced important changes to its Commercial Mobile Radio Services (CMRS) spectrum aggregation cap. Before 2001, licensees could only own 45 MHz of combined 800/900 MHz, cellular and PCS spectrum in each geographic market, acquired either in the auction or in the secondary market for spectrum. FCC raised the cap to 55 MHz in late 2001 and then abolished it completely in 2003, preferring to resort to the case-by-case analysis of spectrum transactions instead. This case-by-case approach uses a two-part procedure to identify geographic areas that require further competitive analysis; the first part is based on the post-transaction Herfindahl-Hirschman Index[13]), and the second part is based on the so-called "spectrum screen", which was first set at 70 MHz (as part of the Cingular-AT&T Wireless transaction in 2004) and later increased to 95 MHz (as part of the AT&T-Dobson transaction in 2007). These values correspond to roughly one third of all available commercial spectrum used in the provision of mobile wireless services.

1.3.10 Auctions 58, 71 & 78 – Fourth, Fifth and Sixth Re-auctions

In 2005, 10 years after the first initial auction FCC held its fourth re-auction (so-called Auction 58[14]), which marked the first time an A or B block license made its way back to the auction. These licenses were never terminated and confiscated; they simply expired. At the same time, FCC also auctioned licenses covering parts of BTAs for the first time. So-called Auctions 71[15] and 78[16] followed in 2007 and 2008, respectively.

[13]Herfindahl-Hirschman Index (HHI) is defined as the sum of squared market shares (multiplied by 10,000).

[14]http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 58$

[15]http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 71$

[16]http://wireless.fcc.gov/auctions/default.htm?job=auction$_s ummary\&id = 78$

1.3.11 Rebanding of Sprint's 800 MHz Spectrum

In 2005, FCC awarded 10 MHz of at-the-time unlicensed nationwide spectrum near the existing PCS band to Sprint (at the time known as Sprint Nextel) in exchange for its spectrum holdings in the 800 MHz band. Its iDEN ("push-to-talk") service in that band caused radio interference and public safety concerns made FCC push for the so-called rebanding of Sprint's spectrum. As these additional 10 MHz weren't acquired in a spectrum auction and/or in the secondary market but were instead the result of an administrative decision (even though Sprint had to pay for the costs of relocating other users), I ignore these G block licenses in my subsequent analysis.

1.4 Timeline of other auctions for commercial spectrum

Cellular technology is the predecessor of the PCS technology and even though the market for PCS was designed to attract new entrants, most current major mobile wireless service providers (and at the same time PCS licensees) can trace their roots back to the telecommunications companies that received cellular licenses in the early '80s. A notable exception to this is T-Mobile, which has almost no cellular spectrum. However, all cellular spectrum licenses have been allocated before spectrum auctions were implemented except for three cellular licenses sold in the so-called Auction 45[17].

The 700 MHz spectrum was first auctioned in 2003 (so-called Auctions 44[18] and 49[19]), but has not attracted the attention of major PCS licensees until sometime before Auction 73 in 2008, which was more than 10 years after the close of the third initial PCS auction. FCC

[17] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary$&$id = 45$

[18] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary$&$id = 44$

[19] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary$&$id = 49$

also ran two spectrum auctions (so-called Auctions 33[20] and 38[21]) for the so-called 700 MHz guard band licenses, however as these are not suitable for the provision of mobile wireless services, I ignore them in my analysis. AWS-1 spectrum (so-called Auctions 66 and 78) was first auctioned off in 2006.

1.5 Construction of Spectrum License Dataset

I collected comprehensive data starting in 1990 that span all five spectrum bands which were at some point used to provide mobile wireless services to end users (cellular, 700 MHz, 800/900 MHz, broadband PCS, AWS-1). The discussion below will focus specifically on PCS spectrum licenses and markets, but the same approach was used to collect data on other bands as well.

1.5.1 Spectrum Auctions Data

Except for the G block licenses that Sprint got in exchange for its 800 MHz SMR spectrum, all other PCS licenses were initially allocated via spectrum auctions. I used official FCC data found online[22]. These data had to be complemented with information from various Public Notices published before and after each auction as FCC does not offer a single unified source of data on eligible bidders, winning bidders, markets and licenses. Additional information was found in Forms 175 submitted by qualified bidders before each auction[23].

[20] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary$&$id = 33$

[21] http://wireless.fcc.gov/auctions/default.htm?job=auction$_summary$&$id = 38$

[22] http://wireless.fcc.gov/auctions

[23] https://auctionfiling.fcc.gov/form175/search175/index.htm

1.5.2 Spectrum Market Data

Once the winning bidder wins a particular license in a spectrum auction, it files an application for a new license. It officially becomes a licensee when the application is granted, at which time FCC gives the license a unique call sign. This is the point in time at which the license officially begins to exist (and can be traded in the secondary market). This information on matching the auction-specific names of licenses to their corresponding market-specific call signs was often missing, so I manually matched them using FCC's ULS License Archive database[24].

ULS is an online filing system that licensees and FCC use to enter information related to each license and that comprises multiple databases; in principle data should be available for all licenses, however pre-2000's data is often unreliable and had to be manually compared with FCC's digitized documents (if available). The archives used for matching auction-specific names to market-specific call signs are not available in a downloadable form and can only be accessed one entry at a time (contrary to the current version of ULS License database[25]). To get around this restriction, I scraped all information pertaining to licenses I was interested in. Matching was then based on the characteristics of licenses (frequency block, market area, quantity of spectrum) to prevent potential disaggregation or partitioning (see below). The date of entry of each license in the PCS market is based on the official grant date found in the scraped data.

ULS License Archive database does not record potential ownership changes of licensees nor does it keep track of partial sales of the licenses. Further, it may trigger a false alarm if every change in the licensee's name is to be interpreted as the sale of the license. As such, it cannot be used to track the evolution of licenses over time. Because of this I used

[24]http://wireless2.fcc.gov/UlsApp/LicArchive/searchArchive.jsp

[25]http://wireless2.fcc.gov/UlsApp/UlsSearch/searchAdvanced.jsp

ULS Applications database[26], which contains information on all applications related to each individual call sign. The most important applications are those that deal with substantial changes in licenses including license transactions, license leases and license exits.

To reconstruct the individual history of each license, I focused first and foremost on non-pro forma "Assignment of Authorization" (AA) and non-pro forma "Transfer of Control" (TC) applications. The former are filed with FCC in case of a complete or partial sale of the license due to partitioning or disaggregation. TC applications are used whenever there is a change in the ownership structure of the licensee (e.g. a merger); partitioning and disaggregation are not possible with TC applications.

I complemented this with information found in pro forma AA applications where part of the license was partitioned or disaggregated. Even though the pro forma nature of the license means the controlling entity of the newly-issued license stayed the same, the fact that the derivative license suddenly got its own call sign meant that the two licenses could go their separate ways anytime.

The information found in AA applications allows me to reconstruct how each license was traded among licensees and/or if and how it was split and partially sold; in the latter case I can use both ULS databases to determine the call sign of the newly-issued derivative license, meaning I can also reconstruct its history. Adding the information from TC applications helps me identify changes in the licensee ownership structure. The relevant dates are the dates FCC consented to AA & TC applications and not the consummation dates; however if the transaction is consented to but never consummated I ignore it. For applications which FCC only needs to grant or accept, I use the date of acceptance or the grant date. I also collect data on voluntary cancellations of licenses, notifications of construction, etc. All in all, combining both ULS databases I can trace the path of each license over time[27].

[26] http://wireless2.fcc.gov/UlsApp/ApplicationSearch/searchAdvanced.jsp

[27] In general ULS data can be very unreliable. Many times the call signs of derivative licenses were missing or were incorrect, or there was no indication of partitioning/disaggregation at all. To correct for this, I

1.5.2.1 Spectrum Leasing

Even though spectrum leasing was instituted in 2003 FCC did not have an efficient online filing system for spectrum leasing applications until 2006 when its interim Form 603-T was replaced by Form 608. Because of this, comprehensive data for years 2003 and 2004 that contains both the names of the lessor and the lessee together with exact geographic determination of the leasing agreement and the quantity of the associated spectrum do not exist[28]. Such data is available only from year 2005 onward.

I removed all short-term leases that can last up to a year, but are usually far shorter. I also removed all those long-term leases where the controlling entity changed over the course of the lease, and both the old and the new entity exercised control over the lessee for less than a year[29]. This basically means that such long-term leases were identical to short-term leases. Further, I removed all pro forma leases where the lessor and the lessee were both controlled by the same controlling entity, i.e. parent company.

1.5.3 Corporate Structure and Licensee Ownership Data

To identify controlling entities I cannot use any of the two ULS databases as they include no unique identifiers for firms that would be used consistently over time. Most notably, they do not consistently use FCC Registration Number (FRN) scheme, i.e. Commission Registration System ID (CORESID) assigned to each firm. The same company can have

identified all changes in geographic coverage and quantities of the associated spectrum of each license over time that were not documented, then looked for undocumented derivative call signs in the documentation enclosed with each application or used geographic search to comb through all licenses in that area that fit the characteristics of spectrum missing from the first license. If I had not done that spectrum in some counties would amount to less than 120 MHz (even after accounting for spectrum held by FCC). Entries for cellular licenses and associated applications are especially prone to the missing data problem. One can search for official Public Notices (which contain more information or simply make more sense) online, however only those from 1997 onwards are systematically available.

[28]Technically they exist, but only in the form of barely legible PDF documents.

[29]This is a lease-equivalent of the TC application; there is no lease-equivalent of the AA application. Also, this removed only a handful of leases.

two different FRNs according to FCC; unfortunately, there are also many instances of completely different companies using the same FRN. Also, FRNs have not been used before 2001 leading to problems with firms that left the market before that date. LicenseID, a supposedly unique identifier for actual licensees, also suffers from the same non-uniqueness problem.

Instead, I use the TC applications as my guideline and complement them with data coming from other sources. I define the controlling entity as any company that wholly owns the licensee or has a majority voting interest in it. A majority economic interest is not considered ownership under this definition; this would have eradicated many entrepreneurs that were just fronts for large companies. I define majority voting interest as anything above 50%. Partnerships or joint ventures where two parties have a 50% interest each are considered independent licensees, with the only exception being Cingular (a joint venture between SBC Communications and BellSouth). If ownership and control are tiered, the controlling entity is the ultimate parent company. This is broadly consistent with FCC's own informal "Common Name" category used in its Spectrum Dashboard online application:

> "For purposes of the Spectrum Dashboard, Common Name is defined as an entity that: (1) wholly owns or has majority interest in the license; (2) is the general partner of the limited partnership or manager of an LLC that holds the license; or (3) is the name under which the service being provided via the license is marketed to the public." (FCC Spectrum Dashboard [2013])

I do not automatically consider a general partner or a manager to be the controlling entity unless it has a majority voting interest in the licensee. I also don't consider brand names as defining the ownership and control; especially in the early years of the mobile wireless industry there were several instances of independent licensees offering services under a common brand name[30]. The biggest drawback of the Common Name category is that it is only

[30]In the late 90's Sprint had 12 affiliates which were independent companies operating under the same brand. Over time most of them were acquired by Sprint.

available for current licensees; no historical data are available.

Instead I use the Ownership Disclosure Information database, which is also part of ULS. Information contained in this database is submitted by firms with certain applications informing FCC of the ownership structure of applicants. Companies are classified into four groups: "Filers", "Disclosable Interest Holders (DIHs)" (which hold a certain interest in filers), "FCC Regulated Businesses" (in which filers hold a certain interest) and "FCC Regulated Businesses of DIHs". Using this intertwined and frequently tiered ownership and corporate structure information I can identify many seemingly unrelated licensees. Unfortunately these data suffer from the same problems as other ULS databases; the dates are often unreliable, making it hard to determine who owned whom at each point in time. Also, the coverage starts only in 1999 when many licensees have already left the market.

Many licensees were privately-owned companies or partnerships for which accurate historical high-frequency ownership data were impossible to find outside of ULS. Because of this I annualized my entire data set; spectrum portfolios, license characteristics and most importantly ownership data are thus observed on March 1st of every year. I chose this date for two reasons:

1. "American Corporate Families", "D&B's Who Owns Whom" and "LexisNexis Corporate Affiliations" print directories, which I used extensively, are generally updated before March (and then published in June of that year).

2. 10-K reports (including Exhibit 21 which lists all subsidiaries) of publicly-listed companies are typically filed around March and can be easily found via SEC's EDGAR system.

I also searched for all M&A's in US from 1990 to present in the in SDC Platinum database [31] and used the 2006 edition of the Wireless Travel Guide. Additionally, I re-digitized almost

[31] My search was restricted to the "Radiotelephone communications" industry (SIC code 4812) and "Telephone communications, except radiotelephone" industry (SIC code 4813).

200,000 attachments enclosed with AA and TC applications, many of which were initially not searchable. Using all these additional sources I was then able to supplement, verify and correct the information found in the Ownership Disclosure Information database and in actual attachments describing specific AA or TC applications.

1.5.4 Geographic Data

With licensees being able to partition and disaggregate their licenses, relevant geographic markets for each specific band are no longer defined at the level of various county aggregations. This meant that I first had to deconstruct the original license areas into individual counties covered by the same license. As MTAs and BTAs are based on a proprietary delineation, which has been further modified by FCC, I followed FCC's published standard of deconstructing market areas, which is in turn based on the 2000 US Census county division[32]. FCC never published the 2010 equivalent of that standard and for the sake of consistency I did not modify the old one. After conversion I had 3234 counties, and removing additional 125 counties left me with 3109 counties and county-equivalents covering the entire continental US[33].

I added a spatial dimension to my data set by introducing the notion of distance between counties. I used the 2010 US Census' "County Adjacency File" which I had to modify to suit the 2000 county division by reversing the changes in counties. This allowed me to map every county to its adjacent counties; using Dijkstra's shortest path algorithm I then generated a matrix of distances between any two counties. While an admittedly crude and imperfect measure of true geographic distance given the highly asymmetric size of some of the counties, this can nonetheless capture the closeness of geographic markets, especially since a license

[32]BEA uses a different definition of counties in Virginia; to correct for this and convert its definitions to the ones used by US Census, I used the conversion table found here: http://www.economy.com/support/blog/buffet.aspx?did=869A03D1-5D74-4376-A606-00A8C64DDB0B.

[33]This loss of 125 counties does not affect any of the retained licenses; in other words, no PCS license was partially removed and partially retained.

allows the use of associated frequencies everywhere within the county.

To model the market area of cellular licenses, which are licensed on a site-based approach where the licensee cannot automatically operate in the entire CMA, but is limited to the area where its registered cell towers and cell sites are located, I collected data on more than 100,000 cell sites and cell towers for which licensees had FCC's permission to operate. These data can be found in ULS License Archive, and indicate how licensees were shifting their cellular coverage over time. I then use the coordinates of these sites and reverse geocode them so that I can map them to their respective counties. I assume every county in which a cell tower is located is fully covered.

1.5.5 Other Sources of Data

Spectrum licenses authorize the licensee to some capacity level. This does not necessarily mean that all of this capacity will be actually put to productive use, however. It is conceivable that some licensees purchase spectrum in order to prevent others from purchasing it even though they have no need for it. Some spectrum transactions could then be seen as motivated by foreclosure motives rather than by pure efficiency motives, especially if the purchased spectrum is not utilized productively. Some claim that such hoarding behavior has actually been the standard practice of some of the biggest vertically integrated PCS licensees in the past.

To investigate such hypotheses and to evaluate motives for spectrum purchases, one would require detailed and comprehensive data tracking the actual utilization of spectrum. Unfortunately such data does not exist. In fact, the need for such data set has also been recognized by the Obama Administration, which in its 2010 National Broadband Plan called for an comprehensive annual assessment of spectrum utilization, results of which should be made available to the public. These data are yet to be collected.

A reasonable approximation to data on spectrum utilization could be demand-side data from the downstream market. Downstream quantities, i.e. market shares of subscribers, could be seen as proxies for the actual quantities of spectrum supplied by the upstream market. However, these data seem to be a very closely guarded secret and getting them is almost impossible. When they exist, they have been collected by telecommunications intelligence companies and as several industry analysts pointed out they are never available in highly geographically disaggregated form, but are instead aggregated at the regional or national level. Since I observe a lot of variation in my license data at the level of individual counties, such aggregates would not be particularly useful.

Notable exceptions to this general lack of geographically disaggregated data are the Appendix to the DOJ's complaint in the "US v. AT&T Inc., T-Mobile USA, Inc. and Deutsche Telekom AG" case[34] and an excerpt from a supposedly confidential industry report published in a public internet forum[35]. Besides, these firms track just major mobile wireless service providers and completely ignore the smaller ones (somewhat of an exception in this regard is the confidential "Bank of America/Merrill Lynch Global Wireless Matrix").

To make matters worse, there exists no authoritative list of mobile wireless service providers operating in US; even FCC relies on data collected by others. For example, in its most recent 16th Competition Report published in March 2013, FCC states the following: "Based on Mosaik[36] data, we estimate that there were approximately 95 smaller, facilities-based providers in the continental United States, Alaska, and Hawaii as of October 2012." Identifying all current and past smaller providers (and potentially matching them with licensees in the spectrum market) is therefore basically impossible, especially since many of them were

[34]http://www.justice.gov/atr/cases/f274600/274613.pdf (DOJ declined to comment on the source of its data).

[35]http://www.howardforums.com/showthread.php/1766584

[36]Mosaik (formerly American Roamer) collects telecommunications business intelligence.

privately-owned. Even sources like RCR Wireless[37] and FCC's own annual Mobile Wireless Competition Report (previously called Commercial Mobile Radio Services (CMRS) Competition Report) list only the biggest providers.

Another crude, yet reasonable approximation to estimating market shares of mobile carriers would be to inspect their presence in local markets. Unfortunately, neither data on coverage nor data on the allocation of mobile phone numbers can be used. The former is collected by a telecommunications intelligence company Mosaik, but is based on self-reported data published by wireless mobile providers and is not verified by a 3rd party; plus, roaming coverage might be included in providers' reports. The data on the allocation of mobile phone numbers is based on biannual Numbering Resource Utilization and Forecast (NRUF) reports filed by providers; however these reports are confidential and the portability of mobile phone numbers represents an additionally confounding factor. Also, time coverage of both sources might be problematic.

[37]For example, http://www.rcrwireless.com/assets/Assets/pdf/CR12812221.PDF.

CHAPTER 2

Do Secondary Markets Undo Auctions? Long-Run Effects of Eligibility Restrictions on the Structure of the Market for Broadband PCS Spectrum

2.1 Introduction

Spectrum, sometimes also called the "lifeblood of mobile communications", is the range of electromagnetic radio frequencies used to wirelessly transmit information. The laws of physics dictate how much of these invisible airwaves can be used. With the aggregate amount of spectrum fixed and the demand for mobile broadband skyrocketing, the Federal Communications Commission (FCC) plans to run the world's first incentive auction in mid-2015, repurposing the broadcast TV spectrum and selling it to mobile wireless service providers (FCC [2013a], Deloitte [2012], Kwerel et al. [2012]). The desirable properties and scarce nature of these airwaves, however, mean that both incumbents and potential new entrants will be interested in them. This has prompted the Department of Justice (DOJ) to recommend to the FCC to consider designing the incentive auction in favor of smaller bidders by placing limits on how much spectrum the two providers with the largest spectrum portfolios, Verizon Wireless and AT&T, could acquire (DOJ [2013]).

There is an extensive literature on the effects of such auction restrictions offering preferential treatment to small and disadvantaged firms (e.g. Ayres and Cramton [1996], Crandall and Ingraham [2007], Hazlett and Boliek [1999], Dippon [2009], Cramton et al. [2011], and Hyndmany and Parmeter [2013]; also, **?**). Recently, there has also been a surge in the number

of studies analyzing DOJ's proposal[1]. The vast majority of the literature investigates the effects of such restrictions on participation, auction competition, and the outcomes immediately following the auction together with the revenues the Treasury will collect. However, there appears to be no consensus on the effects of these restrictions, with many studies often reaching markedly different conclusions.

In contrast to the existing literature that concentrates on the short-run effects of auction restrictions, I believe the focus of the discussion of the interactions between auction design and competition policy should shift to the long-run market outcomes generated in the secondary markets. Only so can we fully understand the extent to which auction restrictions affect the evolution of the market and its structure.

Theoretical research on the interactions between auctions and secondary markets is abundant; many theoretical papers explore the two-way interactions between auctions and secondary markets, endogenizing one or the other. In the first group are papers modeling how auctions respond to the presence of secondary markets, for example Haile ([1999], [2001] and [2003]), Hafalir and Krishna [2008], Jehiel and Moldovanu [2000], Campos e Cunha and Santos [1995], Zheng [2002], and Zhong [2005]. In the second group are papers studying the effects that auctions have on secondary markets and their market structure, for example Hoppe et al. [2006], Gebhardt and Wambach [2008], Haan and Toolsema [2011], Dana and Spier [1994], and Rodriguez [2002]. On the other hand, there appear to be no empirical studies exploring the long-run outcomes; CBO [2005] is somewhat of an exception. One reason for this is the lack of reliable data (GAO [2010]).

This chapter fills this void by investigating the effects of auction restrictions similar to the

[1]Marx [2013], Balto and Singer [2013], Mobile Future [2013a], Shapiro et al. [2013], Earle and Sosa [2013], Ford [2013] and Campbell [2013] oppose restrictions; Baker [2013] and Besen et al. [2013] provide evidence for using them. Che and Haile [2013] do not directly address auction restrictions; instead their focus is on another modification of the bidding procedure proposed by T-Mobile.

ones proposed by the DOJ on the evolution of post-auction competition in the market for broadband Personal Communications Services (PCS) spectrum. To the best of my knowledge, this is the first study to empirically analyze such interactions between auction design and competition policy, and their effects on the market structure in the long run. My analysis is based on the first comprehensive data set of spectrum holdings of firms created using data mining techniques and spanning almost 20 years. I am aware of only two studies that have used similar data (CBO [2005], Bazelon and Zarakas [2009]), however this study is the first to combine these data with additional sources to track spectrum holdings over time.

The Omnibus Budget Reconciliation Act of 1993 that authorized the FCC to allocate PCS spectrum using auctions required not only that these auctions maximize efficiency and revenues collected, but that they also foster competition and provide an equal opportunity for entrepreneurs to participate in the market for spectrum. To achieve this goal, FCC used eligibility restrictions ("set-asides"), reserving one third of the entire market for entrepreneurs to protect them from large companies, and in turn created two separate parallel markets for PCS spectrum. Bidding credits and installment payment plans were also used.

I first document the outcomes in the market for PCS spectrum by investigating the parallel evolution of the markets for restricted and unrestricted licenses. The initially restricted market started opening up relatively quickly to large companies, which used to dominate the market for licenses with no restrictions. Both markets experienced a significant increase in market concentration over time. In 2012, the biggest four firms, none of which started off as an entrepreneur, controlled 94% of the market for unrestricted licenses and 75% of the market for restricted licenses. The recent takeovers of the last two major remaining entrepreneurs, MetroPCS and Leap Wireless, which in 2012 still held a significant combined share of the restricted market, can be seen as a continuation of this trend of market concentration. Further, my data show the growing asymmetry in the distribution of firm sizes. The four biggest firms are growing at the expense of the medium-sized firms, which are disappearing from both markets. Finally, I provide evidence that eligibility restrictions attracted

many firms that were either not capable or not willing to stay in the market; entrepreneurs that never won any licenses in auctions where all firms were allowed to participate have the lowest probability of survival.

In addition to documenting these outcomes, I also provide the first empirical analysis of the effects of preferential treatment provisions on the observed patterns of firms' trades of spectrum licenses. The existing empirical literature on PCS auctions (e.g. Cramton [2006]) suggests that there was little market activity, that is resale of licenses immediately following the auctions. In contrast, I show that in the first two years following each auction almost a third of all licenses have been sold either in full or in part. The discrepancy with former studies is the result of the detailed nature of my data, which allow me to track the effects of spectrum transactions on licenses at the individual county level.

In order to understand what drives some firms to sell their licenses immediately following the auction and whether such behavior can be attributed to eligibility restrictions and to other types of preferential treatment, I model the decision to sell the license (or its part) using a state-dependent probit model with license, licensee and auction characteristics as explanatory variables. The results show that entrepreneurs are significantly more likely to sell their licenses in the first two years; also, holding everything else fixed the probability of a sale is higher for restricted licenses, especially if bidding credits were used. Entrepreneurs that won at least one license in an auction with no preferential treatment are less likely to sell their licenses and thereby hold onto them longer.

To explain the relatively quick transition of the initially restricted licenses from entrepreneurs to large companies, and therefore the entry of the latter in the market initially reserved only for the entrepreneurs, I exploit the institutional design of eligibility restrictions. To insulate entrepreneurs from large companies and to prevent arbitrage, FCC did not allow the sale of restricted licenses to large companies unless the construction requirements have been met. All licenses had to be built out in 5 years after they were granted, generally giving the

licensees no incentive to meet the requirements ahead of time given the significant cost of build-out. However, faced with the high demand for unrestricted spectrum (e.g. Wallsten [2013]) entrepreneurs had an incentive to meet the requirements early and profit by selling their licenses to large companies. The data confirms there are considerable differences in the build-out behavior of both types.

The econometric analysis of the build-out patterns is based on the behavior of each licensee, modeled as a sequence of contingent decisions over time. In every period, the licensee can decide to construct the license given that it has not yet done so; if it constructs the license, it can keep it or sell it; and if decides to sell it, it can choose who it will sell it to. These conditional choices are estimated using a sequence of probit models. To allow for sample selection bias, I test additional specifications using bivariate probits with potentially non-zero correlation in the binormal distribution of errors. The results show a consistent pattern of entrepreneurs building out their restricted licenses early only to immediately sell these licenses to large companies. Sample selection tests indicate a statistically significant correlation between decisions.

Overall, the evidence suggests the eligibility restrictions have not achieved their long-run goal in terms of the desired market structure (I ignore the potential adverse effects on revenues collected and on social welfare due to the historically poor utilization of these licenses; see e.g. CBO [2005]). This is even more evident in light of the recent takeovers of MetroPCS and Leap Wireless. Furthermore, market activity immediately following each PCS auction was in part driven by preferential treatment offered to entrepreneurs. In fact, the specific design of the eligibility restrictions has introduced opportunistic financial motives for these firms: many of them found it more profitable to quickly sell their initially restricted licenses to large companies than to enjoy the legal protection these licenses offered.

In general, it seems that the current focus of the competition policy on the design of the upcoming 600 MHz incentive auction might be overstated. The evidence from the evolu-

tion of the market for PCS spectrum shows that eligibility restrictions no doubt distort the short-run auction outcomes (and revenues collected), but it appears that in the long-run market outcomes are not affected. As such, this long-run result is similar to the famous Coase theorem, even though significant transaction costs are present in this industry.

The chapter proceeds as follows: section 2 provides a brief institutional overview of the PCS spectrum auctions and the subsequent secondary market, while section 3 briefly discusses the data (for a detailed discussion of both PCS spectrum, PCS auctions and the construction of the dataset, the interested reader should refer to Chapter 1). In section 4 I provide the descriptive analysis of the evolution of the PCS market, whereas in section 5 I empirically investigate the sales patterns of restricted licenses.

2.2 Industry Background

2.2.1 PCS Spectrum

The PCS band was initially composed of 6 frequency blocks (A to F) totaling 120 MHz, which represented the total quantity of PCS spectrum available in each geographic area. Initially, the geographic areas that licenses covered were defined in terms of Major Trading Areas (MTAs) and Basic Trading Areas (BTAs). These are different methodologies of aggregating individual counties and county-equivalents, e.g. parishes in Louisiana. There are 51 MTAs and 493 BTAs, with several BTAs making up one MTA. As a consequence of disaggregation and partitioning, later the relevant geographical areas were individual counties.

2.2.2 Allocation of PCS Spectrum

Licensees can obtain spectrum licenses either directly from FCC in a spectrum auction or in the secondary market from other licensees. Since 2003, they can also lease spectrum from each other.

2.2.2.1 Spectrum Auctions

All PCS auctions were simultaneous multi-round ascending auctions[2]. In such an auction several licenses are auctioned at the same time and the bidders then bid on individual licenses; the auction ends when bidding on every single license stops. This process allows for the discovery of other bidders' valuations and for the flexibility of shifting resources among packages of different licenses, that is for designing new combinations of licenses based on highest standing bids in each period (Cramton [2002]). While these types of auctions do suffer from some well-known problems[3], these can be mitigated with careful auction design.

The legislation that authorized the FCC to allocate spectrum using auctions required not only that these auctions maximize efficiency and revenues collected, but that they also foster competition and provide equal opportunities for entrepreneurs to participate in the market for spectrum[4]. Such companies often lack access to capital required to succeed in a capital-intensive industry such as telecommunications; also, minority- or women-owned businesses may face discrimination (Holtz-Eakin et al. [1993], and Bradford [2000]). According to the CBO [2005], the requirement that FCC should ensure the participation of entrepreneurs should not be interpreted as referring to spectrum auctions only; instead it should be viewed in a broader context of the provision of mobile wireless services.

To meet its statutory obligation, FCC first had to define criteria for determining which companies should be entitled to preferential treatment. Referring to such companies as entrepreneurs, FCC required that they "had gross revenues of less than $125 million in each of

[2]See Goeree and Lien [2009a] for a theoretical model.

[3]For example, exposure problem, tacit collusion, demand reduction, signaling, etc. (see Bulow et al. [2009], Brusco and Lopomo [2002], Goeree et al. [2012], Goeree and Lien [2009b], and Weber [1997]).

[4]Specifically, the Act requires that FCC "promotes economic opportunity and competition and ensures that new and innovative technologies are readily accessible to the American people by avoiding excessive concentration of licenses and by disseminating licenses among a wide variety of applicants, including small businesses, rural telephone companies, and businesses owned by members of minority groups and women."

the last two years and total assets of less than $500 million at the time" they applied to participate in the spectrum auction. The definition of an entrepreneur did not change over time.

Only firms that qualified as entrepreneurs were eligible to bid on C and F block licenses covering 40 MHz of PCS spectrum in each geographic market (that is, one third of the entire spectrum available in each geographic area). These eligibility restrictions ("set-asides") insulated these firms from having to compete with large companies and essentially reserved one third of the entire PCS market for entrepreneurs only. The remaining blocks of PCS frequencies, that is frequency blocks A, B, D and E that together covered 80 MHz, were offered to both entrepreneurs and large companies. Even though all six frequency blocks were perfect substitutes, eligibility restrictions initially created two parallel markets for an otherwise homogeneous product. This two-tiered market structure was not limited to the duration of the auction only; FCC's rules extended the insulation of entrepreneurs to the secondary market for a certain period of time (similarly, Ellis and DuMars [1978]).

Some entrepreneurs bidding on restricted C and F block licenses could also qualify for the other two types of preferential treatment: bidding credits and installment payment plans. Bidding credits ranged from 15% to 25% and were conditional on the firm's size. Bidders with less than $40 million in gross revenues got a 15% bidding credit and bidders with less than $15 million in gross revenues got a 25% bidding credit (47 CFR 24.712 & 47 CFR 24.717). Bidding credits allowed entrepreneurs to purchase spectrum licenses at a discount provided they were the winning bidders. In order to qualify for bidding credits firms also had to qualify as entrepreneurs; however, every entrepreneur did not necessarily qualify for bidding credits. Nonetheless, 99% of all bidders in the first auction where eligibility restrictions were used (that is, in Auction 5) qualified for bidding credits. Also, all entrepreneurs with less than $40 million in gross revenues got a 25% bidding credit in Auctions 5 and 10.

Installment payment plans with generous government-subsidized interest rates that spread out payments over 10 years were also offered to qualified entrepreneurs only. Expecting

that they will be able to secure additional financing before payments will be due, these entrepreneurs bid more aggressively and more than they would have otherwise; however, many faced difficulties in obtaining such additional capital and consequently defaulted on their payments. This caused a systemic problem following Auctions 5 and 10, forcing FCC to subsequently offer amnesty (the so-called C block election) to these winning bidders. As a result, FCC quickly stopped offering the installment payment plans.

FCC was planning to run 3 PCS auctions in 3 years; in these 3 auctions it wanted to allocate all 120 MHz of nationwide PCS spectrum (see Chakravorti et al. [1995]). Instead, it took it more than 10 years and 6 additional re-auctions to allocate the entire quantity; these additional re-auctions were required to sell the licenses that FCC had to terminate or that were returned by the licensees. With very few exceptions all these licenses were first reserved for entrepreneurs, who took advantage of FCC's preferential treatment policies mandated by the US Congress.

2.2.2.2 Secondary Market for PCS Spectrum

After winning bidders pay for the licenses they have won in an auction, FCC grants these licenses by assigning each license a unique identifier[5]. At this point winning bidders become licensees and can enter the secondary market for spectrum. Here, licensees trade licenses, either directly or indirectly by acquiring other licensees. FCC must consent to every transaction that involves a substantial change in the ownership or control of the license or of the licensee, be it "de iure" or "de facto"; this sometimes causes administrative delays leading some economists to call for a more flexible and streamlined approach (Mayo and Walsten [2009]). On the other hand, pro forma transactions involve only non-substantial changes and therefore do not require FCC's consent.

[5]That is, a unique "call sign", e.g. KNLF200. Radio stations typically use their call signs as their names, e.g. KCRW in Santa Monica, CA.

When trading individual licenses (but not licensees), firms can partition and/or disaggregate them at the county level[6]. This means that licenses can be sold in full or in part; if the entire license is sold, the licensee gives up all associated spectrum in the entire license area covered by the license. When the license is sold only partially, there are two ways of splitting it:

1. If *partitioned*, the licensee splits the license in two (or more) geographic areas consisting of individual counties that once constituted the original license area. This results in two (or more) licenses covering the same geographic area that the first license covered before.

2. Licensees can also *disaggregate* licenses, that is split the quantity of spectrum associated with the first license; in this case two licenses cover the same geographic area but authorize their holders to smaller quantities than the first license did.

Licensees can also choose to combine the two approaches, partitioning and disaggregating their licenses at the same time. Whenever a market transaction involves partitioning of an original license, the resulting new license areas do not coincide with MTAs or BTAs anymore.

If an existing license is partitioned or disaggregated, FCC issues a new license with a new call sign to each new buyer. The existing license retains its call sign unless it has been completely partitioned or disaggregated in one simultaneous transaction. This ability to reconfigure spectrum licenses promotes efficient use of spectrum by providing licensees with the flexibility to directly respond to market forces. Note that only licenses can be partially traded; licensees cannot be acquired only partially. Re-aggregation of several licenses into one is generally not possible.

In 2003 FCC proposed various secondary market initiatives "designed to remove regulatory barriers and increase access to spectrum" (FCC [2013b]), allowing firms to lease spectrum

[6]Firms can also partition or disaggregate licenses without having to sell them afterwards

from each other for the first time[7]. With the first PCS licenses sold and granted in 1995, this means that leasing was not an option in the early years of the market for PCS spectrum.

2.2.3 Construction Requirements

Every license won in a PCS spectrum auction came with a 5-year construction requirement. Initially, the latter required that the licensee covered at least one third of the population of the license area in the first 5 years since the license was granted (first construction requirement). Additional one third of the population had to be covered in another 5 years, that is before the license expired and the licensee requested its renewal (second construction requirement). Later the requirements were relaxed for all licenses covering less than 30 MHz; this included 30 MHz C block licenses that were disaggregated into 15 MHz ones as a result of the C block election. For these licenses only one construction requirement remained: licensees only had to cover one quarter of the population living in the license area in the first 5 years. Failure to meet the construction requirement led to the termination of the license, making the associated spectrum available in one of the subsequent re-auctions.

In the case of partitioning or disaggregation, the deadline for the new derivative license was inherited from the original one. This meant that the licensees of such new derivative licenses had anywhere from 5 years to 1 year to meet the requirement[8]. If the current licensee already met the construction requirement and then split its license, the new derivative license was not subject to the construction requirement anymore.

[7]The difference between leasing and roaming is that the former grants the lessee certain rights with respect to using the license, whereas roaming allows end users of some mobile carrier to seamlessly transition and use another firm's spectrum on a contractual basis. Roaming agreements between mobile carriers were very common in the formative stages of the mobile industry enabling competitors with non-overlapping networks to mutually extend their geographic coverage.

[8]This is a simplification; the existing licensee and the buyer could agree on who will meet the deadline for the newly partitioned/disaggregated part of the original license (47 CFR 24.714). Since I do not observe this choice for every derivative license in the data, I assume each licensee had to meet its own deadline.

If an entrepreneur had not yet met the construction requirement for a restricted CF license, it could only sell it to another entrepreneur. Similarly, if a restricted CF license was partitioned or disaggregated before its construction requirement was met, FCC consented to the transaction and issued the new (restricted CF) derivative license only if the buyer was also an entrepreneur. Only after the requirement was met could any such initially restricted CF license won in an auction with eligibility restrictions be sold to a large company; only at that point was such an initially restricted CF license converted to an unrestricted CF license.

2.2.4 Definitions of Relevant Markets

2.2.4.1 Relevant Input Market

With the exception of the cellular spectrum, the structure of the PCS spectrum market did not substantially depend on the availability and firms' holdings of other bands of spectrum used in the provision of mobile wireless services. This was especially the case in the early years of the market.

Cellular spectrum used by the 2G technology was the only type of commercial spectrum available in the early days of the PCS market. However, FCC's historical records for cellular licenses (when they exist), especially data that were entered ex-post in FCC's electronic systems, are more often incorrect than correct. In order to reliably reconstruct the flow of cellular licenses and each firm's cellular spectrum holdings at every point in time physical access to hard copies of official documents and files would be required. Also, only three cellular licenses were ever sold in an auction (Auction 45); the rest were allocated before auctions were used.

The 700 MHz spectrum has not attracted the attention of major PCS licensees until sometime before Auction 73 in 2008, which was more than 10 years after the close of the third initial PCS auction. The early evolution of the PCS market was therefore not affected by firms' 700 MHz spectrum holdings. Similarly, AWS-1 spectrum (Auctions 66 and 78) was

not auctioned off until 2006.

None of the major 800/900 MHz licensees was a PCS licensee with significant spectrum holdings until Sprint took over Nextel in 2005. This band was initially not meant for advanced two-way wireless communications and was used by an inferior and outdated SMR technology. The 800/900 MHz band was therefore never seen as a real competitor or a complement to the PCS band, although it did count toward the same CMRS spectrum aggregation limit.

2.2.4.2 Relevant Geographic Market

FCC initially issued licenses at the MTA/BTA level, but by allowing licensees to partition and disaggregate them at the county level, the relevant geographic market should be consequently defined at the level of an individual county. Ignoring the possibility of disassembling licenses into multiple smaller packages of geographical areas and of associated quantities, and simply analyzing firm-level average spectrum holdings in each BTA would lead to the loss of the county-specific variation and fixed effects, and to the loss of spatial information.

Even more problematic is the economic interpretation: averaging over all licensees in some BTA assumes that each licensee is present in every county of that BTA. Market concentration in such broadly defined geographic market would understate the true county-level market concentration. This is especially the case considering the geographical exclusivity of licenses and their (geographical) unsubstitutability: no amount of spectrum in some other county can be used as a substitute in a market where a licensee is not present.

Lastly, due to the specific geographical features the nature of the competition outside continental US appears to be significantly different, both in the number of competitors and their identity, the number and volume of transactions, and also the auction competition itself. Because of this I ignore all such self-contained geographic markets[9].

[9]Markets ignored: Alaska, Hawaii, American Samoa, Guam, the Gulf of Mexico, Northern Mariana Islands, Puerto Rico and the Virgin Islands.

2.2.4.3 Relevant Level of Corporate Control

Vertically integrated licensees usually have a complex corporate structure with several hierarchical levels. Parent companies almost never directly participate in spectrum auctions; instead, a new shell company or a subsidiary is formed for the sole purpose of participation in the auction. These winning bidders then often assign their licenses to either their parent company or to one of its other subsidiaries in a pro forma transaction, or get absorbed during an equally pro forma internal reorganization (i.e. a pro forma merger). The observed number of such pro forma transactions with no substantial change of control is very high.

The analysis at the level of actual licensees is therefore not particularly interesting. Instead I focus on the entities that ultimately own or control licensees. In other words, I am only interested in controlling entities; if there are several licensees in the market that are all controlled or owned by the same entity, I treat all such licensees as one firm. If not, the existence of such nominally different licensees would result in an artificially high fragmentation of the market and would lead me to underestimate the actual level of market concentration. The challenge, however, is to identify the controlling entities for those licensees for which very little data are available, e.g. privately-owned companies, individuals or partnerships.

2.3 Data

I collected an unbalanced panel data set of spectrum license ownership at both the license and county-license level using various data mining techniques. The data collection process took several years; full details of data sources and approaches used can be found in Chapter 1.

Even though the data coverage starts with the inception of the PCS market in late 1994[10],

[10]Recorded as March 1st, 1995. Data were annualized by recording effective ownership on March 1st of each year to overcome the problem of limited accurate historical ownership and corporate structure data for many licensees.

most of the analysis investigates post-1997 outcomes when the market was at its full capacity. In order to make sure that both the ABDE and the CF markets are not growing over time, the descriptive analysis starts after FCC ran its third initial auction (Auction 11), expecting to finalize the sale of the remaining 40 MHz of unallocated PCS spectrum. The auction closed in January 1997, but since FCC started granting licenses only in late April of that year, this effectively means that the descriptive analysis starts with year 1998. By that time all geographically relevant Auction 11 licenses were granted (same holds for Auction 4 and Auction 5 licenses). Also, from the perspective of the activity in the secondary market this truncation does not result in a significant loss of information as I observe very few pre-1998 market transactions. The data coverage ends in 2012, resulting in 18 years of data, 15 of which are used in the descriptive analysis. Licenses need to be observed at least once to be included in the data set. This is not a very restrictive requirement; it results in 11 discarded licenses. Whenever I use pre-1998 data, I explicitly mention this.

Table 2.1 summarizes the data used in the empirical analysis. Spectrum auctions data include auction-specific policies such as the use of eligibility restrictions, bidding credits and installment payment plans; license-specific data includes the identities of all licenses and their respective frequencies, frequency blocks, license areas, data on whether the license was initially restricted, etc. I also observe the identities of all bidders and their sizes, that is whether they qualified as entrepreneurs, small entrepreneurs or very small entrepreneurs. I do not observe any other bidder characteristics that would carry over after they are grouped together at the level of controlling entities. For the sake of consistency with other auctions, I split the bidders from Auctions 5 and 10 in two groups based on the $15 million threshold by manually checking financial documentation submitted to FCC together with these bidders' auction applications.

County-license-level variables	N	Mean	Std. Dev.	Min	Max	FE
Quantity ("bandwidth") [MHz]	356219	16.197	8.762	2.500	30	
Volume [MHzpop]	356219	1462453	5479196	335	286000000	
License volume [MHzpop]	356219	58900000	109000000	3645	846000000	
Partitioned	356219	0.061	0.239	0	1	
Initial auction	356219	0.852	0.355	0	1	✓
Original license	356219	0.819	0.385	0	1	✓
ABDE license	356219	0.649	0.477	0	1	✓
Restricted CF license	356219	0.096	0.295	0	1	
Construction requirement	356219	0.289	0.040	0.25	0.33	
Bidding credits used [%]	356219	0.024	0.072	0	0.25	✓
Construct	98005	0.233	0.423	0	1	
Periods remaining	90974	1.979	1.356	0	4	
Keep control	22697	0.768	0.422	0	1	
Sell to entrepreneur	5267	0.159	0.365	0	1	
Buyer size [1-5]	5267	5.365	0.827	2	6	

County-level variables	N	Mean	Std. Dev.	Min	Max	FE
Population	356219	89631.49	295033.5	67	9519338	✓
Average firm size [1-5]	356219	5.236	0.462	3.5	6	
Land area [sqm]	356219	953.076	1313.265	1.99	20052.5	✓
Population density [%]	356219	246.691	1697.034	0.1	66940.1	✓
Hhs with income > $35,000 [%]	356219	49.337	10.723	19.4	89	✓
Median income [$]	356219	35243.61	8817.128	12692	82929	✓
Local area personal income [$]	356219	29001.17	8657.693	6494	124742	
Unemployment rate [%]	356107	6.24	2.85	0.7	33.2	
HHI	346945	2161.91	425.779	902.778	5138.889	

Firm-level variables	N	Mean	Std. Dev.	Min	Max	FE
Entrepreneur	356219	0.234	0.423	0	1	✓
ABDE-winning entrepreneur	356219	0.103	0.304	0	1	✓
Firm size in the ABDE market [1-5]	356219	4.898	1.798	0	6	
Firm size in the CF market [1-5]	356219	4.092	2.246	0	6	
Firm size [1-5]	356219	5.299	1.042	2	6	
Licensee has other licenses in county	356219	1.63	0.89	1	8	
Local death	356219	0.01	0.08	0	1	
Local sale	356219	0.09	0.29	0	1	

Table 2.1: Summary of the main variables.

The histories of individual licenses are primarily reconstructed using FCC's Universal Licensing System databases, a public online filing system used by both FCC and licensees to record events related to individual licenses. I am aware of only two studies that have used certain aspects of this data source before; CBO [2005] analyzes the performance of entrepreneurs in PCS auctions in a less-detailed manner and without specifically focusing on the transition of restricted spectrum to large companies, while Bazelon and Zarakas [2009] deal with measuring the market concentration at just one period in time.

Secondary market transactions data include data on the effective ownership of each license in every year after license entry and until the license ceases to exist, i.e. until license exit (if observed). I observe how licenses get partitioned and disaggregated, and the identities and characteristics of these new derivative licenses and their new holders. I know when licensees meet the construction requirements of their licenses and the subsequent conversion of restricted CF licenses to unrestricted CF licenses. Due to the aggregation of licensees at the level of effective control, some licensee-specific information is lost.

Other than the winning bids generated in each auction, I do not observe any prices as secondary market transactions are typically highly confidential; even when reported to the FCC, the contracting parties almost always ask for a confidentiality waiver so that publicly available documents contain no sensitive financial information. While it is possible to obtain estimates for some high-profile transactions from specialized sources like SDC Platinum, such reported figures are often aggregated with other assets such as cell towers, network equipment, subscribers, etc. There also exist no comprehensive data on prices that licensees charge to downstream firms[11].

I also do not observe profits that firms in the market for PCS spectrum earn. For publicly-listed companies it may be possible to obtain such financial information from reports filed with SEC. However, such licensees are most often vertically integrated and have a complex corporate structure, making it difficult to attribute a certain share of their revenues or profits to the spectrum operations of the company[12]. Additionally, I do not observe the actual spectrum utilization, that is whether a licensee uses a smaller quantity of spectrum than the license authorizes it to. Unfortunately, no data of spectrum utilization exist even though the

[11]For reasons described in Chapter 1, getting estimates of downstream input costs and using them as proxies for prices upstream firms charge for their services is also not possible.

[12]For example, in August 2013 D&B's "Who Owns Whom" database reported that AT&T's corporate family consisted of 539 companies, 478 of which were located in US.

2010 National Broadband Plan calls for a comprehensive annual assessment.

US Census county division data and FCC's own delineation standards are used to deconstruct market areas of PCS licenses (MTAs and BTAs) into 3109 counties covering the continental US. Other county-level data include population, population density and the share of households with annual income above $35,000 (with the latter motivated by Ausubel et al. [1997]); all these data are based on 2000 US Census. Time-varying county-level data are BEA local area personal income and BLS local area unemployment rate.

Dropping all licenses covering license areas outside the continental US leaves me with 2679 unique original licenses. Their number can increase only if FCC runs another spectrum auction; on the other hand, the number of derivative licenses does in fact increase over time. After removing 317 licenses that cover undefined areas only and all STA ("Special Temporary Authority") licenses I have 1075 unique derivative licenses. In total I track 3754 licenses over time, resulting in 40190 unique license-year observations.

Depending on the context of the analysis I sometimes treat licenses in individual counties as individual units of observation and refer to them as county-licenses. The advantage of tracking licenses at the level of an individual county rather than at the level of a license area is that I do not need to differentiate between partitioning (splitting the license geographically), disaggregation (splitting the quantity of spectrum associated with the license), and/or combinations thereof. This means transactions can affect only the quantity of spectrum associated with each license and/or its ownership; the only two possible consequences of a spectrum transaction on the county-license level are therefore a complete sale or a partial sale. Even though county-licenses are distinct units of observation as they can be sold independently from other county-licenses belonging to the same license, I allow for a non-zero correlation between them. Deconstructing license areas of 3754 licenses into county-licenses results in 356219 unique county-license-year observations.

2.4 Descriptive Analysis

2.4.1 Licenses

2.4.1.1 License Entry and Transactions

Spectrum licenses appear in the data set in the first period after FCC has issued them. Licenses are issued after a spectrum auction or because of a market transaction that results in the split of an existing license. I consider only those original licenses that were eventually given a call sign by the FCC.

License transactions are a result of non-pro forma AA and TC applications filed with FCC. The former are used when licensees transact licenses, either in part or in full; the latter are used when firms acquire other licensees (at the same time acquiring their stock of licenses). For reasons discussed in Chapter 1, I do not distinguish between AA and TC applications, i.e. between purchases of licenses vis-à-vis purchases of licensees. I do not track spectrum ownership based on actual licensees but am instead interested in their controlling entities; both the AA and TC application therefore result in a complete sale of the license. Partial sales (based on AA applications only) that partition or disaggregate licenses by definition result in at least one new derivative license.

On average, there are 270 complete sales of individual licenses per year; these change the effective owners of both original and derivative licenses. Also, on average 72 partial sales take place every year, resulting in the annual inflow of additional 72 new derivative licenses. With the total supply of PCS spectrum in each county fixed at 120 MHz, issuing derivative licenses means that the volume associated with original licenses must be decreasing. Figure 2.1 shows this is indeed the case; in 2012, derivative licenses already account for 20% of

the total nationwide volume[13].

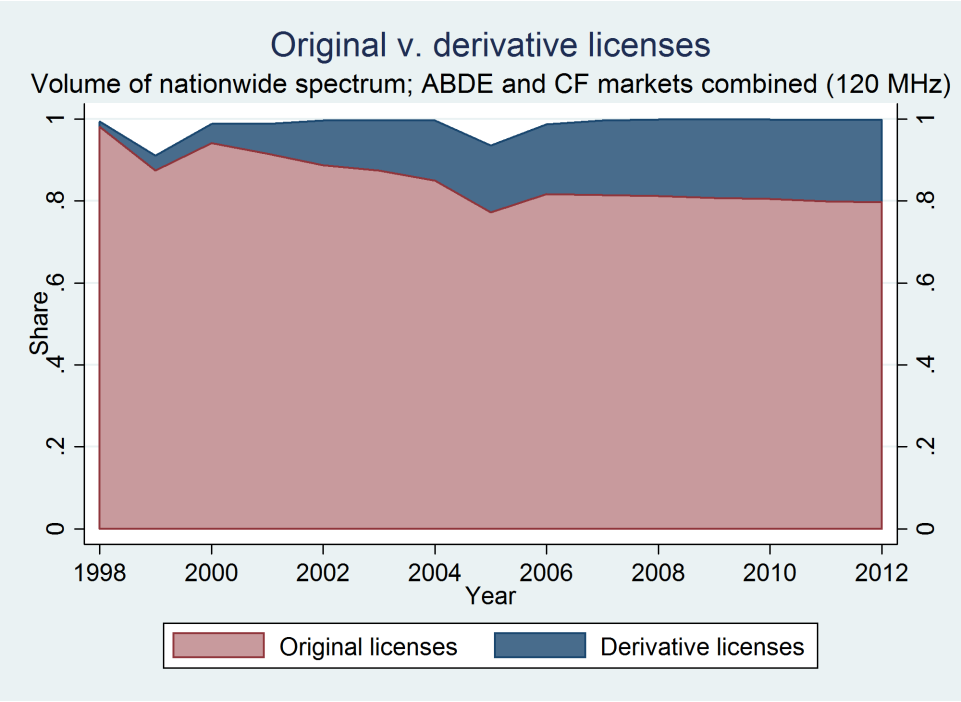

Figure 2.1: Original v. derivative licenses over time in terms of total nationwide volume, pooled over both markets. Total quantity in each geographic market equals 120 MHz.

2.4.1.2 License Exit

The way a license exits the market, i.e. leaves the data set does not depend on whether it originates from an auction or from the secondary market. I classify exits in four broad groups: terminations, voluntary cancellations, expirations, and complete partitioning or disaggregation.

Most licenses are terminated by the FCC due to the licensee's default on the payment (be it a one-time or an installment payment) or its bankruptcy, or because the licensee failed to meet

[13]Note the two sharp decreases in the available nationwide volume corresponding to the C block election in June 1998 (recorded in 1999) and to the forfeiture agreement NextWave reached with FCC in April 2004 (recorded in 2005). For details of these events, please see Chapter 1.

the construction requirements[14]. Voluntary cancellations (for unspecified reasons) requested by licensees themselves are rare, and expirations of licenses even more so. In the case of complete partitioning or disaggregation, there is a discontinuity in the license but not in the spectrum previously associated with that license. The existing license is simultaneously and completely split up, and therefore ceases to exist; at the same time new derivative licenses are issued by the FCC and given to the new licensees.

When a license ceases to exist, this frees up the associated spectrum, which is then put back onto the market via one of the re-auctions. The only exception is complete partitioning or disaggregation; here, spectrum associated with the exiting license is not freed up, but is associated with new derivative licenses instead. In this case, no re-auctioning is required.

Table 2.2 provides a break-down of all types of exit observed in the data. Altogether 460 licenses left the market over time; the vast majority of these licenses were restricted licenses won by entrepreneurs in auctions where eligibility restrictions were used.

	ABDE licenses	**CF licenses**
Complete partitioning or disaggregation	15	40
Voluntarily cancellation	1	20
Expiration	0	6
Termination	35	326
Failure to construct	*34*	*20*
Not paid for	*1*	*80*
Bankruptcy (NextWave)	*0*	*59 (56)*
C block election	*0*	*184*

Table 2.2: Reasons for license exit

[14]Only two licenses were ever terminated due to the licensee's failure to meet the second construction requirement. I treat these two cases as expirations.

2.4.1.3 The CF Market and the Conversion of Restricted To Unrestricted Spectrum

The CF market is made out of 40 MHz of C and F block licenses; all these licenses were initially restricted as they originated from auctions with eligibility restrictions, in which only entrepreneurs could participate. At that time, the CF market was synonymous with the market for restricted licenses. However, with the conversion of these restricted licenses to unrestricted the composition of the CF market started to change; although its size remained the same, the share of unrestricted CF licenses to restricted CF licenses started to increase. The process of the CF market gradually opening up is depicted in Figure 2.2.

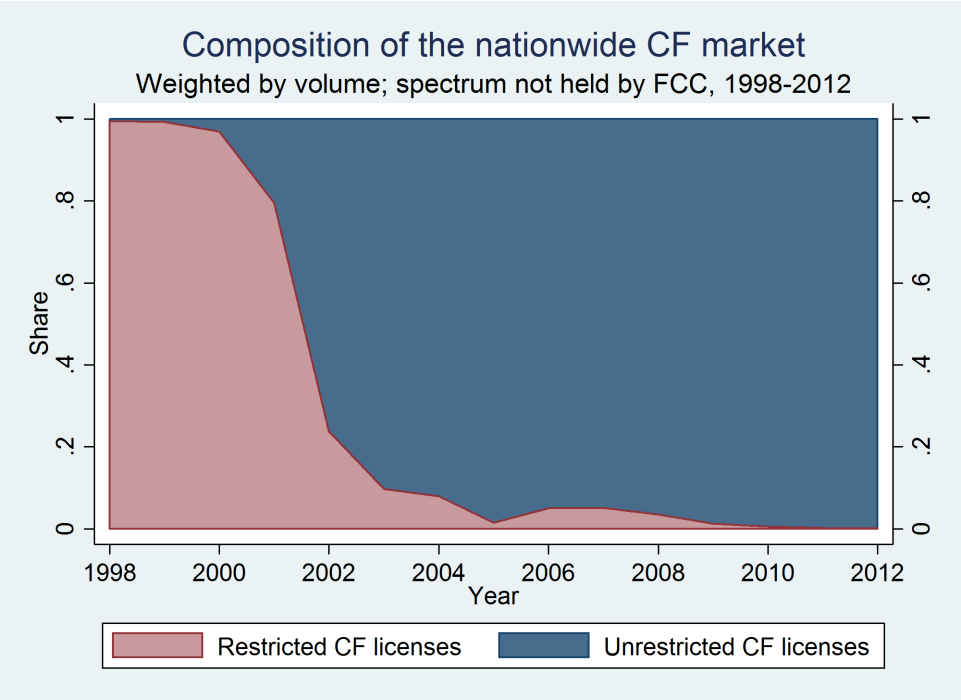

Figure 2.2: Gradual opening up of the CF market, i.e. conversion of the restricted CF spectrum to unrestricted CF spectrum.

There is a sharp increase in the share of unrestricted CF licenses between 2000 and 2003. This period corresponds to the 5-year construction deadlines tied to licenses won in the initial CF auctions (Auctions 5 and 11). The vast majority of these licenses were returned to FCC though and had to be re-auctioned well after these initial auctions. This means that the

entrepreneurs must have been actually meeting the requirements of the re-auctioned licenses well before their respective 5-year deadlines. This unusual behavior, which differs from the build-out patterns observed in large companies, will serve as the basis for the 2nd part of the empirical analysis.

2.4.2 Firms

2.4.2.1 Firm Entry and Size

Just like licenses, firms can enter via spectrum auctions (as winning bidders) or via spectrum purchases in the secondary market (as buyers). With few exceptions, each winning bidder is also the first licensee. The majority of firms entered before or in 1998, that is after FCC ran its three initial auctions. Re-entry of firms is rare. My data set initially consisted of 1839 distinct licensees; only 395 controlling entities remained after I consolidated all licensees based on their corporate structure and ownership.

The ABDE market was established after FCC sold the first 60 MHz in Auction 4[15]. Because of this, all firms that entered via Auction 4 were strictly speaking new entrants; however, most of them were already established telecommunications companies with significant presence in the market for cellular spectrum and as such incumbents in a broader sense. In contrast, the firms that entered the CF market via Auction 5 were new firms with no cellular holdings and therefore genuine new entrants. However, since I observe new entry in both ABDE and CF markets in each period, I cannot use the incumbent-entrant dichotomy to refer to firms' time-invariant types.

Instead, I use FCC's definition of an entrepreneur and extend it to the secondary market[16].

[15]The first three ABDE licenses were actually granted even before Auction 4 under the Pioneer's Preference program.

[16]This is in line with the spirit of the FCC's provisions. Even though the definition in 47 CFR 24.709 refers only to bidders in auctions for restricted CF licenses, 47 CFR 24.839 requires that all firms buying such licenses in the secondary market before the construction requirement is must meet the same eligibility criteria. That is, these buyers must also qualify as entrepreneurs.

Formally, an entrepreneur is therefore "any firm which *in its year of entry in the spectrum market* had gross revenues of less than $125 million in each of the last two years and total assets of less than $500 million, where *entry can be either via spectrum auctions or via the secondary market*". All other firms that do not meet these eligibility criteria are considered large companies. Also, an entrepreneur remains an entrepreneur even though it may grow over time[17].

I identify the entrepreneurial status of bidders using FCC's official spectrum auctions data and actual auction outcomes. By referring to the license transactions data and to the reconstructed ownership history of each license, I can identify all licensees (other than the winning bidder), which held the restricted CF license before the construction requirement was met. By definition, no large company could have held a restricted CF license before that date; therefore all such licensees must have qualified as entrepreneurs. I then verify the status separately for each such entrepreneur by manually inspecting the documentation that was filed with either its AA or TC application; same source is used to determine whether a specific entrepreneur also qualified as a small or very small entrepreneur in case its status is not directly observable from auction data.

Very small entrepreneurs often receive lower bidding credits in later auctions, which indicates they grow over time[18]. Not all entrepreneurs bid in multiple spectrum auctions, meaning I observe such growth for only a selected sample. Because of this, I treat their sizes as time-invariant and fix them at the level observed at the time of market entry.

For the approximately 20% of remaining unclassified firms for which ULS data were of no use (e.g. some firms buy initially restricted CF licenses after they become unrestricted and

[17]This is consistent with re-auction provisions: if a firm qualified as an entrepreneur in the initial auctions, it was eligible for bidding on re-auctioned restricted spectrum even if it did not satisfy the criteria anymore.

[18]Only two entrepreneurs shrink so that the bidding credits they get in subsequent auctions are bigger.

thus freely tradable, meaning no additional financial information has to be provided), I use all available online and print sources to determine whether they qualified as entrepreneurs, and if so, if they additionally qualified as small or very small entrepreneurs.

In the end, I classify 251 firms as entrepreneurs and the remaining 144 firms as large companies; out of 251 entrepreneurs, 31 are small entrepreneurs and 157 are very small entrepreneurs. I also identify entrepreneurs that won licenses in auctions with no preferential treatment offered, that is when directly competing with large companies. The data show there are 44 such entrepreneurs; by definition, they are all winning bidders. Most of them won licenses in Auction 11, which was the only auction to offer parallel bidding on ABDE licenses and restricted CF licenses in all market areas at the same time.

2.4.2.2 Firm Growth

Table 2.3 shows the summary statistics of the distribution of firm sizes over time, expressed in terms of the total nationwide spectrum. Few large companies are growing while the majority are shrinking, as indicated by the median-sized firm moving to the left of the distribution, and by the corresponding share of the smallest and the largest firm in each year. The biggest entrepreneurs are rapidly shrinking too; as soon as NextWave sold off most of its licenses in 2005, the share of the nationwide spectrum held by the biggest entrepreneur fell to around 3%. With the quantity of the PCS spectrum in each geographic market fixed at 120 MHz, firms can increase their spectrum holdings within an individual county only via one of the re-auctions or via market purchases. There is extensive literature documenting the wave of M&A's in the telecommunications industry in the late '90s and early 2000's motivated by the aggressive expansion of geographic coverage (Fox and Perez-Saiz [2006], Fox [2005], and GAO [2010]).

	Large companies				Entrepreneurs			
Year	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
1998	1.48	0.124	0.0010	15.53	0.28	0.039	0.0005	12.18
1999	1.43	0.086	0.0010	21.03	0.27	0.026	0.0005	12.18
2000	1.61	0.059	0.0010	21.01	0.25	0.026	0.0005	12.18
2001	1.67	0.021	0.0010	21.00	0.22	0.021	0.0005	12.18
2002	1.71	0.014	0.0010	21.01	0.20	0.020	0.0005	12.18
2003	1.76	0.015	0.0011	20.94	0.21	0.022	0.0005	12.18
2004	1.70	0.014	0.0004	20.90	0.18	0.022	0.0003	9.66
2005	1.61	0.012	0.0004	25.82	0.13	0.021	0.0003	3.04
2006	1.48	0.009	0.0004	25.72	0.15	0.020	0.0002	3.04
2007	1.32	0.007	0.0004	26.92	0.16	0.017	0.0003	3.04
2008	1.34	0.006	0.0004	27.88	0.13	0.016	0.0003	2.79
2009	1.38	0.006	0.0004	27.94	0.12	0.015	0.0003	2.90
2010	1.20	0.006	0.0004	28.00	0.12	0.015	0.0003	2.90
2011	1.20	0.006	0.0004	28.60	0.12	0.013	0.0003	2.83
2012	1.20	0.006	0.0004	28.66	0.12	0.011	0.0003	2.87

Table 2.3: Mean, median, minimum and maximum sizes of large companies and entrepreneurs; shares of the total volume of nationwide spectrum, in percent.

There appears to be a substantial asymmetry in the volume of spectrum firms hold. To keep the analysis tractable, I first grouped all firms in five non-equally wide bins depending on their share of the total nationwide volume held. The width of each bin is ten times that of the previous one. Firms that belong in the first bin have individual spectrum holdings of up to 0.01% of the nationwide volume; firms that belong in the second bin hold from 0.01% to 0.1% of the nationwide volume. The final, i.e. fifth bin contains firms that individually hold more than 10% of the total nationwide volume.

Figure 2.3 shows the evolution of the distribution of firm sizes in the entire nationwide market for PCS spectrum over time. A general observation, which also holds for both ABDE and CF markets separately, is that the net number of firms in bin 1 is increasing and that the net number of firms in every other bin except bin 5 is decreasing. The (net) number of the biggest firms remains constant over time; in fact, after 2006 when Verizon Wireless acquired enough spectrum to switch from bin 4 to bin 5 the identities of these bin 5 firms remained the same as well. There is also a considerable churn in this market with many

firms entering and exiting in each period, especially the smaller firms (i.e. firms in bins 1 and 2); the difference between the latter is that net entry of bin 1 firms is positive, whereas the net entry of bin 2 firms is negative. However, given the exponentially asymmetric widths of the five bins, even a rising trend in the number of firms in bin 1 cannot possibly explain the exodus of the bigger firms (excluding those in bin 5). A more plausible explanation is that the biggest firms are growing at the expense of the medium-sized ones.

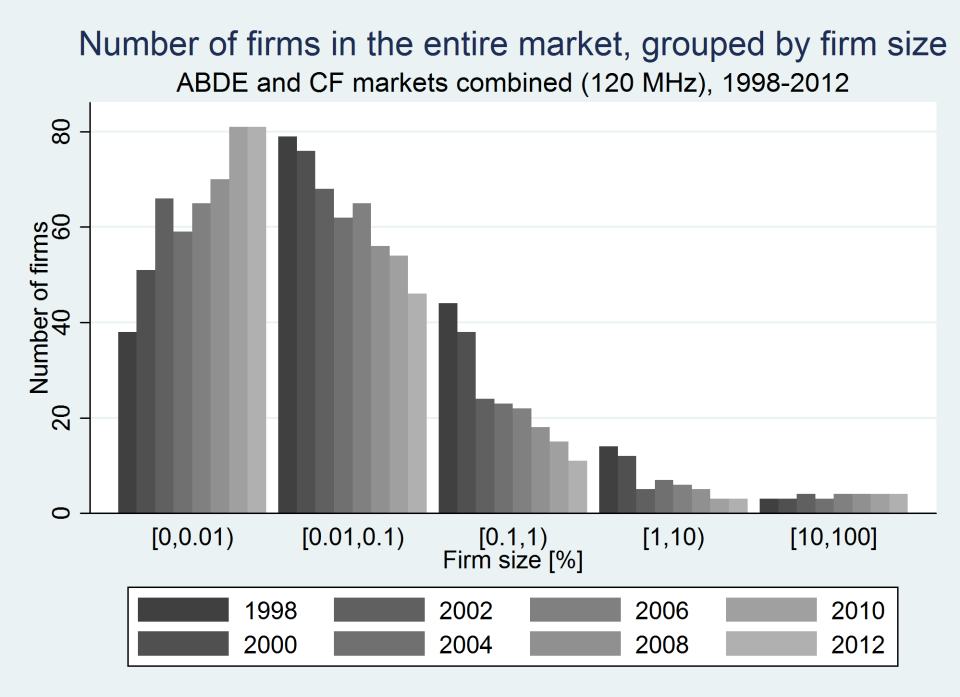

Figure 2.3: Number of firms in the entire market for PCS spectrum, grouped by firm size. Firms' market shares are defined relative to the entire stock of nationwide PCS spectrum.

To investigate whether this is indeed the case, I look at the evolution of aggregate shares of volume held by each group (i.e. bin) in the ABDE and the CF markets separately; I do so because of different institutional features that caused both markets to evolve differently over time. Each firm is grouped in two bins if present in both markets. Figure 2.4 shows how aggregate market shares of firms of different sizes evolved over time. The biggest firms have indeed expanded at the expense of the medium-sized ones, especially in the ABDE market. By inspecting the actual market transactions underlying these changes, I can conclude there are two reasons for this expansion of the biggest firms. Some firms in bin 4 have grown

sufficiently enough to qualify as the biggest firms (e.g. Verizon Wireless); all other medium-sized firms in bin 4 have been taken over by the biggest firms. In the CF market medium-sized firms still have a substantial presence, even though firms in bin 3 have almost disappeared over time; data show most have been acquired, with only a few outgrowing the 1% upper bound. The biggest firms in the ABDE market also dominate the CF market with the exception of Sprint; the latter owns a relatively small volume of the CF market and is actually one of the firms in bin 4[19]. The other two firms in bin 4 in the CF market are MetroPCS and Leap Wireless; while still present as independent entities in my data set in 2012, both firms have since been acquired by the biggest firms in bin 5.

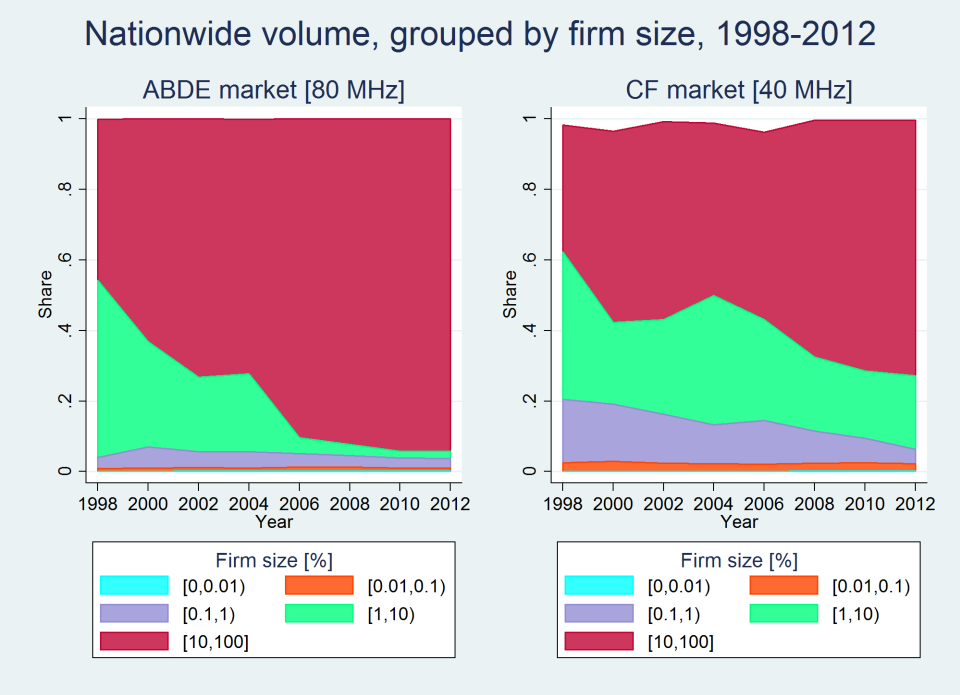

Figure 2.4: Volume of spectrum available in the ABDE and the CF markets and held by groups of firms of different sizes, not including spectrum held by FCC. Market shares are defined relative to the entire stock of spectrum in each market (i.e. relative to 80 MHz/40 MHz per county).

[19]This may be related to Sprint's ownership of nationwide 10 MHz of G block PCS spectrum. Please see Chapter 1.

2.4.2.3 Firm Exit

I distinguish two ways firms can exit at the global level: firm deaths and mergers. In the context of this chapter, I define a merger as every simultaneous sale of all firm's licenses in all geographic markets to a single buyer; the result of such sale is that the acquired firm ceases to exist. The identification of the major mergers is based on the SDC Platinum database; for smaller transactions I use the definition above with the requirement that the acquired firm owns at least 2 licenses. A firm death is the simultaneous loss of all licenses of a firm for which the latter receives no financial compensation. Firm deaths were most common among entrepreneurs in the early days of the PCS spectrum market.

Each year I observe on average 5.1 large companies that exit due to a merger; in contrast, 11.1 entrepreneurs disappear for the same reason. Also, 4.2 large companies die every period, whereas the average death rate of entrepreneurs is 12.3 firms per year.

I also examine the average life span of different types of firms using the Kaplan-Meier estimator of the survival function. All firms present in 2012 are treated as right censored. The results shown in Figure 2.5 are somewhat surprising. ABDE-winning entrepreneurs, that is the subset of entrepreneurs that won at least one ABDE license (in an auction where they received no preferential treatment, that is when competing with large companies) have a probability of survival that is much higher than that of both the non-ABDE-winning entrepreneurs and large companies. This is consistent with the prediction that these entrepreneurs may on average be superior to the non-ABDE-winning ones and as such able to effectively compete with large companies even with no regulatory intervention[20]. Non-ABDE-winning entrepreneurs, i.e. those that never won any ABDE licenses or have not

[20]This, however, does not mean that all non-ABDE-winning entrepreneurs are inferior. Both Leap Wireless and MetroPCS, the two biggest entrepreneurs to have survived until 2012, never won any ABDE license in any auction. At the same time, there are ABDE-winning entrepreneurs that did not stay in the market for long: Omnipoint (taken over by Voicestream), Telecorp (taken over by the "old" AT&T, i.e. AT&T Wireless) and NextWave (went bankrupt) were all part of the ABDE-winning group. In fact, these three ABDE-winning entrepreneurs represent more than 90% of all volume held by the entire group.

participated in spectrum auctions at all, have the lowest probability of survival.

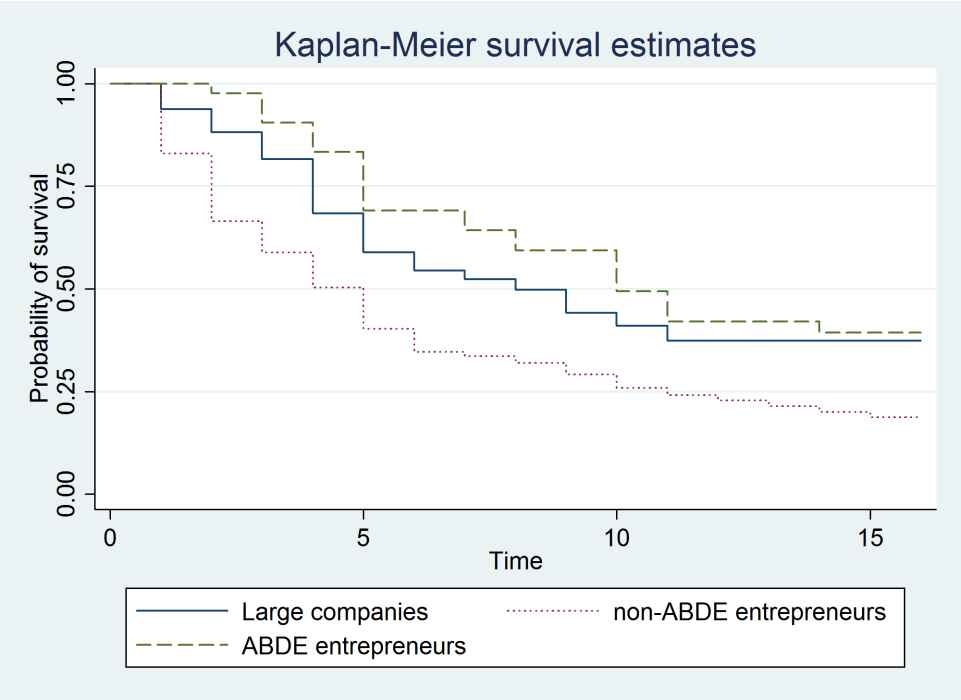

Figure 2.5: Kaplan-Meier estimates of the survival probability of large companies and the two types of entrepreneurs.

2.4.3 Market Concentration

With detailed county-level data on spectrum holdings of firms, I analyze market concentration at the county level using the widely used Herfindahl-Hirschman Index (HHI)[21] and generally adopt the same position as DOJ & FTC in their 2010 Horizontal Merger Guidelines (DOJ & FTC [2010]). That is, in general I consider the market unconcentrated if HHI is below 1500, moderately concentrated if HHI is between 1500 and 2500 and highly concentrated if HHI is above 2500. I do not conduct the second part of the test, i.e. inspect the changes in HHI.

As the spectrum available in the ABDE and the CF markets is perfectly substitutable, I treat

[21] HHI is defined as the sum of squared market shares (multiplied by 10,000).

the combined quantity in both markets as the basis for defining individual market shares of firms. Market shares are calculated relative to the total possible quantity of spectrum in each county (120 MHz) rather than the actual quantity held by firms (and not by FCC) in each respective year. This prevents markets from artificially shrinking and expanding based on how much spectrum gets returned to FCC.

If disaggregation of licenses would not be possible and if FCC would sell 6 different licenses to 6 different firms, with one license for each frequency block, the HHI would be $2083.3\bar{3}$[22]. I consider this my benchmark case for evaluating the market concentration in each county and therefore modify the definition of 2010 Horizontal Merger Guidelines accordingly: a moderately concentrated market is thus any market with HHI above $2083.\bar{3}$ and below 2500. The definition of a highly concentrated market remains the same. The number of counties exceeding this benchmark in every year is reported in Table 2.4. In 2012, more than 75% of counties had market concentration above the benchmark value of $2083.3\bar{3}$. Furthermore, 36% of all counties were highly concentrated with the value of HHI above 2500. Figures 2.6 and 2.7 show the map of continental US indicating the counties with above-threshold values of HHI and counties that were highly concentrated in 1998 and in 2012. The overall increase in market concentration is apparent.

[22] $((\frac{30}{120})^2 + (\frac{30}{120})^2 + (\frac{30}{120})^2 + (\frac{10}{120})^2 + (\frac{10}{120})^2 + (\frac{10}{120})^2) * 10000 = 2083.3\bar{3}$.

	Counties with HHI$\geq 2083.\bar{3}$		Highly concentrated counties with HHI≥ 2500	
Year	**Number**	**Share**	**Number**	**Share**
1998	690	0.22	152	0.05
1999	191	0.06	85	0.03
2000	558	0.18	209	0.07
2001	837	0.27	365	0.12
2002	1264	0.41	582	0.19
2003	1244	0.4	563	0.18
2004	1057	0.34	454	0.15
2005	1384	0.45	661	0.21
2006	1519	0.49	659	0.21
2007	1799	0.58	780	0.25
2008	1978	0.64	929	0.3
2009	2170	0.7	1041	0.33
2010	2180	0.7	1049	0.34
2011	2350	0.76	1122	0.36
2012	2348	0.76	1123	0.36

Table 2.4: Market concentration relative to all 120 MHz of spectrum in each county, even if held by FCC; continental US only, i.e. 3109 counties based on the 2000 US Census.

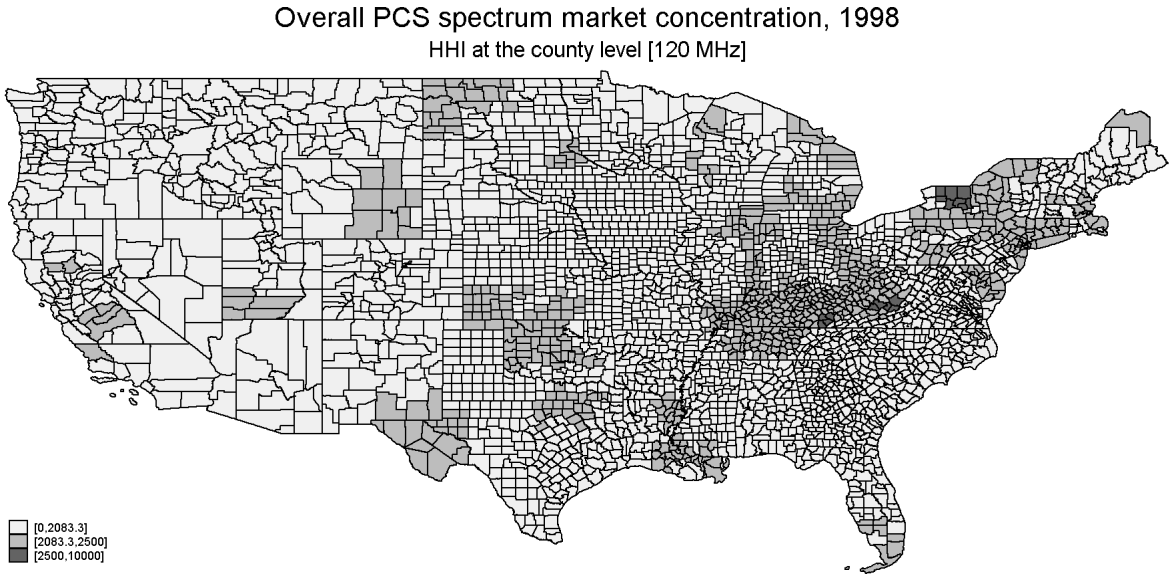

Figure 2.6: Market concentration in 1998 relative to all 120 MHz of spectrum in each county, even if held by FCC.

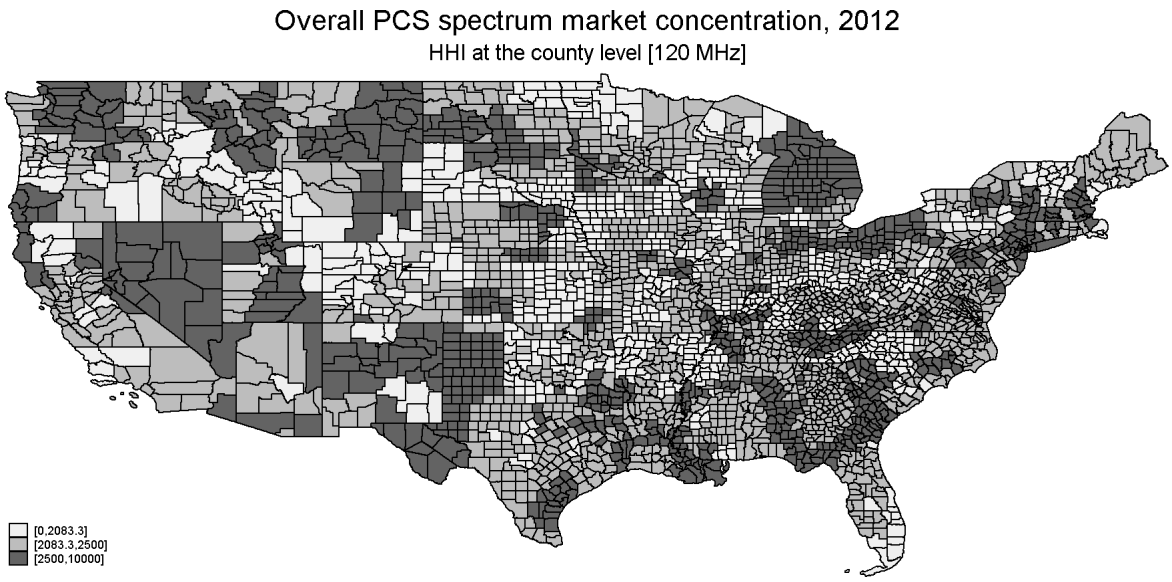

Figure 2.7: Market concentration in 2012 relative to all 120 MHz of spectrum in each county, even if held by FCC.

Another way to look at the rising concentration is to inspect the path of CR4, i.e. the cumulative share of the 4 biggest firms. In Figure 2.8 I do this separately for the two markets to account for their different institutional features. In the CF market CR4 exhibits two big drops: one corresponds to the C block election in 1999, and the second is due to NextWave's forfeiture of its licenses in 2005 (see Chapter 1). To control for the "NextWave effect", I exclude it from the calculation of CR4 whenever it was among the 4 biggest firms (that is, until it left the market in 2008) and graph the modified CR4 excluding NextWave's share (together with only the NextWave's share) alongside the traditionally-calculated CR4. With the effect NextWave had on CR4 in the CF market removed and taking the C block election into account, the market concentration in this market starts increasing even before large companies are able to enter. I also depict the combined market share of AT&T, Verizon Wireless, Sprint and T-Mobile. In the ABDE market these four firms control 94% of the entire volume in 2012[23]; in the CF market, their combined share is steadily rising and has reached 75% in 2012.

[23]Note that this does not include Sprint's additional 10 MHz of nationwide PCS spectrum in the G band, which it got for its 800 MHz spectrum in 2005.

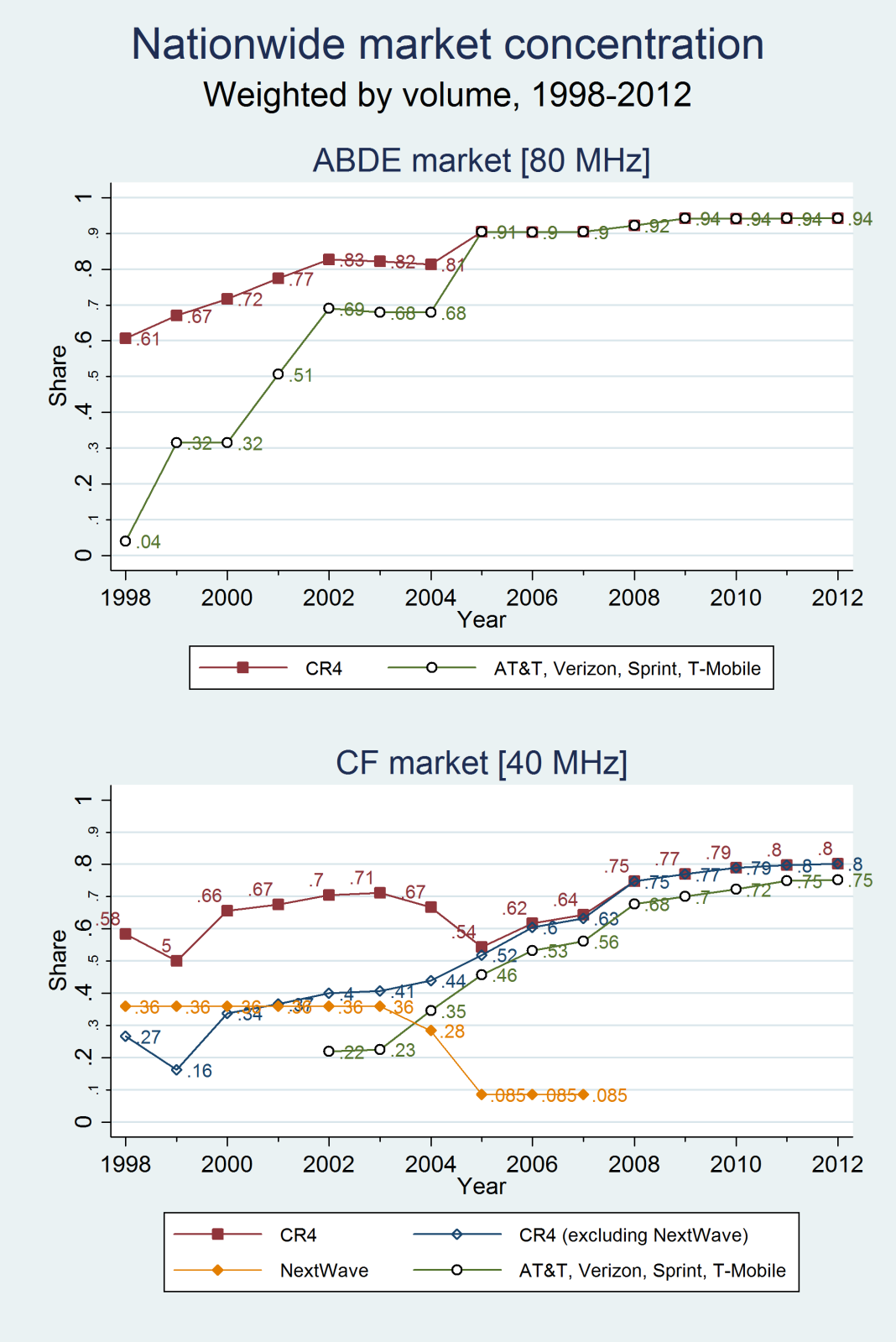

Figure 2.8: CR4 and the cumulative share of AT&T, Verizon Wireless, Sprint and T-Mobile, ABDE and CF markets. For the CF market, NextWave's share and CR4 without NextWave are also depicted.

Not pictured are the shares of the two biggest entrepreneurs that survived until 2012: Leap Wireless and MetroPCS. In 2012, they together hold 15% of the CF market[24]. Assuming that AT&T, Verizon Wireless, Sprint and T-Mobile did not divest any of their PCS spectrum since 2012 and that Leap Wireless and MetroPCS kept their market shares, the AT&T's acquisition of Leap Wireless (to be confirmed by DOJ and FCC) and T-Mobile's acquisition of MetroPCS in March 2013 increased the combined share of the biggest four firms in the CF market to more than 90%. Even though large companies including the four biggest firms have not been able to enter the CF market for some time, it appears the market structure of the ABDE and CF markets are converging, i.e. the CF market is becoming more and more like the ABDE market.

2.4.3.1 Spectrum Leasing and Its Effect on Market Concentration

Theoretically, spectrum leasing should have an effect on the market concentration on both the county and also nationwide level. The data show, however, that spectrum leasing does not represent a widely used long-term alternative to spectrum purchases. In total I observe 258 unique leasing agreements with 258 unique call signs. Although there are two types of spectrum leases (de facto transfer leases and spectrum manager leases), I do not differentiate between them.

Table 2.5 shows the annual shares of the nationwide volume of PCS spectrum leased to lessees, which are controlled by substantially different entities as lessors. Leasing arrangements reached their maximum volume in 2007 when 1.2% of nationwide spectrum was leased. In every year the top lessee and the top lessor was either AT&T, Sprint or T-Mobile.

[24]Their combined market share of the ABDE market amounts to less than 1%.

Year	Nationwide spectrum leased [%]
2005	0.42
2006	0.83
2007	1.24
2008	1.02
2009	0.77
2010	0.76
2011	0.47
2012	0.52

Table 2.5: Share of volume of nationwide PCS spectrum leased, in percent.

2.5 Empirical Analysis

2.5.1 Market Activity Immediately Following the Auctions

Cramton [2006] and Bajari and Fox [2013] suggest that there was little resale of licenses following the auctions (or perhaps even none at all). Cramton concludes that this absence of resale suggests that the auctions were highly efficient. On the other hand, Bajari and Fox recognize that many of the winning bidders were eventually involved in the consolidation of the mobile industry that created mobile carriers with nationwide footprints (see GAO [2010], Fox [2005], Fox and Perez-Saiz [2006], Sabat [2008a] and Sabat [2008b]). They believe Cramton's conclusion is too strong; the allocations might not have been efficient, but have been "pairwise stable in matches". However, when estimating a structural model of bidding in Auction 5 (the second initial auction in the context of this chapter) they nonetheless motivate their approach with an observation that there was "very little resale or swaps of licenses between bidders immediately after the auction, even though such activity was legally permissible and presumably had low transactions costs".

Using the reconstructed histories for each original license starting in 1995 I can empirically

assess if there is evidence of any resale, and if so, to what extent can these resales (and relatively quick entry of large companies in the initially restricted market) be attributed to the eligibility restrictions and to other types of preferential treatment.

Figure 2.9 shows every PCS auction (except the most recent and insignificant Auction 78). On the horizontal axis is the number of periods following the period at the end of which a license originating from a certain auction is observed for the first time. By convention, this first period is denoted as period 0[25]. This is to account for the fact that I only observe licenses once a year on every March 1st and that this date usually does not correspond to the date the license was granted. Since hypothetically licenses can exchange hands before I observe them for the first time, I must record such changes and chronologically place them before the first period in which the license is observed. This relative convention regarding timing also implies that I treat all licenses equally when it comes to their entry even if FCC granted some of them several periods later.

[25]Period 2 is then the second period after period 0; in other words, if the license is observed for the first time at the end of period 0, it must be that at the end of period 2 the license is observed for the third time (conditional on its survival).

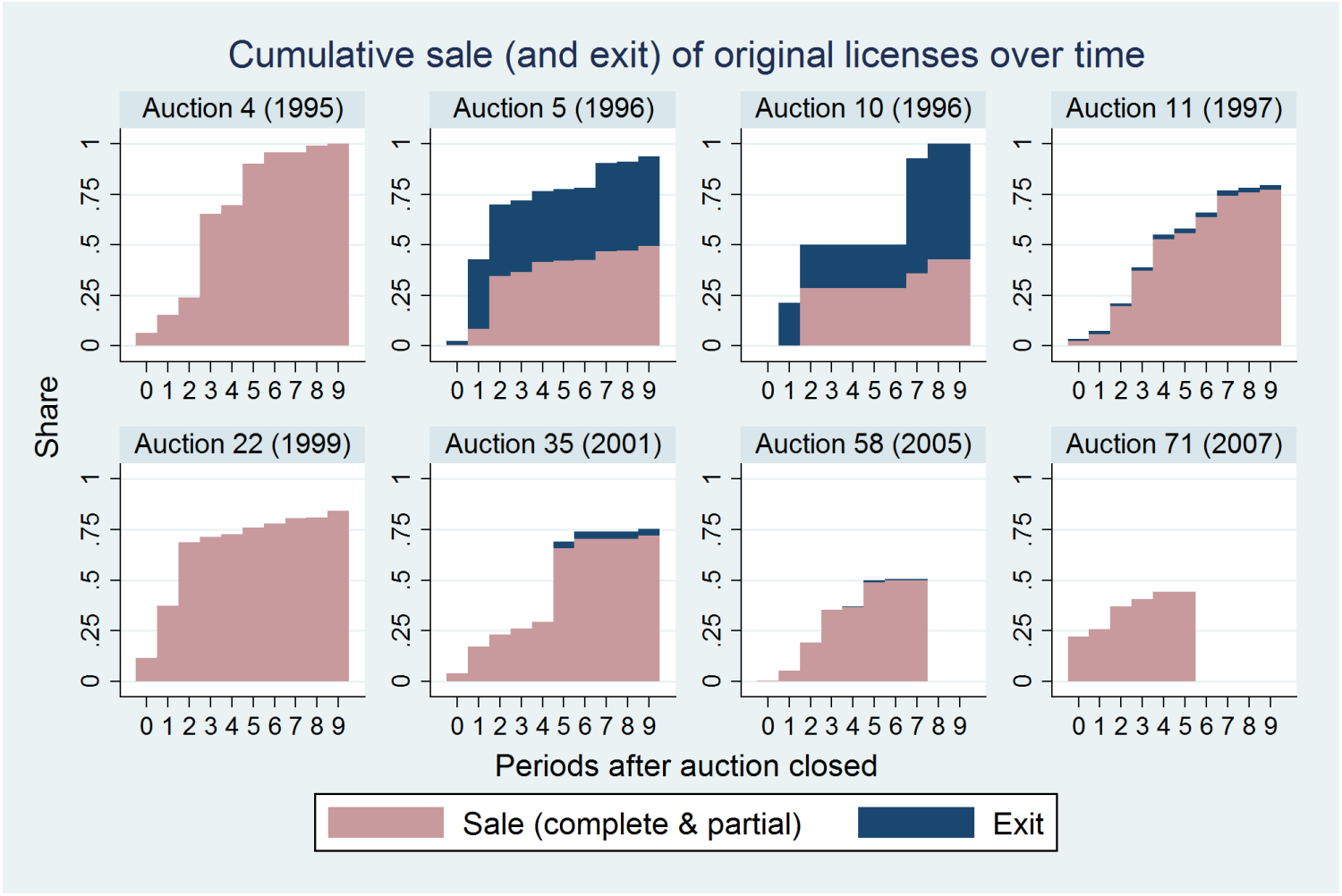

Figure 2.9: Cumulative share of licenses auctioned in each auction that are sold in the secondary market after each period. Licenses are observed for the first time at the end of period 0; period 0 captures the time between the official grant date and the first recorded date. Also depicted are cumulative exits.

On the vertical axis is the cumulative share of licenses auctioned in that auction that were affected by one complete or partial sale. That is, I flag all licenses as soon as they have been sold in their entirety or as soon as they were partitioned or disaggregated. I also record all licenses that have left the market up until the end of each period.

Table 2.6 shows the cumulative shares of affected licenses for each auction for the first two years, i.e. the first three observations of the ownership status for each license. Together with Figure 2.9 it provides evidence that there was indeed an active market for original licenses even right after the auctions closed. On average, 6% of licenses were affected by the time I observe them for the first time at the end of period 0; 14.4% were affected after their first year in my data set and almost a third of all issued original licenses (31.9%) were affected after two years.

	Cumulative share at the end of		
Auction	**Period 0**	**Period 1**	**Period 2**
4	0.065	0.152	0.239
5	0.002	0.085	0.346
10	0	0	0.286
11	0.024	0.059	0.196
22	0.116	0.373	0.688
35	0.041	0.171	0.233
58	0.005	0.052	0.192
71	0.222	0.259	0.370

Table 2.6: Cumulative share of licenses that were completely or partially sold in the first two years following each spectrum auction.

To test whether any of the observed characteristics of the winning bidders (licensees), licenses and auctions themselves might help explain this pattern of reselling, I set up a simple probit model explaining the observed first resale of the license in the first two years following the auction. This is in line with Cramton's observation that no transactions took place two years after PCS auctions (Bajari and Fox do not explicitly mention the time window they consider "immediate").

Specifically, I estimate the following probit model at the level of each individual license i:

$$\mathbb{P}(y_{ijmt} = 1|X_{ijmt}, t) = \mathbb{P}(y_{ijmt} = 1|\tilde{X}_{ijmt}) = \Phi(\tilde{X}'_{ijmt}\beta)$$

where $\tilde{X}_{ijmt}$ is the matrix of potentially time-varying explanatory variables for each license i (and county m and licensee j) including the time period t in question. I need to explicitly include the latter as my explanatory variable as I am basically modeling a series of up to 3 sequential decisions where this sequence ends as soon as the license (or its part) is sold for the first time, i.e. as soon as $y_{ijmt} = 1$ for license i. In period 0 resale can be potentially observed in all licenses; however, in period 1 only those licenses that have not yet been resold in period 0 will be again considered for resale (similarly for period 2). Resale in period 1 is therefore conditional on the period-0 decision; resale in period 2 is conditional on period-1 (and at the same time period-0) decision. Resale is therefore state-, i.e. time-dependent.

Table 2.7 presents the results of the two specifications. The baseline specification does not control for auction-fixed effects and potential complementarities between the license i and its holder's other licenses in adjacent markets. The latter variable is the only time-varying explanatory variable used. Both specifications give reasonable estimates for the effects of the explanatory variables and the state variable t; regarding the latter, each additional year increases the probability of the first resale. With respect to bidder characteristics, entrepreneurs resell their licenses more often than large companies; however the effect is smaller for the ABDE-winning entrepreneurs. ABDE licenses are resold less often than CF licenses, both restricted and unrestricted; also, the higher the bidding credits received the more probable it is the licensee will resell its license. License complementarities have the expected negative sign, decreasing the probability of the sale.

Dependent variable	License sold (1)	License sold (2)
Period	0.501	0.608
	(7.56)***	(8.44)***
ABDE license	-0.400	-1.462
	(-3.09)***	(-5.71)***
Restricted CF license	1.597	0.139
	(1.70)*	(2.13*
Entrepreneur	1.038	0.992
	(7.76)***	(4.70)***
ABDE entrepreneur	-0.629	-0.757
	(-6.38)***	(-3.38)***
Quantity ("bandwidth") [MHz]	0.0435	0.0252
	(9.92)***	(2.64)***
Bidding credits used [%]	1.023	2.759
	(2.20)**	(4.05)***
Log(population)	-0.0390	0.0634
	(-1.45)	(1.83)*
i(Entrepreneur*Restricted)	2.746	1.905
	(2.91)***	(1.95)*
i(ABDE entrepreneur*Restricted)	-0.342	-0.612
	(-1.89)	(-2.28)**
Number of licenses in adjacent markets		-0.141
		(-6.35)***
Constant	-2.291	-2.414
	(-6.17)***	(-3.49)***
Observations	4763	4739
Pseudo R^2	0.1425	0.2387
Auction FE		✓

Notes: An observation is a license. Population of all original licenses observed up to three times conditional on no resale and no exit. Dependent variable is the observed first sale of the license or its part in the first two years taking 0th period into account. Explanatory variables are license, licensee (winning bidder) and auction characteristics. Number of licenses in adjacent markets is the only time-varying explanatory variable. Auction fixed effects are auction-specific dummy variables. Z-values based on bootstrapped standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.7: License, licensee and auction characteristics as determinants of resale in the first two years following the auction.

2.5.2 Analysis of the Incentives of Entrepreneurs That Hold Restricted CF Licenses

While results of the previous subsection show that restricted CF licenses were more actively traded immediately following each PCS auction, this does not necessarily explain why did restricted licenses so quickly transition from entrepreneurs to large companies. These trades of restricted licenses could simply take place between entrepreneurs and not necessarily between entrepreneurs and large companies. A different identification strategy is required to capture this phenomenon.

To explain the actual transition and conversion of the restricted licenses owned by the entrepreneurs into the unrestricted licenses owned by large companies, I exploit the institutional design of eligibility restrictions, which prevented the sale of restricted licenses to large companies unless the construction requirements have been met. Every license had to be built out in 5 years after it was granted, generally giving no licensee an incentive to meet the requirements ahead of time. On the other hand, entrepreneurs were able to potentially sell their licenses to any firm once the license was constructed and could therefore profit by arbitrage given the high demand for unrestricted spectrum once all restrictions were lifted and licenses became freely tradable.

In a way, these rules introduced a dynamic decision problem for entrepreneurs. With non-negligible cost of construction delaying the build-out as long as possible should be preferred. At the same time PCS license were sought-after by large companies expanding their geographic coverage and so constructing the license early allowed the entrepreneur to sell it to the large company right away. Another interpretation (given my identical treatment of mergers and individual transactions) is that the large company could not take over the entrepreneur unless its licenses were constructed.

The decision to construct is not exogenous, so this situation doesn't fit the framework of a

natural experiment, for which regression discontinuity design techniques may be appropriate. Instead I model this as a sequence of three contingent decisions: the decision to construct, the conditional decision to keep (if constructed) and the conditional decision of an entrepreneur to sell the license to a large company (if not kept). Given my data constraints, I use a series of univariate binary choice probit models and additionally test for the correlation between the latter. The data from 1995 to 2012 are used.

2.5.2.1 Build-Out Patterns

After taking into account partitioning and disaggregation of licenses that have yet to be built out, which results in a similar requirement for new derivative licenses, my data set contains 2854 licenses for which construction requirements need to be met. Because the decision to construct will be followed by the decision to keep (or sell) the license at the beginning of the next period, which is by definition a county-level decision (given that partitioning and disaggregation are allowed), my unit of observation is therefore a county-license.

Each holder of particular license in a particular period has to decide whether to construct the license or not. Construction takes place at the end of each period after licenses have potentially already changed hands. Given that licensees had 5 years to meet their construction requirements (and possibly less for some derivative licenses), a sequence of up to 5 binary decisions per license in each county should be observed[26].

Figure 2.10 shows how build-out patterns vary for large companies and entrepreneurs, and for entrepreneurs that hold restricted and unrestricted licenses. It appears almost all large companies and entrepreneurs holding unrestricted licenses wait until the deadline to meet the requirement; on the other hand, entrepreneurs holding restricted licenses build some of them as early as in the first period (that is, with four more periods to go), with less than 50%

[26]Very few licensees took more than 5 years to built out their networks. Those are the licensees with whose licenses have been tied up in legal and/or bankruptcy proceedings. I account for this gap in my analysis.

of restricted licenses built out just before the deadline. A closer inspection of the data shows that there is only a small overlap between entrepreneurs constructing both restricted and unrestricted licenses. Most entrepreneurs build out either restricted or unrestricted licenses, but not both.

Figure 2.10: Build-out patterns for large companies and entrepreneurs, and for entrepreneurs holding restricted and unrestricted licenses.

To recover the estimates of the coefficients of observable characteristics that can explain such behavior, I first estimate a probit model of the decision to construct the license for all firms, i.e. large companies and entrepreneurs.

Specifically,

$$y^*_{ijmt} = X'_{ijmt}\beta + \epsilon_{ijmt}$$

is the latent profit function of the firm where

$$y_{ijmt} = 1 \iff y^*_{ijmt} = X'_{ijmt}\beta + \epsilon_{ijmt} > 0.$$

y_{ijmt} is the dummy variable indicating whether the firm j built out the license i in a specific county m in the period t. As in the previous section, probit implies

$$\mathbb{P}(y_{ijmt}) = 1|X_{ijmt} = \Phi(X'_{ijmt}\beta).$$

The vector X_{ijmt} contains various license-, market- and firm-specific explanatory variables and the variable τ indicating the number of periods left until the deadline $\tau = 5-t$. Summary statistics of variables can be found in Table 2.1. Time t is relative, that is $t \in [1, 5]$ and indicates the age of the license (or in the case of derivative license, the age of the original license). To account for the fact that licensees had 5 years to build out their licenses, and that the threat of termination meant that the probability of build-out (conditional on not yet meeting the construction requirement) is increasing, the closer the firm is to the 5-year deadline, I include the number of periods remaining (τ) as one of the baseline explanatory variables. This variable should capture the fact that the probability must be time-dependent. To control for correlation between county-licenses belonging to the same group, i.e. to the same license, I cluster standard errors at the license level. The results of different specifications are reported in Table 2.8.

Dependent variable	Decision to construct (1)	Decision to construct (2)	Decision to construct (3)	Decision to construct (4)	Decision to construct (5)
Periods remaining	-0.906	-1.052	-0.947	-0.949	-1.200
	(-23.16)***	(-21.78)***	(-24.48)***	(-21.77)***	(-28.34)***
Entrepreneur	0.653	0.876	0.834	1.203	1.298
	(4.16)***	(4.24)***	(4.55)***	(6.90)***	(5.53)***
Restricted CF license	0.0823	0.962	0.319	-0.0309	1.118
	(0.51)	(4.05)***	(1.73)*	(-0.18)	(4.33)***
ABDE license	-0.0328	1.389	0.356	0.122	1.889
	(-0.71)	(7.24)***	(4.78)***	(1.88)*	(8.47)***
i(ABDE license*Entrepreneur)	-0.463	-0.664	-0.552	-0.364	-0.562
	(-2.73)***	(-3.01)***	(-2.82)***	(-1.55)	(-1.73)*
Local area personal income [$]			0.0000248		-0.000000126
			(6.01)***		(-0.04)
HHI			0.000327		0.000336
			(4.44)***		(4.28)***
ABDE entrepreneur				0.253	0.671
				(2.43)**	(5.66)***
i(ABDE license*ABDE entrepreneur)				-0.575	-0.807
				(-2.72)***	(-2.95)***
Size of licensee [1 to 5]				0.289	0.296
				(12.03)***	(10.97)***
Licensee has other licenses in county				0.132	-0.0527
				(3.69)***	(-1.04)
Constant	0.464	-2.963	-3.327	-1.375	-4.091
	(8.80)***	(-7.63)***	(-11.67)***	(-8.48)***	(-8.19)***
Observations	90974	90972	83973	90974	83971
Pseudo R^2	0.3799	0.4440	0.4196	0.4233	0.4774
Auction FE		✓			✓
County FE			✓		✓

Notes: An observation is a county-license. Population of county-licenses for which the construction requirement has not yet been met. Dependent variable is the observed decision to construct the license. Explanatory variables are license, licensee, county and auction characteristics, both time-varying and time-invariant. Auction fixed effects are auction-specific dummy variables; county fixed effects are the share of households with income > $35,000, log(population) and population density. Z-values based on standard errors clustered at the license level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.8: Determinants of the licensee's decision to meet the license construction requirement.

Specification #1 is the baseline specification; even very few explanatory variables do a relatively good job at predicting the dependent variable. Specification #2 adds auction fixed effects, i.e. dummy variables for each auction; specification #3 adds county-level fixed effects in the form of the share of households with income greater than $35,000, log(population) and population density. Also, time-varying HHI (observed in the same period but before the decision is made) and BEA local area personal income are added; the latter acts as a demand shifter[27]. Specification #4 adds additional licensee-specific characteristics and specification #5 combines and jointly estimates the coefficients for all these variables.

Even though estimated coefficients in the probit model do not have a direct interpretation, the inspection of the signs shows that the entrepreneurs consistently build out their licenses early. Estimated coefficients make sense; the closer the firm to the deadline (i.e. the smaller the τ), the greater the probability to construct. Entrepreneurs have a consistently significant positive coefficient across all five specifications. Also, when licenses are not pooled over all auctions, that is when auction fixed effects are used, the coefficient on restricted licenses and their marginal effects are both positive and economically significant.

2.5.2.2 Post-Build-Out Behavior

When entrepreneurs meet the construction requirements, their restricted licenses become freely tradable, i.e. unrestricted. Only then can large companies purchase once-restricted C and F block licenses. The data shows that this was indeed happening en masse; large companies have been purchasing large quantities of the newly-unrestricted spectrum by either acquiring licenses or simply taking over the entrepreneurs. Figure 2.11 shows the gradual opening of the CF market, and its share which large companies have bought once they could do so. Figure 2.11 is the same as Figure 2.2 but with large companies' holdings of once-restricted spectrum superimposed. Figure 2.12 shows the share of (unrestricted) ABDE

[27]Other demand shifters for the same county were strongly correlated with this variable, so I excluded them.

spectrum entrepreneurs held over time.

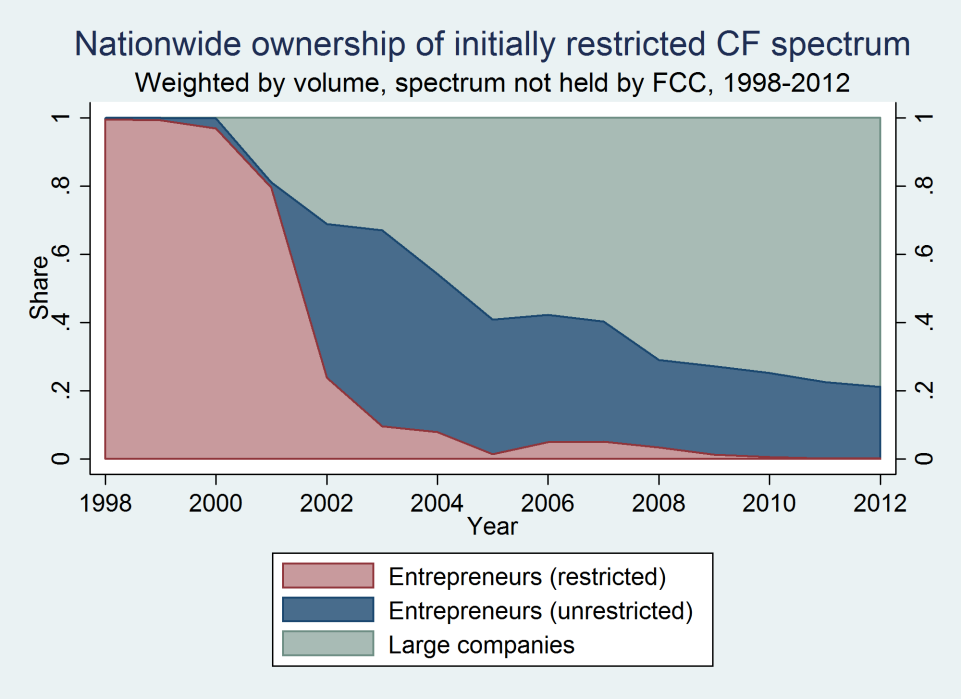

Figure 2.11: Gradual opening up of the CF market, i.e. conversion of the restricted CF spectrum to unrestricted CF spectrum, with the share of spectrum owned by large companies superimposed.

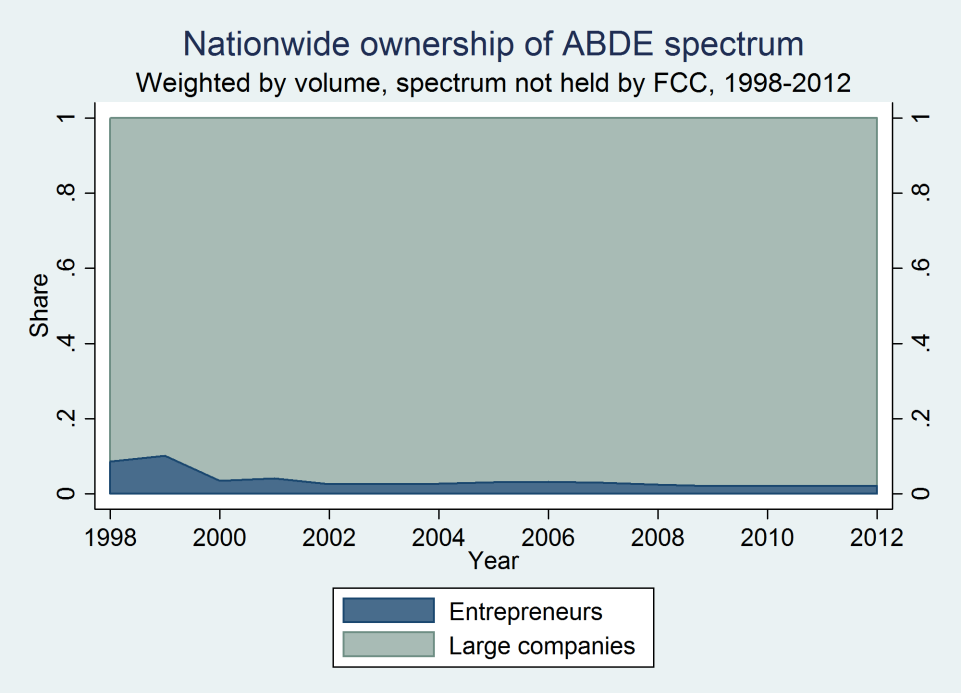

Figure 2.12: Composition of the ownership of the ABDE spectrum.

Figure 2.11 shows that large companies did not enter the CF market until 2000, even though a small portion has already opened up in 1998. In 2001, around 20% of the entire nationwide CF spectrum has been bought by large companies when Voicestream acquired Omnipoint. Between 2000 and 2003 there was a sharp decrease in the share of restricted spectrum, or vice versa, a sharp increase in the share of the unrestricted spectrum. Even though this roughly corresponds with the 5-year construction requirements that were imposed on the licenses won in the initial auctions (Auctions 5 and 11), the majority of those have actually been terminated and so the observed pattern is due to entrepreneurs building out their networks well before the deadlines. Also, one can see the increasing share of the unrestricted CF spectrum that is owned by large companies. In 2012, only approximately 20% of CF spectrum is held by entrepreneurs, with an insignificant share of spectrum still restricted. However, if one takes into account that more than three quarters, i.e. more than 15% of the entire nationwide CF spectrum are in 2012 held by Leap Wireless and MetroPCS, it seems that the entrepreneurs were basically driven out of this market with these two recent major transactions. The difference in the distribution of the ownership of the restricted CF spectrum can also be seen in Figures 2.13 and 2.14.

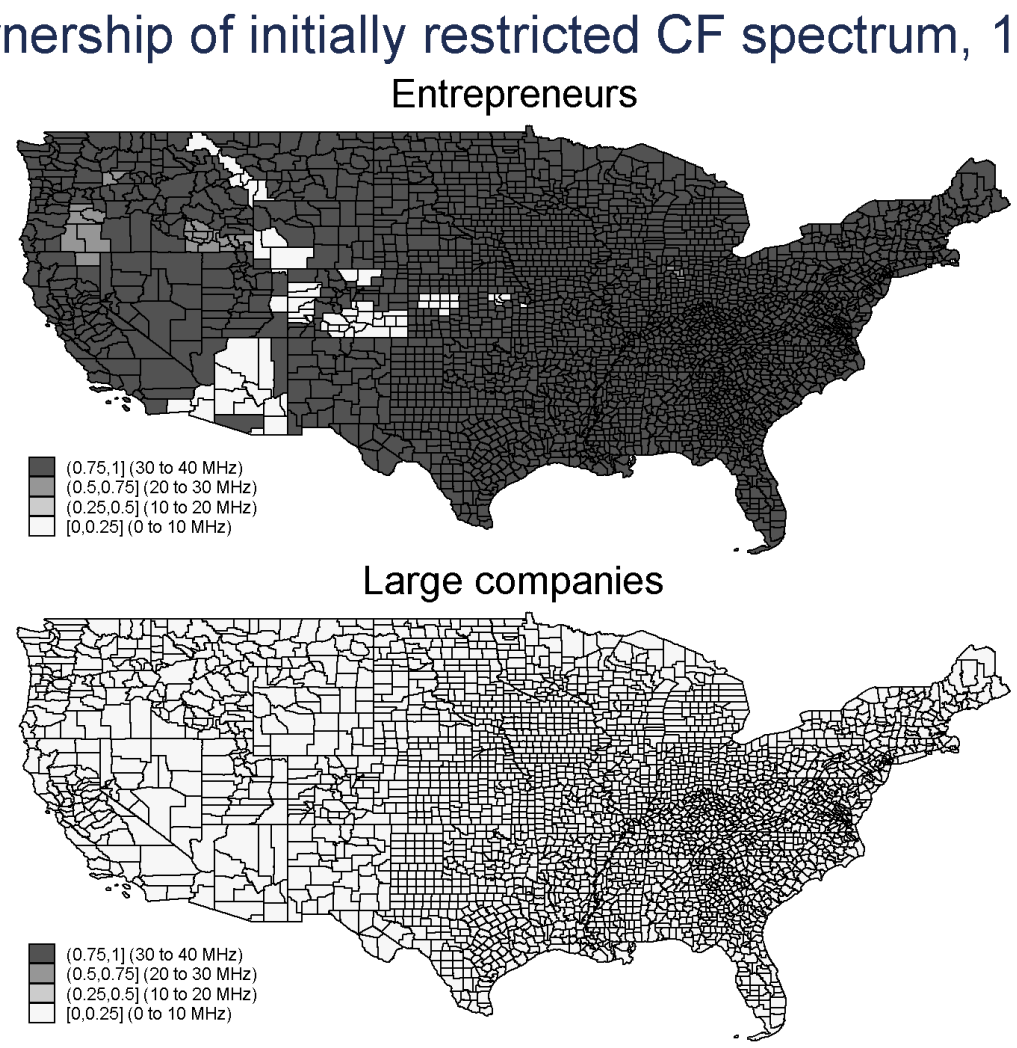

Figure 2.13: Restricted CF spectrum, 1998. Some Auction 5 licenses were not sold in 1998 (and/or were already returned).

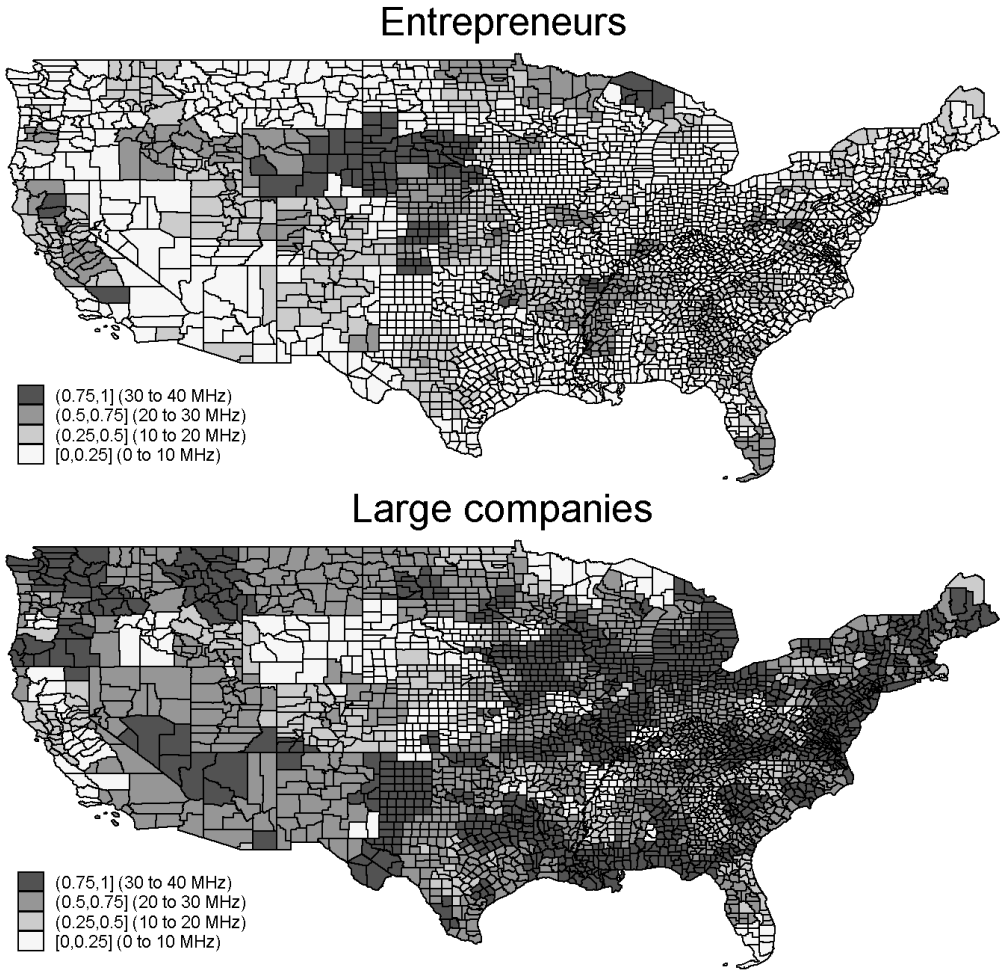

Figure 2.14: Restricted CF spectrum, 2012.

To investigate whether entrepreneurs were indeed constructing their restricted licenses only to be able to later resell them to large companies, I analyze the immediate decision to sell of all firms that met the requirement. Table 2.9 shows the decision to keep the license (conditional on constructing it) for entrepreneurs and large companies. The majority of large companies that met the construction requirements kept their licenses; in fact, out of almost 13000 such licenses at the county level only 13% were sold immediately following the construction. Entrepreneurs, on the other hand, sold more than 35% of almost 10000 licenses at the county level. Table 2.10, which shows who firms sell their licenses to. is even more telling.

	Sell	**Keep**	**Total**
Large companies	1710	11072	12782
Entrepreneurs	3557	6358	9915
Total	5267	17430	22697

Table 2.9: Tabulation of decisions to keep for entrepreneurs and large companies, conditional on meeting the construction requirement.

	Sell to large company	**Sell to entrepreneur**	**Total**
Large companies	1678	32	1710
Entrepreneurs	2753	804	3557
Total	4431	836	5267

Table 2.10: Tabulation of decisions whom to sell the license to, conditional on meeting the construction requirement and not keeping the license.

98% of all sales by large companies are to large companies and less than 2% of licenses are sold to entrepreneurs. Entrepreneurs, on the other hand, sell more than 77% of their licenses to large companies. It appears there is a significant asymmetry in the direction of the license flow from sellers to buyers. In the transactions immediately following the construction of licenses, very few of these end up with entrepreneurs; the majority is bought by large companies.

These cross-tabulations are however pooled over all observed variation contained in the ex-

planatory variables in my data set. To formally analyze this problem controlling for the observed heterogeneity two more probit models need to be estimated. The first probit models the decision to keep the license conditional on the firm just meeting the construction requirement. As before five specifications are tested by separately adding auction-fixed effects, county-fixed and time-varying effects and firm-level heterogeneity. Here, licenses can be freely traded at the county level, so I do not use clustering anymore; instead I use bootstrapping.

Table 2.11 shows the results. As expected, the τ variable has a negative coefficient given that it is decreasing and that we expect the probability to keep the license to increase over time. Note that an increase in the predicted value of the dependent variable implies a higher probability to keep the license; the expected behavior of entrepreneurs (that is, "selling after constructing") requires a decreasing probability. For example, a negative coefficient on the entrepreneur variable is consistent with the expected behavior as we expect entrepreneurs to keep the licenses less often (and sell them more often). The effect of restricted licenses additionally amplifies the "entrepreneur" effect; note that while the coefficient on the ABDE license is also negative, its marginal effect on the dependent variable is of smaller magnitude.

Dependent variable	Decision to keep (1)	Decision to keep (2)	Decision to keep (3)	Decision to keep (4)	Decision to keep (5)
Periods remaining	-0.194	-0.368	-0.256	-0.253	-0.720
	(-21.01)***	(-30.91)***	(-25.18)***	(-26.20)***	(-43.64)***
Entrepreneur	-1.729	-2.658	-1.694	-1.356	-2.207
	(-11.09)***	(-16.81)***	(-10.48)***	(-8.03)***	(-12.96)***
Restricted CF license	-0.256	-0.403	-0.0641	-0.372	-0.305
	(-4.88)***	(-4.83)***	(-1.18)	(-6.95)***	(-3.42)***
ABDE license	-1.464	-1.527	-1.252	-1.423	-1.348
	(-9.88)***	(-9.18)***	(-8.11)***	(-8.90)***	(-7.62)***
i(ABDE license*Entrepreneur)	1.202	1.880	1.192	6.348	7.772
	(7.50)***	(11.48)***	(7.19)***	(0.06)	(0.10)
Log(license volume)		-0.0288			-0.125
		(-3.00)***			(-10.35)***
Local area personal income [$]			0.0000397		0.0000127
			(16.60)***		(4.61)***
HHI			0.0000798		0.0000242
			(2.37)**		(0.58)
ABDE entrepreneur				0.166	0.256
				(5.48)***	(7.35)***
i(ABDE license*ABDE entrepreneur)				-5.593	-6.035
				(-0.05)	(-0.08)
Size of licensee [1 to 5]				0.238	0.570
				(20.48)***	(35.59)***
Licensee has other licenses in county				0.0825	-0.185
				(3.96)***	(-6.79)***
Constant	2.557	5.359	0.872	1.164	5.702
	(17.34)***	(24.72)***	(4.34)***	(6.76)***	(22.25)***
Observations	22697	22686	22461	22697	22450
Pseudo R^2	0.1942	0.2211	0.2140	0.2254	0.3082
Auction FE		✓			✓
County FE			✓		✓

Notes: An observation is a county-license. Population of county-licenses for which the construction requirement has been met. Dependent variable is the observed decision to keep the license. Explanatory variables are license, licensee, county and auction characteristics, both time-varying and time-invariant. Auction fixed effects are auction-specific dummy variables; county fixed effects are the share of households with income > $35,000, log(population) and population density. Z-values based on bootstrapped standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.11: Determinants of the licensee's decision to keep the license conditional on meeting its construction requirement.

As this is a selected sample of all firms that had to decide whether or not to construct, coefficients are valid only for those firms that have actually constructed their licenses. In other words, coefficients obtained are biased if interpreted as valid for all firms since we are not directly controlling for sample selection.

To address the problem of sample selection, one cannot estimate the selection equation and simply form the inverse Mills ratio, which is then used as an additional regressor in the (linear) outcome equation (as suggested by Heckman [1979]). Probit model is nonlinear and so a bivariate probit model with sample selection needs to be estimated using the maximum likelihood technique (van de Ven and van Praag [1981]). Even though the model can be in principle identified via distributional assumptions, the usual approach is to have an exclusion restriction in the selection equation, i.e. a variable that does not appear in the outcome equation. Since there is no theoretical prediction underlying the choice of the exclusion restriction in the context of our analysis, I estimate the bivariate probit with sample selection by using the full specification for the decision to construct (except for the auction dummies) and the baseline specification for the decision to keep the license. More complicated specifications of the outcome equation generally resulted in a non-concave log-likelihood function and in the non-convergence of the optimization algorithm[28]. The results are reported in Table 2.12.

[28]I also estimated the same model via gllamm and cmp within Stata. Both had problems converging. Additionally, I estimated the same model using the multiprocess multilevel modeling software aML (http://www.applied-ml.com), but the results were unstable and convergence was typically not achieved. Of all approaches, Stata's heckprob was the most efficient and also allowed for bootstrapping.

Outcome probit

Dependent variable	Decision to keep
	(2)
Periods remaining	0.212***
	(13.85)
Entrepreneur	-1.733***
	(-12.21)
Restricted CF license	-0.358***
	(-7.49)
ABDE license	-1.409***
	(-10.44)
i(ABDE license*ABDE entrepreneur)	1.225***
	(8.40)
Constant	2.708***
	(20.17)

Selection probit

Dependent variable	Decision to construct
	(1)
Periods remaining	-0.977
	(-150.40)***
Entrepreneur	1.262
	(27.01)***
Restricted CF license	0.172
	(5.02)***
ABDE license	0.458
	(13.69)***
ABDE entrepreneur	-0.233
	(-2.92)***
Log(license volume)	-0.0317
	(-7.96)***
Local area personal income [$]	0.0000336
	(25.84)***
HHI	0.000283
	(14.37)***
ABDE entrepreneur	0.303
	(15.89)***
i(ABDE license*ABDE entrepreneur)	-0.797
	(-10.99)***
Size of licensee [1 to 5]	0.291
	(37.25)***
Licensee has other licenses in county	0.0189
	(1.42)
Constant	-3.245
	(-32.98)***
ρ	-0.715 [***]
Observations	83811
Censored/uncensored observations	61350/22461
County FE	✓

Notes: An observation is a county-license. Population of county-licenses for which the construction requirement has not yet been met (selection probit); population of county-licenses for which the construction requirement has been met (outcome probit). Sample selection in the outcome probit if $\rho \neq 0$. Identification via exclusion restrictions. Dependent variable is the observed decision to construct the license (selection probit) and the observed decision to keep the license (outcome probit) conditional on constructing it. Explanatory variables are license, licensee and county characteristics, both time-varying and time-invariant. County fixed effects are the share of households with income > $35,000, log(population) and population density. Z-values based on bootstrapped standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.12: Bivariate probit with sample selection: decision to construct and decision to keep.

Of all estimated coefficients the most interesting is the value of $\rho = -0.70$, that is the correlation of the errors in both probit models. If ρ was 0, the two models would be independent and the selection would be random in the sense that the decision to construct would not have any predictive value for the decision to keep. A statistically significant and negative correlation of ϵ_{1ijmt} and ϵ_{2ijmt} implies that there is indeed sample selection, i.e. those who build out early are more likely to sell the license.

2.5.2.3 Decision to Sell to an Entrepreneur

Turning to the question who do firms sell their licenses to, if they decide not to keep them, shows that I need to modify the estimation approach I have been using so far. As only 32 (out of 1710) licenses are transferred from large companies to entrepreneurs, the entrepreneur variable is an almost-perfect predictor when its value is 0. That is, were it not for these 32 licenses, the fact that the seller is a large company would perfectly predict that its licenses will be sold to a large company.

Knowing that large companies almost never sell to entrepreneurs, I get around the problem by focusing on the latter only. I estimate a probit model of whether an entrepreneur sells its license to another entrepreneur (conditional on, first, constructing it and, second, not keeping it). Instead of focusing on differences between entrepreneurs and large companies, I look at different types of entrepreneurs. This means that I explicitly distinguish between regular-sized entrepreneurs, very small entrepreneurs and small entrepreneurs; additionally, I interact entrepreneurs' sizes with whether they won any ABDE licenses and whether they also held any restricted CF licenses. By specifically focusing on entrepreneurs, I need to adapt my specifications accordingly; I cannot use any variable that is a function of the entrepreneur variable.

In the end, I tested two specifications. In my first specification the probability to sell to an entrepreneur was modeled as a function of characteristics of the seller (i.e. entrepreneur) and

of the license; in the second specification I added several county-level and firm-level effects. The results can be found in Table 2.13.

Dependent variable	Entrepreneur selling to another entrepreneur (1)	Entrepreneur selling to another entrepreneur (2)
Periods remaining	-0.0704	0.0330
	(-2.09)**	(0.86)
Small entrepreneur	-1.730	-1.585
	(-6.25)***	(-5.65)***
Very small entrepreneur	-2.197	-2.725
	(-8.79)***	(-10.08)***
i(Small*Restricted license)	1.582	0.969
	(5.89)***	(3.44)***
i(Very small*Restricted license)	0.308	1.082
	(1.81)*	(5.26)***
ABDE entrepreneur	0.318	0.433
	(5.02)***	(5.95)***
Log(license volume)	-0.390	-0.370
	(-13.83)***	(-11.35)***
HHI		-0.000809
		(-6.92)***
Size of licensee [1 to 5]		-0.602
		(-9.99)***
Bidding credits used [%]		-2.815
		(-5.11)***
Licensee has other licenses in county		0.0335
		(0.42)
Constant	9.113	10.14
	(17.08)***	(15.39)***
Observations	3547	3547
Pseudo R^2	0.3153	0.3640
Auction FE	✓	✓
County FE		✓

Notes: An observation is a county-license. Population of county-licenses for which the licensee is an entrepreneur which met the construction requirement and is not keeping the license. Dependent variable is the observed decision of an entrepreneur to sell the license to another entrepreneur. Explanatory variables are license, licensee, county and auction characteristics, both time-varying and time-invariant. Auction fixed effects are auction-specific dummy variables; county fixed effects are the share of households with income > $35,000, log(population) and population density. License-specific effects are modeled using log(license volume). Z-values based on bootstrapped standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.13: Determinants of the entrepreneur's decision to sell the license to another entrepreneur (conditional on meeting the construction requirement and not keeping the license.

From the results it appears that the smaller the entrepreneur, the higher the probability that its license(s) will be sold to a large company. On the other hand, it appears the ABDE-winning entrepreneurs had a lower probability of selling to a large company. Licenses acquired in closed-bidding auctions where eligibility restrictions were used are also more often sold to large companies. Demand (proxied by the local area personal income) increases the probability of selling to a large company, as does a higher HHI and higher bidding credits the entrepreneur received for a specific license.

To control for potential correlation between the entrepreneur's decision to sell/keep the license and its decision to sell it to a large company, I estimate another bivariate probit model with sample selection. Convergence was again a problem, so I use a simple specification which guarantees the concavity of the log-likelihood function. The results can be found in Table 2.14.

Outcome probit

Dependent variable	Entrepreneur selling to another entrepreneur (2)
Periods remaining	-0.238***
	(-9.12)
Small entrepreneur	0.549**
	(1.98)
Very small entrepreneur	-1.128***
	(-4.47)
i(Small*Restricted license)	0.0656
	(0.23)
i(Very small*Restricted license)	0.721***
	(3.66)
i(Small*ABDE license)	-6.816***
	(-3.87)
i(Very small*ABDE license)	1.359***
	(5.48)
ABDE entrepreneur	0.273***
	(4.81)
Constant	0.391
	(1.64)

Selection probit

Dependent variable	Decision to keep if entrepreneur (1)
Periods remaining	0.300
	(29.84)***
Entrepreneur	0.118
	(2.31)**
ABDE license	0.100
	(1.81)*
Log(license volume)	0.00919
	(0.68)
Local area personal income [$]	-0.0000536
	(-11.27)***
HHI	-0.000325
	(-5.59)***
Size of licensee [1 to 5]	-0.155
	(-8.19)***
Licensee has other licenses in county	0.156
	(5.11)***
Constant	0.385
	(1.94)*
ρ	-0.657 [***]
Observations	9893
Censored/uncensored observations	6336/3557
County FE	✓

Notes: An observation is a county-license. Population of county-licenses owned by entrepreneurs for which the construction requirement has been met (selection probit); population of county-licenses owned by entrepreneurs for which the construction requirement has been met and county-license is not kept (outcome probit). Sample selection in the outcome probit if $\rho \neq 0$. Identification via exclusion restrictions. Dependent variable is the observed decision of an entrepreneur to keep the license (selection probit) and the observed decision of an entrepreneur to sell the license to another entrepreneur (outcome probit) conditional on not keeping it. Explanatory variables are license, licensee and county characteristics, both time-varying and time-invariant. County fixed effects are the share of households with income > $35,000, log(population) and population density. Z-values based on bootstrapped standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.14: Bivariate Probit: decision (not) to keep and sell to entrepreneur if licensee is an entrepreneur.

Again, I am mainly interested in the correlation parameter between the errors of the two models, i.e. whether selection at the keep/sell stage was random. It appears this was not the case. ρ parameter is statistically significant and negative with a value of $\rho = -0.66$, meaning that there is a negative correlation between the entrepreneur's decision to keep and its decision to sell to a large company. In other words, entrepreneurs who decide not to keep their license (after they have met the construction requirements) are more likely to sell it to a large company than to another entrepreneur.

The sequence of all three probit models could also be analyzed in the framework of a trivariate probit with double sample selection. There is no built-in command that would allow something like this in any software package I know; instead, I used cmp (within Stata) and aML. Even for a very simple three-stage specification, however, the optimization would break down.

2.6 Conclusion

Using a novel transaction-level data set this chapter provides the first detailed historical overview of the market for PCS spectrum and its evolution in response to auction restrictions used by FCC. While there is an abundance of theoretical studies, the lack of reliable data has been often cited as the major problem for empirical work. By creating the first comprehensive data set of spectrum holdings of firms, this study fills this void and allows for the first empirical analysis of long-term market outcomes.

The descriptive analysis shows how eligibility restrictions created two separate markets for PCS spectrum by initially barring large companies from holding licenses meant for entrepreneurs. The data shows how the market structures of the two markets gradually converge, especially after the recent takeovers of the last two major remaining entrepreneurs. Further, the chapter documents the growing asymmetry in the distribution of firm sizes. Also, the probability of survival of entrepreneurs that won licenses in auctions with eligi-

bility restrictions is considerably lower than the probability of survival of other firms. This result implies that, on average, the eligibility restrictions attracted many firms that were either not capable or not willing to stay in the market.

Additionally, the chapter provides evidence of significant market activity immediately following PCS auctions even though the existing empirical literature suggests otherwise. The discrepancy is the result of the detailed nature of my data. While prior studies observed only transactions where entire licenses changed hands, I can observe how licenses get split and sold at the level of each individual county. Such activity can be attributed to specific characteristics of licenses, licensees and auctions, most notably the eligibility restrictions and other types of preferential treatment.

Finally, I explore the factors that explain the observed transition of once-restricted spectrum into the hands of large companies. My identification strategy relies on the institutional design of FCC's rules. I endogenize the observed behavior of firms by modeling it as a sequence of contingent decisions. This allows me to provide evidence showing that some entrepreneurs consistently met the construction requirements of their licenses early only to be able to immediately resell such licenses to large companies. It appears that many entrepreneurs found it more profitable to quickly sell their initially restricted licenses to large companies than to enjoy the legal protection these licenses offered.

Overall, the findings imply that in the long run the eligibility restrictions had no effect on the market structure of the market for PCS spectrum. This market and the eligibility restrictions used by FCC can therefore serve as a laboratory for exploring the effects of potential auction restrictions in the upcoming 600 MHz incentive auction. Based on the long-run outcomes in the PCS spectrum market, it appears that the current focus of the competition policy on auction design might be overstated; auction restrictions might change the initial auction allocations and affect the revenues collected by the Treasury, but they do not change the market outcomes in the long run. This result is similar to the one usually obtained in the

Coasean world with no transaction costs, even though the transaction costs in this industry seem to be significant.

Bibliography

1. Athey, S., Coey, D., Levin, J. (2013). Set-Asides and Subsidies in Auctions. American Economic Journal: Microeconomics, 5:1-27.

2. Ausubel, L.M., Cramton, P., McAfee, R.P., McMillan, J. (1997). Synergies in Wireless Telephony: Evidence from the Broadband PCS Auctions. Journal of Economics & Management Strategy, 6:497-527.

3. Ayres, I., Cramton, P. (1996). Deficit Reduction Through Diversity: How Affirmative Action at the FCC Increased Auction Competition. Stanford Law Review, 48:761-815.

4. Baker, J.B. (2013). Spectrum Auction Rules That Foster Mobile Wireless Competition. In the Matter of Policies Regarding Mobile Spectrum Holdings, WT Docket No. 12-269.

5. Balto, D., Singer, H. (2013). The FCC's Incentive Auction: Getting Spectrum Policy Right. Progressive Policy Institute, Backgrounder.

6. Bazelon, C., McHenry, G. (2014). Spectrum Sharing - Taxonomy and Economics. The Brattle Group.

7. Bazelon, C., Zarakas, W.P. (2009). Measuring Concentration In Radio Spectrum License Holdings. The Brattle Group.

8. Besen, S.M., Moresi, S.X., Salop, S.C. (2013). Why Restricting Participation in Spectrum Auctions Can Increase Bidder Participation, Increase Auction Revenues, and Increase Competition in Wireless Markets. In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, WT Docket No. 12-268.

9. Bradford, W.D. (2000). Discrimination in Capital Markets, Broadcast/Wireless Spectrum Service Providers and Auction Outcomes. Working Paper.

10. Brusco, S., Lopomo, G. (2002). Collusion via Signalling in Simultaneous Ascending Bid Auctions with Heterogeneous Objects, with and without Complementarities. Review of Economic Studies, 69:407-436.

11. Bulow, J., Levin, J., Milgrom, P. (2009). Winning Play in Spectrum Auctions. NBER Working Paper 14765.

12. Campbell, F.B. (2013). Maximizing The Success Of The Incentive Auction. Prepared for the Expanding Opportunities for Broadcasters Coalition and Consumer Electronics Association.

13. Campos e Cunha, L., Santos, V. (1995). Secondary markets in auctions with endogenous valuations. Economics Letters, 48:307-311.

14. CBO (2005). Small Bidders in License Auctions for Wireless Personal Communications Services. CBO Paper.

15. Chakravorti, B., Sharkey, W.W., Spiegel, Y., Wilkie, S. (1995). Auctioning the Airwaves: The Contest for Broadband PCS Spectrum. Journal of Economics & Management Strategy, 4:345-374.

16. Che, Y., Haile, P.A. (2013). Comments on T-Mobile's "Dynamic Market Rule" Proposal. In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, WT Docket No. 12-268.

17. Coase, R.H. (1959). The Federal Communications Commission. Journal of Law and Economics, 2:1-40.

18. Corr, O.C. (2000). Money from Thin Air: The Story of Craig McCaw, the Visionary who Invented the Cell Phone Industry, and His Next Billion-Dollar Idea. Crown Publishing Group.

19. Cramton, P. (2002). Spectrum Auctions. In Cave, M.E., Majumdar, S.K., Vogelsang, I. (eds.). Handbook of Telecommunications Economics, Vol. 1: Structure, Regulation and Competition. North-Holland. 605-639.

20. Cramton, P. (2006). Simultaneous Ascending Auctions. In Cramton, P., Shoham, Y., Steinberg, R. (eds.). Combinatorial Auctions. MIT Press. 99-114.

21. Cramton, P., Kwerel, E., Rosston, G., Skrzypacz, A. (2011). Using Spectrum Auctions to Enhance Competition in Wireless Services. Journal of Law and Economics, 54:S167:S188

22. Crandall, R.W. (2005). Competition and Chaos: U.S. Telecommunications since the 1996 Telecom Act. Brookings Institution Press.

23. Crandall, R.W., Ingraham, A.T. (2007). The Adverse Economic Effects of Spectrum Set-Asides. Criterion Economics, Research Paper 2008-03.

24. Dana, J.D., Spier, K.E. (1994). Designing a private industry: Government auctions with endogenous market structure. Journal of Public Economics, 53:127-147.

25. de Vries, J.P., Chan, C. (2010). Edge License Discounts in Cellular Auctions. The 38th Research Conference on Communication, Information and Internet Policy (TPRC 2010).

26. DeGraba, P., Rosston, G.L. (2013). The Proposed Merger of AT&T and T-Mobile: Rethinking Possible (2011). In Kwoka, J.H., White, L.J. (eds.). The Antitrust Revolution: Economics, Competition, and Policy. Oxford University Press, Sixth Edition. 34-61.

27. Deloitte (2012). Airwave overload? Addressing spectrum strategy issues that jeopardize U.S. mobile broadband leadership.

28. Dippon, C.M. (2009). Regulatory Policy Goals and Spectrum Auction Design: Lessons from the Canadian AWS Auction. NERA Economic Consulting, Statement.

29. DOJ (2013). Ex Parte Submission of the United States Department of Justice. In the Matter of Policies Regarding Mobile Spectrum Holdings, WT Docket No. 12-269.

30. DOJ, FTC (2010). Horizontal Merger Guidelines.

31. Earle, R., Sosa, D.W. (2013). Spectrum Auctions Around the World: An Assessment of International Experiences with Auction Restrictions. Analysis Group.

32. Ellis, W.H., DuMars, C.T. (1978). The Two-Tiered Market in Western Water. Nebraska Law Review, 57:333-367.

33. Faulhaber, G.R., Halm, R.W., Singer, H.J. (2012). Assessing Competition in U.S. Wireless Markets: Review of the FCC's Competition Reports. Federal Communications Law Journal, 64:319-369.

34. FCC (2010b). National Broadband Plan: Spectrum. Chapter 5.

35. FCC (2013a). The Broadcast Television Spectrum Incentive Auction: A Staff Summary.

36. FCC (2013b). FCC Encyclopedia: Spectrum Leasing.

37. FCC (2013c). 16th Mobile Competition Report. FCC 13-34

38. Ford, G.S. (2013). Will Bidder Exclusions Increase Auction Revenue? A Review of the Arguments. Phoenix Center Perspectives 13-03.

39. Fox, J.T. (2005). Consolidation in the Wireless Phone Industry. NET Institute, Working Paper #05-13.

40. Fox, J.T., Bajari, P. (2013). Measuring the Efficiency of an FCC Spectrum Auction. American Economic Journal: Microeconomics, 5:100-146.

41. Fox, J.T., Perez-Saiz, H. (2006). Mobile Phone Mergers and Market Shares: Short Term Losses and Long Term Gains. NET Institute, Working Paper #06-16.

42. Galambos, L., Abrahamson, E.J. (2002). Anytime, Anywhere: Entrepreneurship and the Creation of a Wireless World. Cambridge University Press.

43. GAO (2010). Enhanced Data Collection Could Help FCC Better Monitor Competition in the Wireless Industry. Report to Congressional Requesters, GAO-10-779.

44. Gebhardt, G., Wambach, A. (2008). Auctions to implement the efficient market structure. International Journal of Industrial Organization, 26:846-859.

45. Goeree, J.K., Lien, Y. (2009a). An Equilibrium Analysis of the Simultaneous Ascending Auction. Working Paper.

46. Goeree, J.K., Lien, Y. (2009b). Threshold versus Exposure in Simultaneous Ascending Auctions. Working Paper.

47. Goeree, J.K., Offerman, T., Sloof, R. (2012). Demand reduction and preemptive bidding in multi-unit license auctions. Experimental Economics, 16:52-87.

48. Haan, M.A., Toolsema, L.A. (2011). License Auctions When Winning Bids Are Financed Through Debt. The Journal Of Industrial Economics, 59:254-281.

49. Hafalir, I., Krishna, V. (2008). Asymmetric Auctions with Resale. American Economic Review, 98:87-112.

50. Haile, P.A. (2001). Auctions with Resale Markets: An Application to U.S. Forest Service Timber Sales. American Economic Review, 91:399-427.

51. Haile, P.A. (1999). Auctions with Resale. Working Paper.

52. Haile, P.A. (2003). Auctions with private uncertainty and resale opportunities. Journal of Economic Theory, 108:72-110.

53. Hazlett, T.W. (1998). Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years?. Journal of Law and Economics, 41:529-576.

54. Hazlett, T.W., Boliek, B.E.L. (1999). Use of Designated Entity Preferences in Assigning Wireless Licenses. Federal Communications Law Journal, 51:639:663.

55. Heckman, J.J. (1979). Sample Selection Bias as a Specification Error. Econometrica, 47:153-161.

56. Holtz-Eakin, D., Joulfaian, D., Rosen, H.S. (1993). Sticking it out: Entrepreneurial Survival and Liquidity Constraints. Princeton University, Working Paper 319.

57. Hoppe, H.C., Jehiel, P., Moldovanu, B. (2006). License Auctions and Market Structure. Journal of Economics & Management Strategy, 15:371-396.

58. Hyndmany, K., Parmeter, C. (2013). Efficiency or Competition? A Structural Econometric Analysis of Canada's AWS Auction and the Set-Aside Provision. Working Paper.

59. Irwin, M.R., McConnaughey, J. (2000). Telecommunications. In Adams, W., Brock, J. (eds.). The Structure of American Industry, Tenth Edition. Prentice Hall. 296-322.

60. Jehiel, P., Moldovanu, B. (2000). Auctions with Downstream Interaction among Buyers. The RAND Journal of Economics, 31:768-791.

61. Kalmus, P., Wiethaus, L. (2010). On the competitive effects of mobile virtual network operators. Telecommunications Policy, 34:262-269.

62. Kurtin, O.D. (2003). NextWave Supreme Court Victory Ends Five-Year Struggle Over U.S. Wireless Spectrum Auction Rules. Telecomfinance, 99.

63. Kwerel, E., LaFontaine, P., Schwartz, M. (2012). Economics at the FCC, 2011-2012: Spectrum Incentive Auctions, Universal Service and Intercarrier, Compensation Reform, and Mergers. Review of Industrial Organization, 41:271-302.

64. Marx, L.M. (2013). Economic Analysis Of Proposals That Would Restrict Participation In The Incentive Auction. In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, WT Docket No. 12-268.

65. Mayo, J.W., Wallsten, S. (2009). Enabling Efficient Wireless Communications: The Role of Secondary Spectrum Markets. Information Economics and Policy, 22:61-72.

66. McConnaughey, J. (2004). Telecommunications. In Brock, J. (ed.). The Structure of American Industry, Eleventh Edition. Prentice Hall.

67. McConnaughey, J. (2008). The Telecommunications Industry. In Brock, J. (ed.). The Structure of American Industry, Twelfth Edition. Prentice Hall. Milgrom, P., Levin, J., Eilat, A. (2011). The Case for Unlicensed Spectrum.

68. Mobile Future (2013a). The Case For Inclusive Spectrum Auction Rules: How Failed International Experiments with Auction Bidding Restrictions Reveal the Strength of Inclusive Rules that Put Consumers and Innovation First.

69. Mobile Future (2013b). FCC Spectrum Auctions and Secondary Markets Policies: An Assessment of the Distribution of Spectrum Resources Under the Spectrum Screen.

70. Murray, J.B., Dickey, L., Murray J.B. Jr. (2002). Wireless Nation: The Frenzied Launch Of The Cellular Revolution. Basic Books.

71. Rodriguez, G.E. (2002). Auctions of licences and market structure. Economic Theory, 19:283-309.

72. Sabat, H.K. (2008a). Spectrum acquisition strategies adopted by wireless carriers in the USA. Information Systems Frontiers, 10:77-102.

73. Sabat, H.K. (2008b). Why different carriers adopt different spectrum acquisition strategies. Information Technology and Management, 9:251-284.

74. Salant, D.J. (1997). Up in the Air: GTE's Experience in the MTA Auction for Personal Communication Services Licenses. Journal of Economics & Management Strategy, 6:549-572.

75. Shapiro, R.J., Holtz-Eakin, D., Bazelon, C. (2013). The Economic Implications of Restricting Spectrum Purchases in the Incentive Auctions. Georgetown Center for Business and Public Policy, Working Paper.

76. Sterling, C.H., Bernt, P.W., Weiss, M.B.H. (2005). Shaping American Telecommunications: A History of Technology, Policy, and Economics. Routledge.

77. van de Ven, W.P.M.M., van Praag, B.M.S. (1981). The demand for deductibles in private health insurance: A probit model with sample selection. Journal of Econometrics, 17:229-252.

78. Wallsten, S. (2013). Is There Really a Spectrum Crisis? Quantifying the Factors Affecting Spectrum License Value. Technology Policy Institute.

79. Weber, R.J. (1997). Making More from Less: Strategic Demand Reduction in the FCC Spectrum Auctions. Journal of Economics & Management Strategy, 6:529-548.

80. Zheng, C.Z. (2002). Optimal Auction with Resale. Econometrica, 70:2197-2224.

81. Zhong, H. (2005). License Auctions with Post-bid Market Competition. Working Paper.