Ownership Concentration and Strategic Supply Reduction*

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Abstract

We explore ownership concentration as a means to seek rents in the context of the U.S. government's planned acquisition of broadcast TV licenses in the upcoming incentive auction. We document the significant purchases of licenses by private equity firms in the run-up to this auction and perform a prospective analysis of the effect of firms controlling multiple licenses on the outcome of the auction. Our results show that multi-license holders are able to earn large rents from a supply reduction strategy where they strategically withhold some of their licenses from the auction to drive up the closing price for the remaining licenses they own. Relative to the case where each license is bid into the auction independently, spectrum acquisition costs increase by one third to one half. Strategic behavior by multi-license holders reduces economic efficiency as the set of licenses surrendered into the auction is not the socially optimal set. A case study illustrates the mechanism in a specific local media market. We propose a partial remedy that mitigates the effect of ownership concentration and reduces the distortion in payouts to broadcast TV license holders by one to two thirds.

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1 Introduction

In 2010, the Federal Communications Commission (FCC) proposed to acquire spectrum from broadcast TV license holders and sell it to wireless carriers to be repurposed into mobile broadband spectrum. The so-called incentive auction, currently scheduled to begin on March 29th, 2016, combines a reverse auction for broadcast TV licenses with a forward auction for selling the thus-acquired spectrum to wireless carriers. The forward auction is expected to raise up to $45 billion, well in excess of the payouts to broadcast TV license holders in the reverse auction, with the balance going towards the costs of "repacking" spectrum into a contiguous block and to the government.[1,2] In this paper, we study the potential for strategic behavior in the reverse auction.

We document that following the announcement of the incentive auction, a number of private equity firms acquired broadcast TV licenses in several local media markets, often purchasing multiple licenses in the same market. Recent newspaper articles and industry reports have claimed that these purchases were undertaken with the goal of trying to "flip" broadcast TV licenses for profit in the reverse auction.[3] Politicians have also raised concerns about speculation.[4] Yet, reselling broadcast TV licenses does not necessarily entail efficiency losses.

We argue that in addition to speculative motivations behind reselling broadcast TV licenses, there is the potential for strategic bidding. We show that owners of multiple licenses have an incentive to withhold some of their licenses from the auction, thereby driving up the closing price for the remaining licenses they own and affecting a large transfer of wealth from the government - and ultimately taxpayers - to themselves. Our prospective analysis of the upcoming auction shows that this strategic behavior has the potential to increase payouts to broadcast TV license holders by potentially billions of dollars. We find supply reduction to be a highly profitable strategy in situations where firms hold broadcast licenses that are not necessarily valuable as businesses, but that confer significant market power in the auction due to repacking constraints. Apart from affecting closing prices, this behavior causes efficiency losses as the set of broadcast TV licenses surrendered in the auction is not the socially optimal set.

The incentive auction is very carefully designed and has many desirable properties such as strategy proofness (Milgrom et al., 2012; Milgrom and Segal, 2014). If broadcast TV licenses are separately owned, then it is optimal for an owner to bid a station's value as a going concern in

[1] See Expanding Opportunities for Broadcasters Coalition (EOBC) Notice of Oral Ex Parte Filing with the FCC, June 13, 2014, available at http://www.tvtechnology.com/portals/0/EOBC0614.pdf, accessed on November 15, 2015.

[2] The Congressional Budget Office (CBO) estimates the net proceeds from the incentive auction to fall between $10 billion and $40 billion, with an expected value of $25 billion, the middle of that range. "Proceeds From Auctions Held by the Federal Communications Commission", CBO Report 50128, April 21, 2015, available at https://www.cbo.gov/publication/50128, accessed on November 15, 2015.

[3] See "NRJ Wins Bidding For WSAH New York," TVNewsCheck, November 29, 2011, "Small TV Stations Get Hot," The Wall Street Journal, September 3, 2012, "Speculators Betting Big on FCC TV Spectrum Auctions," Current.org, February 26, 2013, "TV Spectrum Speculation Nears $345 Million," TVNewsCheck, March 1, 2013, "Broadcast Incentive Spectrum Auctions: Gauging Supply and Demand," SNL Kagan Broadcast Investor, November 20, 2013, and "TV Station Spectrum Deals Expand Into Major Network Affiliates as Players Stake Out Positions Pre-Auction," SNL Kagan Broadcast Investor, December 4, 2013.

[4] See "Rep. LoBiondo Seeks FCC Info On Possible Spectrum Speculation," Broadcasting & Cable, February 12, 2014.

exchange for relinquishing the broadcast license; we refer to this as naive bidding. However, the rules of the auction leave room for strategic supply reduction for firms that own multiple broadcast TV licenses. Such firms can withhold a subset of their licenses from the auction, effectively shifting the supply curve inward, and raise the closing price for the remaining licenses. This behavior is purely rent-seeking, as these firms are attempting to increase their share of existing wealth without creating any new wealth.

We use a simple model to illustrate how strategic supply reduction works in the context of the reverse auction and under what circumstances it is a profitable strategy for multi-license owners. Our model implies that certain types of broadcast licenses are more suitable for a supply reduction strategy and that certain types of local media markets are more vulnerable to this type of behavior. We begin by showing that the ownership patterns in the data are broadly consistent with the implications of the model.

In a second step, we analyze the reverse auction in more detail and quantify increased payouts and efficiency losses due to strategic supply reduction. To do so, we undertake a large scale valuation exercise to estimate reservation values for all currently held broadcast TV licenses. We combine various data sources to estimate a TV station's cash flows and from them infer its value as a going concern. This allows us to construct the supply curve for licenses in a given local media market. The FCC further provides us with an estimate of the number of broadcast TV licenses that it has to acquire in each local media market to meet two alternative targets of spectrum (84 MHz and 120 MHz) to be cleared nationwide for mobile broadband use. With these inputs, we then solve for the equilibrium of a simplified version of the reverse auction. We compare the outcome under naive bidding with the outcome that obtains when we account for the ownership patterns in the data and allow multi-license owners to engage in strategic supply reduction.

We show that strategic supply reduction has a large impact on closing prices and payouts to broadcast TV license holders and causes sizable efficiency losses. For a nationwide clearing target of 120 MHz of spectrum, strategic behavior by multi-license owners alters the closing price, as well as the set of licenses that are surrendered in the auction, in 66 out of the 81 local media markets where the FCC anticipates to purchase at least one license and where multi-license owners are present (47 out of 55 for a 84 MHz clearing target). On average, the closing price increases by 60% (47%) in those markets, and payouts to broadcast TV license holders increase by \$6.75 billion (\$1.66 billion). Netting out the firms' reservation values from their auction payouts, this translates into surplus increases of \$2.16 billion (\$620 million) for multi-license owners and \$3.89 billion (\$860 million) for single-license owners. This reflects that a multi-license owner who withholds a license from the auction creates a positive externality for other market participants by raising the closing price in the market. The multi-license owner, by selling his remaining licenses in the market, captures some of this externality, but not all of it.

Beyond a substantially increased cost to the government of acquiring the desired amount of spectrum, strategic supply reduction also causes an inefficiency in that some broadcast licenses sold in the auction are of higher value as a broadcast business than broadcast licenses that are withheld. The value lost through this inefficient allocation is \$701 million (\$176 million) at the 120 MHz (84 MHz) clearing target.

Strategic supply reduction has a large impact on outcomes because of market features that we illustrate under naive bidding. Abstracting from the ownership patterns in the data yields a supply curve that is fairly inelastic just above the demand for spectrum in many local media markets; hence withholding even a single license from the auction can have a large effect on the closing price. We illustrate the exact mechanism by showing how, in a specific local media market (Philadelphia, PA), multi-license holders have a strong incentive to reduce supply.

We propose a partial remedy that imposes a constraint on the ordering of bids of multi-license owners. The rule change reduces the effect of strategic behavior by roughly one third (84 MHz) to two thirds (120 MHz) across local media markets, and we again illustrate the mechanism with the example of Philadelphia, PA. This result is directly policy relevant as it suggests ways of mitigating the impact of strategic supply reduction, which we hope to be useful in designing future auctions.

Finally, we illustrate how a firm may extend a supply reduction strategy by leveraging technological constraints on the repacking of spectrum across local media markets. While a complete analysis of multi-market strategies is beyond the scope of this paper, we highlight a particular case of a firm owning licenses in geographically adjacent markets and the potential effect of reducing supply in one market on the closing price in another targeted market. We find that in this case payouts to broadcast TV license holders in the target market increase by approximately 39% (27%) or \$290 million (\$98 million) at the 120 MHz (84 MHz) clearing target.

There is a rich literature on strategic bidding in multi-unit auctions. Substantial theoretical work (Wilson, 1979; Back and Zender, 1993; Menezes, 1996; Engelbrecht-Wiggans and Kahn, 1998; Jun and Wolfstetter, 2004; Riedel and Wolfstetter, 2006; Ausubel et al., 2014) and experimental evidence (List and Lucking-Reiley, 2000; Kagel and Levin, 2001; Engelmann and Grimm, 2009; Goeree, Offerman and Sloof, 2013) point to the potential for strategic demand reduction. In addition, case studies of past spectrum auctions have documented strategic demand reduction (Weber, 1997; Grimm, Riedel and Wolfstetter, 2003). Our paper is most closely related to the empirical literature examining market power in wholesale electricity markets (Wolfram, 1998; Borenstein, Bushnell and Wolak, 2002; Hortacsu and Puller, 2008), where firms bid supply schedules and have strategic incentives to alter their bids and raise closing prices for inframarginal units.

Significantly, our paper departs from much of the auction literature in that it does not invert the first-order conditions to recover valuations from observed bids. Instead, we use auxiliary data to directly estimate valuations. We do this for two reasons. First, extending the standard first-order conditions approach to our case of multi-unit auctions with personalized prices is less than straightforward and may entail challenges to identification as discussed by Cantillon and Pesendorfer (2007) in the context of heterogeneous multi-unit first-price auctions. Second, and more importantly, the descending clock nature of the upcoming incentive auction exacerbates identification concerns. While the value of a broadcast license can be inferred from the price at which it leaves the auction, the closing price provides at most an upper bound on the value of a broadcast license that sells into the auction. The closing price may furthermore be uninformative about the value of a broadcast license that a multi-license owner outright withholds from the auction for strategic reasons. This is in contrast to work on wholesale electricity markets where complete supply schedules are observed. We also do not adopt the moment inequalities approach in Fox and Bajari (2013) that - rather than assuming full optimality of bids - would assume that the configuration of licenses that a multi-license owner sells into the auction dominates any alternative configuration. There are typically few alternatives in our setting and this approach identifies relative valuations but not the levels of valuations that are required for the analysis of welfare effects of ownership concentration.

Our work is also related to the extensive literature on collusion in auctions (Asker 2010, Conley and Decarolis 2016, Kawai and Nakabayashi 2015, and Porter and Zona 1993, among others), including spectrum auctions (Cramton and Schwartz, 2002). A multi-license owner in our setting internalizes the profit implications of all licenses he controls as is the case with colluding, but otherwise independent, single-license owners. Finally, we contribute to the literature on distortions induced by incentive schemes and regulation in various settings such as employee compensation (Oyer, 1998), environmental regulation (Fowlie, 2009; Bushnell and Wolfram, 2012), health care (Duggan and Scott Morton, 2006), and tax avoidance (Goolsbee, 2000).

The remainder of this paper is organized as follows: Section 2 describes the setting, Section 3 sets out a simple model of strategic supply reduction, Section 4 presents data and descriptive evidence, Sections 5 and 6 describe the main analysis and results, and Section 7 concludes.

2 The upcoming FCC incentive auction

The rapid growth in data usage by smartphones has significantly increased the demand for mobile broadband spectrum in recent years.[5] At the same time, previously allotted spectrum is no longer used intensively. In particular, each of approximately 8,500 currently operating TV stations owns a license for a 6 MHz block of spectrum covering a particular geographical area for over-the-air transmission of programming. Yet, as of 2010 only about 10% of U.S. TV households used broadcast TV, with a rapidly declining trend.[6]

In its 2010 National Broadband Plan, the FCC under then-chairman Julius Genachowski proposed, and was authorized by Congress in 2012, to conduct a so-called incentive auction to reallocate spectrum from TV stations located in the higher frequency UHF band to wireless providers. The incentive auction consists of a reverse auction in which TV stations submit bids to relinquish spectrum rights in exchange for payment and a forward auction in which wireless operators bid for the

[5]According to FCC Chairman Tom Wheeler, “America has gone mobile. Most Americans would have a hard time imagining life without their smartphones, and tens of millions are similarly in love with their tablets. The problem is that spectrum, the lifeblood of all wireless technologies, is finite. That wasn’t a problem before the mobile web, when most consumers were mostly watching videos or surfing the web at home. If we don’t free up more airwaves for mobile broadband, demand for spectrum will eventually exceed the supply. If you’ve ever been frustrated by websites that loaded slowly or videos that wouldn’t download to your phone, you have a sense what that world could look like.” See “Channel Sharing: A New Opportunity for Broadcasters,” Official FCC Blog, available at https://www.fcc.gov/news-events/blog/2014/02/11/channel-sharing-new-opportunity-broadcasters, accessed on November 15, 2015.

[6]“Connecting America: The National Broadband Plan”, FCC, 2010, Chapter 5, p. 89.

newly available spectrum.

While the FCC has conducted spectrum auctions in the past, the incentive auction is the first time an auction to sell spectrum is combined with an auction to purchase spectrum from existing licensees.[7] Designing this auction is complicated not only by incumbent claims on spectrum, but also by technological constraints for mobile data and broadcast TV uses. Originally projected for early 2014, the incentive auction has repeatedly been postponed due to legal and technological challenges, most recently to the middle of 2015 and then again to March 2016.[8]

The current proposal for the upcoming incentive auction was made public in May 2014.[9] The forward auction to sell spectrum to wireless carriers uses an ascending-clock format similar to previous spectrum auctions. The reverse auction uses a descending-clock format in which the price offered to a TV station for its spectrum usage rights declines with each successive round of bidding. A TV station faces a price for its broadcast license that is personalized to it (see Section 3 for details). If a TV station chooses to participate in the reverse auction, it has several options for relinquishing its spectrum usage rights: going off the air, moving channels from a higher frequency band (UHF channels 14-36 and 38-51 or high VHF channels 7-13) to a lower frequency band (respectively, VHF channels 2-13 or low VHF channels 2-6) to free up more desirable parts of the spectrum, or sharing a channel with another TV station.

Between the reverse and forward auctions, a repacking process takes place in which the remaining TV stations in each local media market are consolidated in the lower end of the UHF band to create a contiguous block of spectrum in the higher end of the UHF band for wireless use.[10] The process is visually similar to defragmenting a hard drive on a personal computer. However, it is far more complex because many pairs of TV stations cannot be located on adjacent channels, even across local media markets, without causing unacceptable levels of interference. As a result, the repacking process is global in nature in that it ties together all local media markets. In practice, the reverse auction is therefore at the national level. A further consequence of interference, primarily within and potentially across markets, is that far more than $6n$ MHz of spectrum are likely required to accommodate n remaining TV stations in a local media market, even though each TV station

[7] "Let's start with the concept of an incentive auction. While it has never been tried before, its power lies in how it addresses the root of all issues: economics. If it is possible to marry the economics of demand with the economics of current spectrum holders, it should be possible to allow market forces to determine the highest and best use of spectrum. In mid-2015 we will run the first ever incentive auction. Television broadcasters will have the opportunity to bid in a reverse auction to relinquish some or all of their spectrum rights, and wireless providers will bid in a forward auction on nationwide, 'repacked' spectrum suitable for two-way wireless broadband services." See FCC Chairman Tom Wheeler's prepared remarks at the "Wireless Spectrum And The Future Of Technology Innovation" Forum, available at https://apps.fcc.gov/edocs_public/attachmatch/DOC-326215A1.pdf, accessed on November 15, 2015.

[8] See "The Path to a Successful Incentive Auction," Official FCC Blog, December 6, 2013, available at https://www.fcc.gov/news-events/blog/2013/12/06/path-successful-incentive-auction-0, accessed on November 15, 2015, and "F.C.C. Delays Auction of TV Airways for Mobile," The New York Times, October 24, 2014.

[9] See https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-50A1.pdf, accessed on November 15, 2015. An excellent and detailed explanation of the mechanism is available from the FCC and greatly informs our analysis. See Appendix D of FCC Public Notice in matter FCC-14-191 "Comment Sought On Competitive Bidding Procedures For Broadcast Incentive Auction 1000, Including Auctions 1001 And 1002 ," released December 17, 2014.

[10] Congress' authorization of the incentive auction required the FCC to make all reasonable efforts to preserve the coverage area and population served by TV stations involved in the repacking.

owns a license for 6 MHz of spectrum covering a particular geographical area.

The auction rules integrate the reverse and forward auctions in a series of stages. Initial commitments from stations and repacking constraints determine an initial maximum nationwide clearing target for the first stage. Each stage of the incentive auction begins with multiple rounds of the reverse auction, followed by multiple rounds of the forward auction. The reverse auction uses a descending clock to determine the cost of acquiring a set of licenses that would allow the repacking process to meet the clearing target. There are many different feasible sets of licenses that could be surrendered to meet a particular clearing target given the complex interference patterns between stations; the reverse auction is intended to identify the low-cost set. Then, the forward auction determines the willingness-to-pay of wireless operators for this amount of spectrum. The clearing target is then decreased, and the process repeats until a "final stage rule" is satisfied that ensures that proceeds in the forward auction (more than) cover payouts in the reverse auction and the cost of repacking spectrum.[11]

The FCC excludes approximately 10,000 low-power, translator, multi-cast signal, and cable stations from the reverse auction. There are a total of 2,166 broadcast licenses that are eligible for the auction.[12] They can be classified by type of service into UHF and VHF stations, by type of use into commercial and non-commercial stations, and by power output into full-power (primary and satellite[13]) and low-power (class-A) stations. Appendix Table 11 summarizes the auction-eligible broadcast licenses.

Broadcast licenses are assigned by the FCC to a local media market, which is the designated market area (DMA) as defined by Nielsen Media Research based on the reach and viewing patterns of TV stations. A DMA is defined as a group of counties such that the home market TV stations hold a dominance of total hours viewed. There are 210 DMAs in the U.S. that vary in size from New York, NY, with over 7 million TV households, to Glendive, MT, with 4,230 TV households. Appendix Table 10 lists the top ten DMAs based on their 2012 rank. In what follows, we consider a separate reverse auction in each DMA. This allows us to highlight the strategic choices of license owners and abstract from the complex combinatoric repacking process that results in the reverse auction being conducted at the national level in practice.

3 Strategic supply reduction

A TV station that participates in the reverse auction is offered a personalized price at which it can either remain in the auction, indicating that it is prepared to accept this price to cease operating

[11] More specifically, the final stage rule requires that proceeds in the forward auction are at least $1.25 per MHz per population for the largest 40 so-called wireless service market areas and not only cover payouts in the reverse auction but also the FCC's administrative costs, the reimbursements of channel relocation costs incurred by TV stations, and the funding of the First Responder Network Authority's public safety operations.

[12] See http://www.fcc.gov/learn, accessed on November 15, 2015. The FCC has since updated the list of auction-eligible stations, see http://transition.fcc.gov/Daily_Releases/Daily_Business/2015/db0609/DA-15-679A2.pdf, accessed on February 10, 2016. In this paper, we work with the earlier list of 2,166 auction-eligible stations as it underlies the FCC's repacking simulations (see Section 4.1).

[13] A satellite station is a relay station that repeats the broadcast signal of its parent primary station.

and surrender its broadcast license, or leave the auction, indicating that the price is too low and that it prefers to continue operating. In the subsequent analysis, we abstract from the options to relocate from a higher to a lower frequency band or to share a channel with another station. We discuss this simplification further and establish the robustness of our main results in Section 6.2.

The reverse auction uses a descending-clock format. In round τ of the auction, TV station j located in a particular DMA is offered the price

$$p_{j\tau} = \varphi_j P_\tau,$$

where P_τ is the base clock price and φ_j is the station's so-called broadcast volume. The base clock price P_τ begins at \$900 and decreases with each successive round of bidding. The broadcast volume

$$\varphi_j = M\sqrt{CoveragePop_j \cdot InterferenceCnt_j} \tag{1}$$

is a known function of the station's population reach $CoveragePop_j$ and the interference count $InterferenceCnt_j$, defined as the number of TV stations that station j can interfere with in the repacking process. Finally, $M = 17.253$ is a scaling factor that is chosen to set the maximum φ_j across the U.S. to one million.

The broadcast volume is an important concept: the FCC uses it to personalize the base clock price to a TV station based on its value as a broadcast business (as proxied by population reach) and the difficulty of repacking the station in case it does not surrender its license (as proxied by the interference count). The broadcast volume thus reflects that the FCC is willing to incentivize a TV station to surrender its license if the alternative of having to repack the station is particularly challenging. Importantly, the broadcast volume for all TV stations is known in advance to all auction participants.

Clock auctions are strategy proof (Milgrom et al., 2012; Milgrom and Segal, 2014). Hence, if a TV station is independently owned, its owner optimally remains in the reverse auction until

$$p_{j\tau} = \varphi_j P_\tau < v_j,$$

where v_j is the reservation value of TV station j that reflects its value as a going concern. We henceforth refer to this strategy as naive bidding. Under naive bidding, if the FCC acquires k broadcast licenses in a DMA and stations are ordered in ascending order of the ratio $\frac{v_j}{\varphi_j}$, then the reverse auction closes at base clock price $\frac{v_{k+1}}{\varphi_{k+1}}$. This is the $(k+1)^{st}$ lowest ratio $\frac{v_j}{\varphi_j}$ in the DMA. The k TV stations with lower ratios cease broadcasting.

Clock auctions are not only strategy proof but also "group-strategy proof" (Milgrom and Segal, 2014). This means that no coalition of bidders has a joint deviation from naive bidding that is strictly profitable for all members of the coalition. However, as Milgrom and Segal (2014) explicitly acknowledge, their results do not apply if bidders are "multi minded," a concept that includes bidders with multiple objects for sale. We show that a firm owning multiple broadcast licenses may indeed have an incentive to deviate from naive bidding. Note that this does not contradict group-strategy proofness as it suffices that the deviating group, i.e., the multi-license owner, is better off as a whole.

In particular, a firm owning multiple broadcast licenses can withhold one of its licenses from the reverse auction and continue operating it as a broadcast business. This may raise the closing base clock price from $\frac{v_{k+1}}{\varphi_{k+1}}$ to $\frac{v_{k+2}}{\varphi_{k+2}}$, thereby increasing the price for the remaining broadcast TV licenses that the firm owns. However, the firm is then left with a TV station that it may have been able to sell into the auction. Therefore, this supply reduction strategy is only profitable if the gain from raising the closing base clock price exceeds the loss from continuing to own a TV station instead of selling it into the auction.

For concreteness, suppose the firm owns TV stations a and b. As above, the FCC intends to acquire k broadcast licenses and stations are ordered in ascending order of the ratio $\frac{v_j}{\varphi_j}$. If $\frac{v_a}{\varphi_a} < \frac{v_k}{\varphi_k}$ and $\frac{v_b}{\varphi_b} < \frac{v_k}{\varphi_k}$, then under naive bidding the reverse auction closes at base clock price $\frac{v_{k+1}}{\varphi_{k+1}}$ and both licenses sell into the auction, yielding the firm a profit of $(\varphi_a + \varphi_b)\left(\frac{v_{k+1}}{\varphi_{k+1}}\right) - (v_a + v_b)$. On the other hand, if the firm withholds station a from the auction and raises the closing base clock price to $\frac{v_{k+2}}{\varphi_{k+2}}$, then its profit is $v_a + \varphi_b \frac{v_{k+2}}{\varphi_{k+2}} - v_b$. It is therefore profitable to engage in strategic supply reduction and withhold TV station a from the auction if the gain in profit from selling the license of TV station b outweighs the loss in profit from not selling the license of TV station a, or

$$\varphi_b \left(\frac{v_{k+2}}{\varphi_{k+2}} - \frac{v_{k+1}}{\varphi_{k+1}}\right) > \varphi_a \left(\frac{v_{k+1}}{\varphi_{k+1}}\right) - v_a. \tag{2}$$

The left-hand side implies that strategic supply reduction is more likely to be profitable if φ_b is large and if the increase in the closing base clock price $\frac{v_{k+2}}{\varphi_{k+2}} - \frac{v_{k+1}}{\varphi_{k+1}}$ is large. The right-hand side implies that it is more likely to be profitable if φ_a is small and v_a is large. In short, strategic supply reduction is more likely to be profitable if the "leverage" of increasing the closing base clock price is large and the opportunity cost of continuing to own a TV station is small.

The mechanism above is straightforward and has been explored in earlier work on multi-unit auctions in wholesale electricity markets (e.g. Wolfram, 1998)[14]: if a firm's bid of one of its licenses has a chance to set the price, it has an incentive to raise that bid if it will earn the price increases on inframarginal licenses. Other electricity market papers consider this the exercise of market power, and note that the effects can be large when demand or supply is inelastic (Borenstein, Bushnell and Wolak, 2002). Unlike in wholesale electricity, a broadcast license is indivisible, leading to sharper behavior in our setting.

The above considerations imply that certain types of DMAs are more vulnerable to a supply reduction strategy and that certain types of broadcast licenses are more suitable for this type of behavior. First, ideal markets from a supply reduction perspective are DMAs in which the FCC intends to acquire a positive number of broadcast licenses and that have relatively steep supply curves around the expected demand level. This maximizes the impact of withholding a license from the auction on the closing price (the left-hand side of equation 2). Second, suitable groups of

[14]This mechanism is also similar to the upper bound of the "bidder exclusion effect" considered by Coey, Larsen and Sweeney (2015) in the case of a non-random merger of auction participants.

licenses consist of sets of relatively low value licenses, some with higher broadcast volume to sell into the auction and some with lower broadcast volume to withhold. We return to these implications of the model below when discussing the data and our results.

4 Data and descriptive evidence

We begin by describing the various sources of data used in the analysis and then turn to providing descriptive evidence in support of the model from Section 3.

4.1 Data sources

We use the MEDIA Access Pro Database (2003 - 2013) from BIA Kelsey (henceforth BIA) and the Television Financial Report (1995 - 2012) from the National Association of Broadcasters (NAB). Together these two data sources allow us to estimate a TV station's cash flows and from them infer its reservation value going into the auction. We provide additional details on the data in Appendix A.

BIA contains the universe of broadcast TV stations. It provides station, owner, and market characteristics, as well as TV stations' transaction histories covering the eight most recent changes in ownership. The BIA's revenue measure covers broadcast-related revenue in the form of local, regional, and national advertising revenue, commissions, and network compensation. We refer to BIA's revenue measure as advertising revenue in what follows. For commercial stations, advertising revenue is missing for 30.9% of station-year observations, which we impute for commercial stations as detailed in Appendix A.1.3. For non-commercial stations, advertising revenue is missing for 99.7% of station-year observations and we do not impute it.

The BIA data excludes non-broadcast revenue, most notably, retransmission fees. These are fees TV stations charge pay-TV providers to use their content, which the trade press mentions as a small but growing source of revenue for many TV stations.[15] To get at non-broadcast revenue and ultimately profitability, we rely on a second source of data. For commercial full-power stations, NAB collects financial information. Revenue is broken down into detailed source categories from which we are able to construct advertising revenue and non-broadcast revenue. NAB further covers expenses related to programming, advertising, and other sources, and profitability as measured by cash flows. However, for confidentiality reasons, NAB reports the distributions of these measures (the 25^{th}, 50^{th}, and 75^{th} percentiles, as well as the mean) at various levels of aggregation, resulting in "tables" such as "ABC, CBS and NBC affiliates in markets ranked 51-60 in 2012" or "CBS affiliates in markets ranked 1-50 in 2012." Appendix Table 13 lists the set of 66 tables for 2012; other years are very similar. In Section 5 we describe a method to combine the station-level data on advertising revenue from BIA with the aggregated data from NAB to estimate a TV station's cash flows.

[15] See, e.g., "SNL Kagan raises retrans fee forecast to $9.8B by 2020; Mediacom's CEO complains to FCC", FierceCable, July 7, 2015.

We obtain the demand for spectrum at the DMA level from the FCC's website.[16] The FCC has performed a large-scale simulation of repacking scenarios to understand the likely number of (commercial and non-commercial, full-power and low-power) UHF stations it has to acquire in each DMA to meet the alternative nationwide clearing targets of 84 MHz and 120 MHz. For a given clearing target, the number of UHF stations the FCC has to acquire varies widely across DMAs because of differences in the previously allocated amount of spectrum and the difficulty of repacking between DMAs. The FCC performed 100 repacking simulations that differ in the identity of the TV stations that do not relinquish their licenses and require repacking after the auction.[17] We restrict attention to the 52 repacking simulations (27 for 120 MHz and 25 for 84 MHz) that assume full participation by UHF auction-eligible licenses and use the median demand for each DMA at the two clearing targets.

The FCC includes 1,672 UHF stations in its repacking simulations.[18] These stations are located in 204 DMAs and make up the large majority of the 2,166 auction-eligible stations.[19] Across these DMAs, the median demand for licenses totals 224 or 414 under the 84 MHz and 120 MHz clearing targets, respectively. Figure 1 shows the distribution of demand across DMAs, broken out by the two clearing targets. The median demand is zero at the 120 MHz target in 83 DMAs (41%) and it is zero in 123 DMAs (60%) at the 84 MHz target. We refer to a DMA as having positive demand if its median demand is greater than zero. In positive demand DMAs, the mean number of licenses the FCC expects to purchase is 3.4 at the 120 MHz target and 2.8 at the 84 MHz target, but in the largest DMAs, such as Los Angeles, CA, and Philadelphia, PA, demand is projected to be several times higher. The range bars in Figure 1 highlight that at the 120 MHz target, there are a minimum of 5 DMAs with 9 or more licenses demanded in all simulations, and that while there is variance across simulations, demand is generally stable across simulations even if the identities of licenses surrendered changes.

While demand varies across DMAs, it is also expected to be correlated across DMAs due to interference patterns. Licenses in neighboring DMAs are imperfect substitutes in the repacking process. Close-by DMAs may be expected to have negatively correlated demand for this reason, although the interlocking nature of interference patterns can also imply positive correlation across DMAs that share a neighbor between them. To assess the extent of correlation, we use the FCC's pairwise interference table[20] to construct 1,143 pairs of DMAs with at least one broadcast licenses potentially interfering with at least one license in the other DMA. We then limit our sample to auction-eligible licenses in DMAs with positive demand in at least one simulation and compute the correlation of simulated demand levels in the paired DMAs at the two clearing targets. There is

[16] See http://data.fcc.gov/download/incentive-auctions/Simulation_Results/, accessed on November 15, 2015.

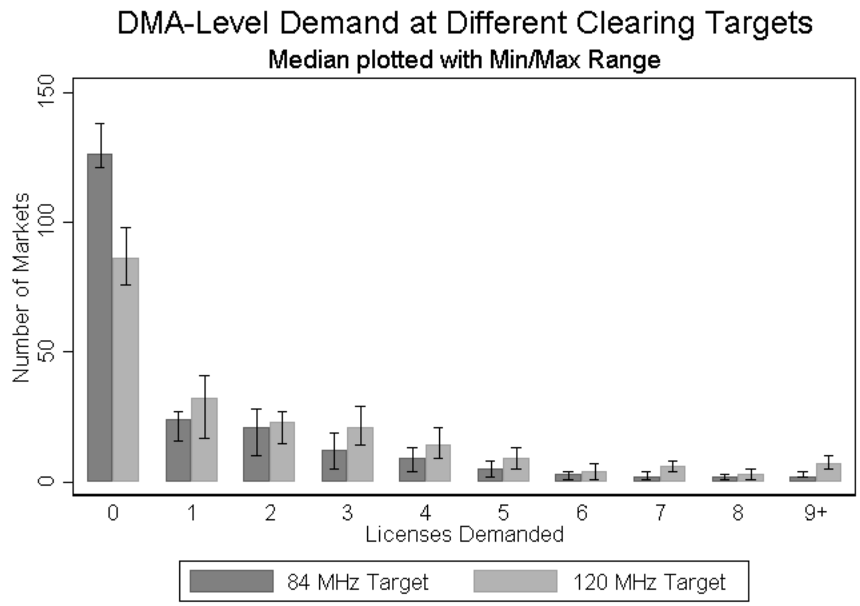
[17] See FCC's Public Notice Appendix, "Analysis of Potential Aggregate Interference," available at https://apps.fcc.gov/edocs_public/attachmatch/DA-14-677A2.pdf, accessed on March 10, 2016.

[18] We drop three stations that the FCC considered as they have zero broadcast volume and so will not participate in the auction.

[19] The FCC excludes 6 DMAs without UHF stations from its repacking simulations. These DMAs are Bangor, ME, Glendive, MT, Juneau, AK, Lafayette, IN, Mankato, MN, and Presque Isle, ME.

[20] Available at: http://data.fcc.gov/download/incentive-auctions/Constraint_Files/. Accessed on February 6, 2016.

Figure 1: Demand Across DMAs



Notes: This histogram indicates how many DMAs need a given number of licenses to be surrendered in order to meet the overall clearing targets. Data are the median, minimum, and maximum of the FCC simulated repacking scenario outcomes that assume 100% participation for each clearing target.

a statistically significant correlation at the 5% level in 167 out of 610 (27%) DMA pairs at the 84 MHz target, and 320 out of 915 (35%) DMA pairs at the 120 MHz target. This implies that correlation of demand across DMAs is an important aspect of the auction. Therefore, we use the full set of simulated repacking scenarios to represent the joint distribution of demand across DMAs as a robustness check.

4.2 Descriptive evidence

Our data reveal significant ownership concentration, both within and across DMAs, consistent with the idea of "chains" of broadcasters. We focus on the 1,672 UHF licenses that the FCC includes in its repacking simulations. In 2012, the 1,672 UHF licenses are held by 514 unique owners. Of these 514 owners, 330 hold a single license, 60 hold two licenses, and 37 hold three licenses. The remaining 87 owners hold at least four licenses. Of the 204 DMAs that the FCC includes in its repacking simulations, 79 DMAs have only single-license owners while the remaining 125 DMAs have at least one multi-license owner.

Ownership concentration has traditionally been a concern of regulators. The FCC Local TV Ownership Rules permit ownership of up to two full-power commercial stations in the same DMA if either the two stations' service areas do not overlap or at least one of the two stations is not ranked among the top four stations in the DMA, based on the most recent audience market share, and at least eight independently owned full-power stations remain in the DMA after the combination.[21] These rules are oriented towards the business of running TV stations and have a limited effect in preventing a firm from accumulating market power in the reverse auction. Waivers for the rules can be - and have been - granted for failing or financially distressed stations. The rules also do not apply to satellite, public, and low-power stations. However, these types of stations still hold licenses to 6 MHz of spectrum and are eligible for the auction.

Table 1 summarizes ownership patterns, first for all 204 DMAs and then for the 121 DMAs with positive demand under a clearing target of 120 MHz. On average, a positive demand DMA has 9 broadcast TV licenses that are held by 7.15 owners. The number of multi-license owners is 1.36 on average for positive demand DMAs compared to 1.20 for all DMAs. The counts of ownership configurations in the bottom panel of the table reinforce that ownership is more concentrated in positive demand DMAs. In 81 out of 121 or 67% of positive demand DMAs at least one firm owns multiple licenses compared to 125 out of 204 or 61% of all DMAs. Taken together, this suggests that multi-license ownership is a broad concern for the reverse auction.

In addition, news reports have pointed out that at least three private equity firms - LocusPoint Networks, NRJ TV, and OTA Broadcasting - spent almost $345 million acquiring 39 broadcast TV licenses from 2010 to early 2013, mostly from failing or insolvent stations in distress, and mostly low-power licenses (25 low-power versus 14 full-power licenses).[22,23] Since those press mentions and through the end of our data set in late 2013, an additional 4 license purchases by the three private equity firms were recorded, for a total of 43 license purchases. Of the 43 transactions, 25 are for licenses that cover the same DMA as that of another purchased license and may thus be indicative of attempts to accumulate market power in the reverse auction. Most of the stations are on the peripheries of major DMAs, primarily ranging from Boston, MA, to Washington, DC, on the Eastern Seaboard and from Seattle, WA, to Los Angeles, CA, along the West Coast.

Table 1 illustrates that ownership is especially concentrated in the 18 DMAs in which the three private equity firms have been active (henceforth, private equity active DMAs). The number of multi-license owners is 2.67 on average for private equity active DMAs and in 15 out of 18 or 83% of these DMAs at least one firm owns multiple licenses. Moreover, the FCC anticipates to purchase 6.67 licenses on average in private equity active DMAs compared to 3.42 licenses in positive demand DMAs. In line with the model in Section 3, the three private equity firms appear to focus on DMAs with robust demand for spectrum.

Section 3 discusses what types of TV stations are best suited for a supply reduction strategy. Table 2 summarizes the characteristics of TV stations transacted from 2003 to 2009 in the first

[21] See Title 47 of Code of Federal Regulations, Chapter I.C, Part 73. H, Section 73.3555.

[22] See, e.g., http://www.tvnewscheck.com/article/65850/tv-spectrum-speculation-nears-345-million or http://current.org/2013/02/speculators-betting-big-on-fcc-tv-spectrum-auctions/, accessed on November 15, 2015.

[23] According to FCC filings, the Blackstone Group LP owns 99% of LocusPoint Networks. NRJ TV LLC is a media holding company funded through loans from Fortress Investment Group LLC according to a recent U.S. Securities and Exchange Commission filing. Lastly, OTA Broadcasting is a division of MSD Capital, L.P., which was formed to manage the capital of Dell Computer founder Michael Dell.

Table 1: Ownership concentration

	All DMAs (n=204)	Positive demand (120 MHz) (n=121)	Private equity active (n=18)
Panel A: DMA averages			
Number of licenses	8.20	9.00	15.94
Number of owners	6.51	7.15	12.22
Number of multi-license owners	1.20	1.36	2.67
Number of licenses demanded (120 MHz)	2.03	3.42	6.67
Panel B: Counts of DMAs with j multi-license owners			
j=0	79	40	3
j=1	53	31	3
j=2	42	30	2
j=3	17	11	3
j=4+	13	9	7

Notes: An observation is a DMA. Table displays average number of licenses, owners, and multi-license owners present in each DMA, together with average of median DMA-level FCC demand at the 120 MHz clearing target. Positive demand DMAs are DMAs where the FCC expects to purchase at least one license (at median) under the 120 MHz clearing target. Private equity active DMAs are DMAs where one of the three private equity firms holds at least one license. Multi-license owners refers to firms owning more than one auction-eligible license within one DMA.

column and those of TV stations transacted from 2010, when the incentive auction was proposed, to 2013 in the remaining columns. The latter are further separated into transactions in the 121 DMAs with positive demand under a clearing target of 120 MHz and transactions involving the three private equity firms.

Consistent with the model, the three private equity firms have acquired TV stations with high broadcast volume but low valuations, as evidenced by the low prices paid and the fact that very few stations are affiliated with a major network. Even compared to transactions in positive demand DMAs, the TV stations acquired by these firms are particularly high in population reach, interference count, and broadcast volume. Private equity firms also concentrate predominantly on positive demand DMAs that have above average levels of demand: at a 120 MHz target, 98% of their transactions fall into positive demand DMAs with average demand of 9 licenses compared to 60% positive demand DMAs with average demand of 3 licenses for all transactions between 2010 and 2013. While we view the data as broadly consistent with the implications of the model, we caution that most differences between the subsamples are not statistically significant in light of the small sample sizes and large variances of many of the outcomes. In Section 6.2, we return to the implication that firms involved in a supply reduction strategy target DMAs with relatively steep supply curves around the expected demand level.

Table 2: Broadcast TV license transactions

	2003-2009	2010-2013		
		All	In positive demand DMAs (120 MHz)	Involving private equity firms
Number of Licenses Transacted	518	329	199	43
Average Transaction Price ($ million)	47.74	23.00	23.58	8.54
Average Interference Count	68.33	71.74	87.95	92.58
Average Interference-Free Population (million)	1.78	1.92	2.68	3.89
Average Broadcast Volume (thousand)	163.43	177.92	232.97	285.01
Percentage major network affiliation (%)	48.84	52.58	40.70	4.65
Positive Demand DMA (%, at 84 MHz)	39.77	39.51	63.32	86.05
Positive Demand DMA (%, at 120 MHz)	58.11	60.49	100	97.67
Average Demand (84 MHz)	1.34	1.57	2.57	5.26
Average Demand (120 MHz)	2.62	2.94	4.85	8.93

Notes: An observation is a station-transaction of auction-eligible stations. “Interference Count” is the number of stations with which a given station would interfere if they were located on adjacent channels. “Demand” is the median number of licenses to be purchased in the DMA according to the FCC repacking scenarios. “Positive Demand DMAs” refers to transactions that involve a license located in a DMA with a positive median demand level under the 120 MHz clearing target in FCC repacking simulations. For the 507 acquisitions that involve multiple stations, some of which may not be eligible for the auction, we use the average price per license as a transaction price.

5 Analysis

We first estimate the reservation value of a TV station going into the auction. Then we simulate the auction and compare the outcome under naive bidding with the outcome that obtains when we account for the ownership pattern in the data and allow multi-license owners to engage in strategic supply reduction.

5.1 Reservation values

The reservation value of TV station j in a particular DMA going into the reverse auction held at time t_0 is the greater of its cash flow value $V_{jt_0}^{CF}$ and its stick value $V_{jt_0}^{Stick}$:

$$v_{jt_0} = \max \left\{ V_{jt_0}^{CF}, V_{jt_0}^{Stick} \right\}. \tag{3}$$

The industry standard for valuing a broadcast business as a going concern is to assess its cash flow CF_{jt_0} and multiply it by a so-called cash flow multiple $Multiple_{jt_0}^{CF}$. Hence, the cash flow value of the TV station is

$$V_{jt_0}^{CF} = Multiple_{jt_0}^{CF} \cdot CF_{jt_0}. \tag{4}$$

This is the price a TV station expects if it sells itself on the private market as a going concern. The stick value $V_{jt_0}^{Stick}$, on the other hand, reflects solely the value of the station's broadcast TV license and tower, not the ongoing business. This is the valuation typically used for unprofitable or non-commercial broadcast licenses. It is computed from the station's population reach $CoveragePop_{jt_0}$ and the stick multiple $Multiple_{jt_0}^{Stick}$ as

$$V_{jt_0}^{Stick} = Multiple_{jt_0}^{Stick} \cdot 6\, MHz \cdot CoveragePop_{jt_0}. \tag{5}$$

For example, a TV station reaching 100,000 people with a license for a 6 MHz block of spectrum and a stick multiple of \$0.30 per MHz per population (henceforth MHz-pop) is worth \$180,000 based on its fixed assets alone.

While we observe a TV station's covered population, its cash flow is only available at various levels of aggregation in the NAB data. Moreover, we observe neither the cash flow multiple nor the stick multiple. Below we explain how we estimate these objects and infer the station's reservation value v_{jt_0}.

Cash flows. We specify a simple accounting model for cash flows.[24] The cash flow CF_{jt} of TV station j in a particular DMA in year t is

$$CF_{jt} = \alpha\left(X_{jt}; \beta\right) AD_{jt} + RT\left(X_{jt}; \gamma\right) - F\left(X_{jt}; \delta\right) + \epsilon_{jt}, \tag{6}$$

[24] In doing so, we follow the Well Fargo analyst report, "Broadcasting M&A 101 Our View of the Broadcast TV M&A Surge," J. Davis Herbert and Eric Fishel, June 26, 2013.

where $\alpha(X_{jt};\beta) AD_{jt}$ is the contribution of advertising revenue to cash flow, $RT(X_{jt};\gamma)$ is non-broadcast revenue (including retransmission fees), $F(X_{jt};\delta)$ is fixed cost, and $\epsilon_{jt} \sim N(0,\sigma^2)$ is an idiosyncratic, inherently unobservable component of cash flow. Only advertising revenue AD_{jt} and station and market characteristics X_{jt} are directly observable in the BIA data. To estimate the remaining components of cash flow, we specify flexible functional forms of subsets of X_{jt} for $\alpha(X_{jt};\beta)$, $RT(X_{jt};\gamma)$, and $F(X_{jt};\delta)$ as detailed in Appendix A.2 and estimate the parameters $\theta = (\beta, \gamma, \delta, \sigma)$ drawing on the aggregated data from NAB.

We proceed using a simulated minimum distance estimator as detailed in Appendix A.2. The parameters $\theta = (\beta, \gamma, \delta, \sigma)$ together with our functional form and distributional assumptions in equation 6 imply a distribution of the cash flow CF_{jt} of TV station j in a particular DMA in year t. We first draw a cash flow error term ϵ_{jt} for each TV station that is included in the aggregated data from NAB. Then we match the moments of the predicted cash flow and non-broadcast revenue distributions to the moments reported by NAB for different sets of TV stations and DMAs. In particular, we match the mean, median, 25^{th} and 75^{th} percentiles of cash flow and the mean of non-broadcast revenue for each NAB table in each year, yielding a total of 3,313 moments.

The correlation between the moments of the predicted distributions at our estimates and the moments reported by NAB is 0.98 for cash flow and 0.84 for non-broadcast revenue. The estimates indicate that major network affiliates are most profitable; that non-broadcast revenue has grown significantly in recent years; and that there are economies of scale in fixed cost. Appendix A.2.4 gives more details on parameter estimates and fit measures.

Multiples. To estimate the multiples $Multiple^{CF}_{jt}$ and $Multiple^{Stick}_{jt}$, we begin with the 350 transactions for an individual broadcast TV station in the eleven years from 2003 to 2013 as recorded by BIA.[25] We extract 136 transactions based on cash flows and 201 transactions based on stick values between 2003 and 2013.[26] We infer the cash flow multiple and stick multiple from the transaction price using equations 4 and 5, respectively. Because the transacted stations may be a selected sample, we incorporate industry estimates of the range of the multiples. Using these estimates as priors, we estimate a Bayesian regression model to project multiples on station and market characteristics X_{jt}. This allows us to predict multiples for any TV station, not just those that were recently transacted. Appendix A.3 provides further details. The resulting posteriors, shown in Appendix Figure 13, are a normal distribution for the cash flow multiple and a log-normal distribution for the stick multiple.

[25] BIA records 877 transactions with full transaction prices, as opposed to station swaps, stock transfers, donations, etc. We focus on the 350 transactions involving a single license in order to evaluate the trading multiples as a function of station and market characteristics. Of these 350 transactions, 26 involve the three private equity firms.

[26] Because 2012 is the last year of availability for the NAB data, we cannot estimate a TV station's cash flow for 2013. To classify transactions, we proceed as follows: We first define a TV station to be a major network affiliate if it is affiliated with ABC, CBS, Fox, or NBC. We then classify a transaction as based on stick value if it is for a non-major network affiliate with a cash flow of less than \$1 million. Regardless of network affiliation, we also classify a transaction as based on stick value if the TV station has a negative cash flow. Finally, we classify a transaction that would have implied a stick value greater than \$4 per MHz-pop to be based on cash flow and a transaction that would have implied a cash flow multiple greater than 30 to be based on stick value. Together, we drop 13 transactions that do not fit the criteria.

Reservation values. We use our estimates to infer a TV station's reservation value for its broadcast license going into the auction. Not all the 1,672 UHF stations that the FCC includes in its repacking simulations are covered in the aggregated data from NAB that we use to estimate the cash flow model in equation 6. The main omissions are 386 low-power UHF stations and 290 non-commercial UHF stations. We therefore extrapolate from our estimates as follows. First, we assume that low-power stations are valued in the same way as full-power stations conditional on station and market characteristics X_{jt}. Second, we assume that non-commercial stations are valued by stick value, consistent with industry practice.

To infer the reservation value of TV station j in a particular DMA going into the reverse auction, we set $t_0 = 2012$ and draw from the estimated distribution of the cash flow error term ϵ_{jt_0} to get $\widehat{CF}_{jt_0}$. We draw from the respective posterior distributions of the multiples to get $\widehat{Multiple}^{CF}_{jt_0}$ and $\widehat{Multiple}^{Stick}_{jt_0}$. A commercial station's reservation value $\widehat{v}_{jt_0}$ is then the higher of the realized draws of its discounted broadcast cash flow value and its stick value as specified in equations 3-5; a non-commercial station's reservation value $\widehat{v}_{jt_0}$ is its stick value. Our estimates imply that the average TV station in our data has a cash flow value of \$42.2 million and a stick value of \$4.5 million. For 31.6% of TV stations, our estimates indicate that the reservation value is given by its stick value rather than its cash flow value.

5.2 Simulations

To quantify the impact of strategic supply reduction, we solve for the equilibrium of a simplified version of the reverse auction. We compare the outcome under naive bidding with the outcome that obtains when we account for the ownership patterns in the data.

To render the analysis tractable, we make two main simplifications. First, to sidestep the forward auction, the repacking process between the forward and reverse auctions, and the multi-stage nature of the overall incentive auction, we fix demand in the reverse auction for each DMA at the median number of broadcast licenses to be acquired at the 84 MHz or 120 MHz clearing target in the FCC repacking simulations. We explore the joint distribution of demand in Appendix Table 19 as a robustness check. The assumption of perfectly inelastic demand for a given draw from the FCC demand simulations is justifiable because the proceeds from the forward auction are expected to greatly exceed the payouts to broadcast TV license holders in the reverse auction.

Second, we model the reverse auction as a normal-form game with complete information. Hence, all auction participants in a DMA know the broadcast volume φ_{jt_0} and reservation value v_{jt_0} of every TV station in the DMA. In line with the analysis in Section 3, the owner of TV station j either bids $\frac{v_{jt_0}}{\varphi_{jt_0}}$ to relinquish his license or withdraws the station from the auction. In particular, an owner of n_o TV stations has $2^{n_o} - 1$ strategies (since withholding all stations from the auction is never optimal). A single-license owner therefore always bids $\frac{v_{jt_0}}{\varphi_{jt_0}}$. A multi-license owner, in contrast, can engage in strategic supply reduction by withholding one or more of his stations from the auction.

Recall that if the FCC intends to acquire k broadcast licenses in a DMA and stations are ordered in ascending order of the ratio $\frac{v_{jt_0}}{\varphi_{jt_0}}$, then the reverse auction closes at base clock price $\frac{v_{k+1,t_0}}{\varphi_{k+1,t_0}}$. The payoff accruing to station j is therefore $\varphi_{jt_0}\frac{v_{k+1,t_0}}{\varphi_{k+1,t_0}} - v_{jt_0}$ if station j and exactly $k-1$ other stations bid into the auction and v_{jt_0} in all other cases. The payoff to an owner is obtained by summing appropriately over all TV stations he owns. Under naive bidding, we simply ignore the ownership pattern in the data and treat TV stations as independently owned.

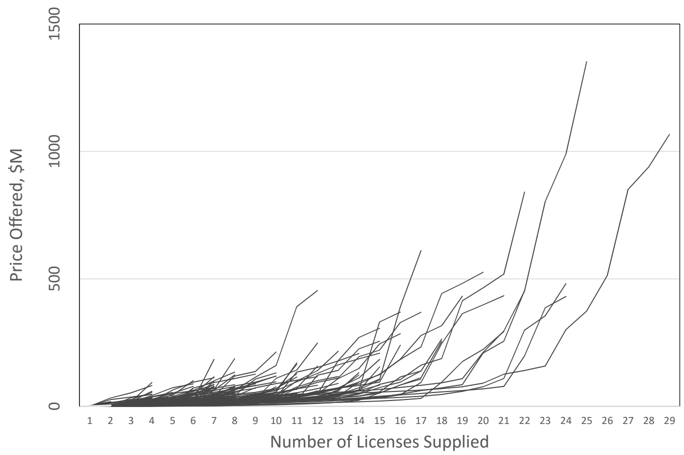
The assumption of complete information greatly simplifies the analysis relative to an asymmetric information formulation. The net effect of this assumption on prices and payouts is ambiguous as it makes it easier for firms to implement supply reduction strategies while also eliminating any possible ex-post regret for multi-license owners. Furthermore, while knowledge of reservation values is a strong assumption, many large broadcasters have engaged consultants to help them estimate valuations heading into the auction. In addition, industry groups of smaller broadcasters have helped their members to similarly estimate valuations in their DMAs. While there may be some residual uncertainty about reservation values, we conjecture that a model with incomplete information has similar but perhaps less sharp implications as our current model. In particular, strategic supply reduction with incomplete information manifests itself by a multi-license owner raising his bid above a station's reservation value instead of outright withdrawing the station from the auction, which may have a smaller impact on closing prices.

With no or one multi-license owner in a DMA, the normal-form game has a unique pure-strategy equilibrium; with more than one multi-license owner, there may be multiple equilibria. We use an iterated best-response algorithm to compute an equilibrium. We start by assuming all TV stations bid into the auction and proceed iteratively. In each iteration of the algorithm, we cycle through all multi-license owners in a randomly assigned but fixed order and update the owner's strategy using his best response. We use a Gauss-Seidel algorithm in that the owner currently being updated best responds to the strategies of the owners that come first in the order and have already been updated in the current iteration of the algorithm, rather than to their strategies from the previous iteration of the algorithm. The algorithm comes to a halt if no owner has an incentive to change his strategy from the previous iteration.[27] Note that a different order of multi-license owners may select a different equilibrium (Facchinei and Kanzow, 2007).

To account for uncertainty in our estimates of reservation values, we simulate the reverse auction. Specifically, we complete 1,000 simulations where we construct reservation values by drawing realizations of the cash flow error term ϵ_{jt_0}, the multiples $Multiple^{CF}_{jt_0}$ and $Multiple^{Stick}_{jt_0}$, and the order of play of multi-license owners. Unless otherwise noted, we report average outcomes of the 1,000 simulations runs below. To further account for uncertainty and interdependency in spectrum demand across DMAs, in Appendix Table 19 we complete 20,000 simulations where we simultaneously draw the DMA-level demand at the 84 MHz and 120 MHz target with replacement from the FCC repacking simulations.

[27] We drop 1-3% of simulation runs in which the algorithm fails to converge.

Figure 2: Unadjusted DMA-Level Supply Curves



Notes: Each line represents a DMA. Different lengths of lines reflect different numbers of eligible broadcast licenses across markets. If for a particular market, a given number of licenses Y correspond to a price of $X, it implies that in that market, the Yth lowest-valued license would sell for a price of $X, on average, across our simulations of reservation values.

6 Results

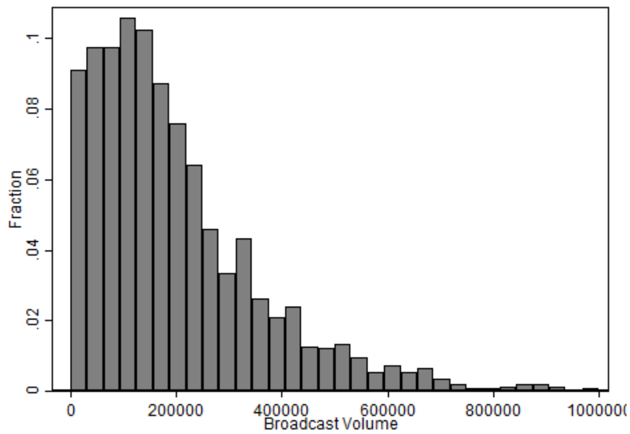
6.1 Naive bidding

Using our estimates we construct the supply curve of broadcast TV licenses under naive bidding where we ignore the ownership pattern in the data. Recall that if broadcast TV licenses are separately owned, then an owner will relinquish his license for his reservation value v_{jt_0}. Figure 2 shows the resulting supply curves for the 121 DMAs with positive demand at a 120 MHz clearing target. The supply curve for a DMA indicates the price, averaged across simulation runs, at which a given number of licenses can be purchased. The supply curve is fairly steep in many DMAs, indicating that licenses holders must be offered rapidly increasing amounts to induce them to part with an additional broadcast TV license over certain ranges.

In the reverse auction, a license holder is shown a personalized price that depends on its broadcast volume φ_{jt_0} as in Section 3. Figure 3 shows the distribution of broadcast volume. The mean is 198,454 and the median is 157,914. We use broadcast volume to re-scale Figure 2 and construct the supply curve of broadcast TV licenses in terms of the base clock price. Under naive bidding, a broadcast TV license sells into the auction as long as the base clock price exceeds $\frac{v_{jt_0}}{\varphi_{jt_0}}$. Figure 4 shows the resulting supply curves. There are many DMAs where several licenses may be purchased at relatively low base clock prices, and there are many DMAs where even clearing two licenses may be very costly.

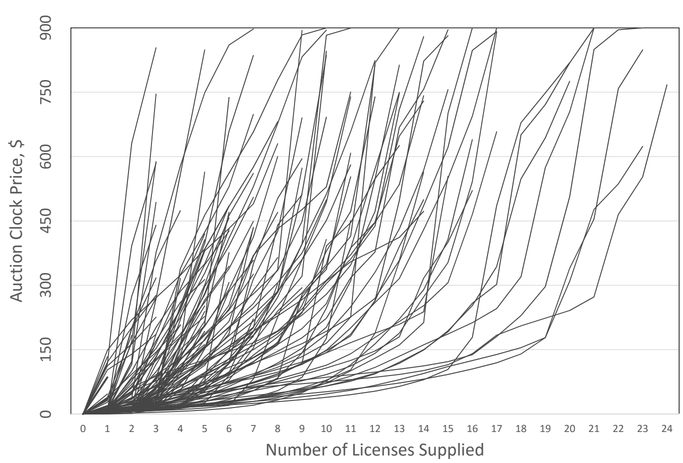
Due to differences in the previously allocated amount of spectrum and the difficulty of repacking

Figure 3: Distribution of Broadcast Volume



Notes: Histogram depicts broadcast volume according to equation 1 for 1672 auction-eligible UHF stations in 2012.

Figure 4: Adjusted DMA-Level Supply Curves



Notes: Each line represents a DMA. Lines plot the average $\frac{v_j}{\varphi_j}$ across simulations for the jth lowest bid. Different lengths of lines reflect different numbers of eligible broadcast licenses across DMAs. We censor reservation prices at the $900 starting clock price.

Table 3: Strategic Purchasing of Licenses

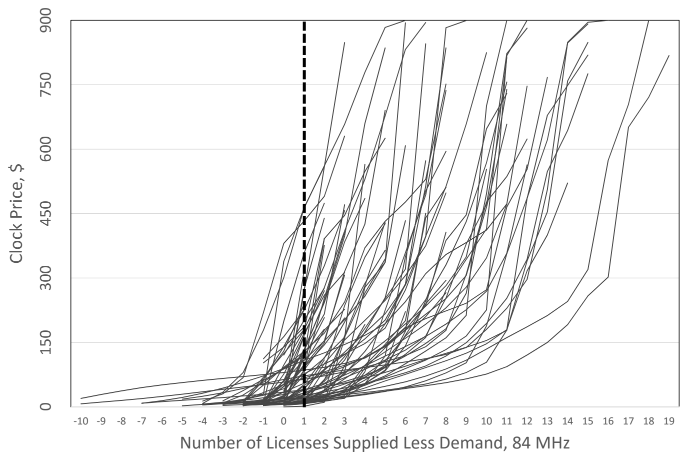
Owner	Indicator for Private Equity Purchase (1)	(2)
Price Increase from Withdrawing 1	0.2512**	
	(0.1069)	
Price Increase from Withdrawing 2		0.1971*
		(0.1225)
Number of Licenses	0.0097	0.0127
	(0.0095)	(0.0105)
log(DMA Population (M))	0.0984*	0.0950*
	(0.0506)	(0.0555)
N	112	101
Pseudo-R^2	0.3359	0.4089

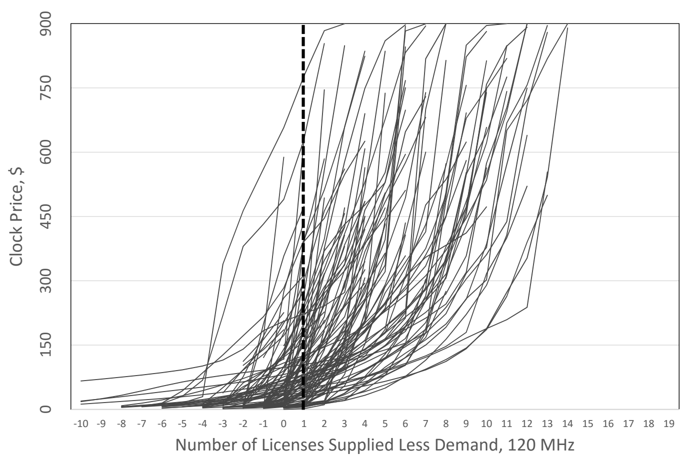
Notes: Dependent variable is an indicator for a purchase by a private equity firm in the DMA. Price increases are computed as the average difference between the reservation prices of the last license to withdraw from the auction and 2nd (3rd) last license to withdraw, in thousands, at the 120 MHz clearing target. Reported coefficients are the marginal effects of the probit regression. * and ** indicate statistical significance at the 5% and 10% level, respectively.

between DMAs, the demand for licenses varies greatly across DMAs. We therefore center the supply curve for each DMA at the median number of UHF stations the FCC has to acquire in the DMA to meet the alternative nationwide clearing targets. Figure 5 shows the demand-centered supply curves for the 81 and 121 DMAs with positive demand under the 84 MHz and 120 MHz clearing targets, respectively. The dashed line indicates the first license that does not sell in the reverse auction, which sets the closing base clock price under naive bidding. The figure emphasizes that there are many DMAs with particularly steep supply curves around the first unsold license, indicating that these DMAs are especially vulnerable to strategic supply reduction. Here, withholding even a single broadcast TV license from the reverse auction can have a large effect on the closing base clock price.

To assess the implications of the model in Section 3, whether pre-auction acquisitions are concentrated in vulnerable DMAs, Table 3 shows the results from a probit regression in the cross section of positive demand DMAs. The dependent variable is an indicator for whether the three private equity firms have acquired licenses in the DMA. The independent variable of interest is the increase in the closing base clock price that results from removing from the auction either one or two licenses that otherwise sell under naive bidding (the term in parentheses on the left hand side of equation 2). In addition, we control for population and number of licenses as these are related to acquisition activity. The number of observations changes between specifications since not all DMAs have a second license to withdraw. The results show that the private equity firms were more likely to acquire licenses in DMAs where the supply curve is relatively steep and strategic supply reduction is thus likely to be profitable.

Figure 5: Adjusted DMA-Level Supply Curves Centered on Demand





Notes: Each line represents a DMA. Different lengths of lines reflect different numbers of eligible broadcast licenses across DMAs. We only show DMAs with positive demand at the given clearing target, which is 81 DMAs for the 84 MHz target and 121 DMAs for the 120 MHz target.

6.2 Strategic supply reduction

We compare the outcome of the reverse auction under naive bidding with the outcome that obtains under strategic bidding when we account for the ownership patterns in the data. The closing base clock price increases (at least in one simulation run) in 66 of the 121 positive demand DMAs under the 120 MHz clearing target and in 47 of the 81 positive demand DMAs under the 84 MHz clearing target. Figure 6 shows the average demand-centered supply curves for those 66 (47) DMAs in gray under naive bidding and in red under strategic bidding. To facilitate interpretation, the thicker red and gray lines are the average across DMAs of the supply curves under naive and strategic bidding, respectively. As can be seen, for both clearing targets the supply curves shift to the left and the closing base clock price increases significantly when moving from the gray to the red supply curves, as a direct result of supply reduction by multi-license owners.

Table 4 shows the closing base clock price and payouts to broadcast TV licenses holders under naive and strategic bidding, for both clearing targets, broken down into different subsets of DMAs. We exclude the 2 (9) DMAs where the reverse auction closes immediately at the initial base clock price of \$900 under the 84 MHz (120 MHz) clearing target; reaching the clearing target in these DMAs requires additional payouts of at least \$0.4 billion (84 MHz) or \$3.1 billion (120 MHz).[28]

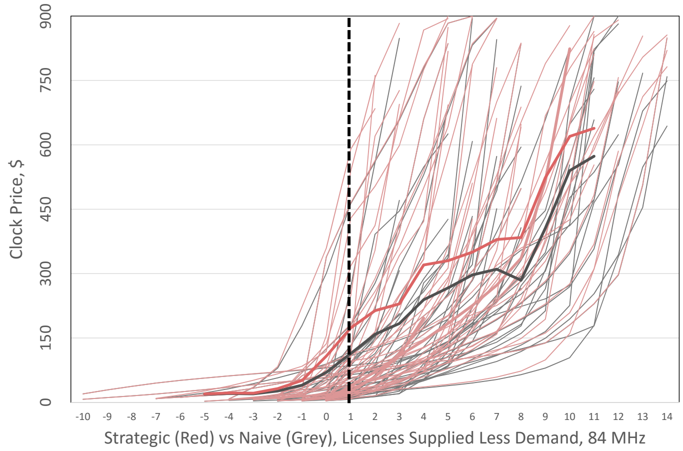
The first thing to remark upon is that the closing base clock price increases significantly due to strategic supply reduction. This behavior implies additional payouts of \$1.66 billion (under the 84 MHz clearing target) or \$6.75 billion (120 MHz) to broadcast TV license holders. In 12 of 17 (8 of 14) private equity active DMAs with positive demand at the 120 (84) MHz target, the closing base clock price increases, providing immediate evidence of the private equity firms' ability to influence the price. As a result, payouts in these DMAs increase by \$175 million (8.3%) or \$3.21 billion (54.1%) depending on clearing target.

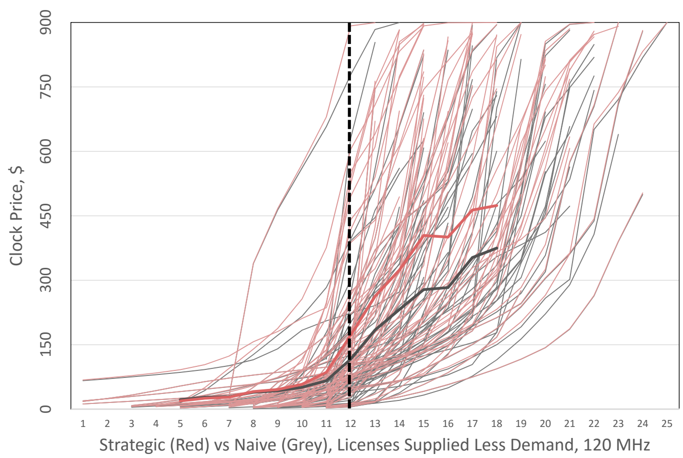
Table 4 masks significant heterogeneity in the impact of strategic supply reduction. Figure 7 shows the distribution across DMAs of the impact of strategic supply reduction at both the 84 MHz and 120 MHz clearing targets. To construct this figure, we sort positive demand DMAs by their average per-license payouts under naive bidding. Each bar represents a DMA and the width of a bar is the number of licenses sold into the auction while its height is the average per-license price in the DMA as given by the closing base clock price times the average broadcast volume of the sold licenses. As a result, its area indicates the payouts to broadcast TV license holders in the DMA. Payouts under naive bidding are in white or gray depending on whether there are multi-license owners in the DMA, while payouts under strategic bidding are in red. As can be seen, the average per-license price can increase dramatically due to strategic supply reduction, and many positive demand DMAs are susceptible to this form of price manipulation.

The changes in the height of a bar from strategic bidding combine two effects: First, the closing base clock price increases as one or more licenses are withheld from the auction. Second, because the composition of licenses sold into the auction changes, so does the average broadcast volume of the sold licenses. To gauge the relative importance of these effects, we eliminate the compositional

[28]This supports the use of multiple stages to discover the correct nationwide clearing target.

Figure 6: Supply Curve Shifts from Strategic Supply Reduction





Notes: Each thin line represents the average demand-centered supply curve for a single DMA in our simulations. Plotted are the supply curves for the 66 (47) DMAs where the closing price changed under strategic bidding for a 120 MHz (84 MHz) clearing target. The gray lines are for simulations where firms naively bid each station they own independently, while the red lines are when firms optimize their bidding across all stations they own. The thicker lines average the DMA-level lines to get an aggregate measure of the effect on supply.

Table 4: Closing Base Clock Prices and Payouts to Broadcast TV License Holders by DMA Type

		Clock Price ($)		Total Payment ($B)		Payment
Types of DMAs	# DMAs	Naïve	Strategic	Naïve	Strategic	Increase %
		84 MHz Clearing Target				
Positive demand	81	90.50 (3.65)	116.28 (5.38)	5.41 (0.24)	7.08 (0.35)	30.86 (6.41)
Multi-License Owners	55	70.39 (3.35)	102.10 (6.02)	3.46 (0.17)	5.12 (0.32)	48.41 (10.32)
Two or more Multi-License Owners	37	70.75 (3.72)	101.91 (6.70)	3.03 (0.17)	4.44 (0.31)	46.82 (11.44)
Private equity active	14	73.29 (4.56)	78.60 (5.80)	2.13 (0.14)	2.31 (0.18)	8.28 (5.90)
		120 MHz Clearing Target				
Positive demand	121	129.01 (4.54)	188.00 (13.86)	13.48 (0.51)	20.22 (1.53)	50.20 (12.21)
Multi-License Owners	81	116.62 (4.21)	184.50 (15.55)	10.60 (0.41)	17.35 (1.50)	63.85 (15.67)
Two or more Multi-License Owners	50	117.80 (4.71)	187.64 (18.77)	8.90 (0.39)	14.52 (1.48)	63.52 (18.42)
Private equity active	17	119.86 (5.80)	180.78 (26.83)	6.00 (0.31)	9.22 (1.39)	54.08 (25.31)

Notes: Data are averages over 1000 auction simulations. Standard deviations across 1000 simulations are in parentheses. In calculating outcomes, we exclude DMAs where the auction closes immediately under naive bidding (2 markets under 84 MHz clearing target, 9 markets under 120 MHz). For the markets that close at the starting price, the total additional payout would be at least \$0.4 billion at the 84 MHz target and \$3.1 billion at the 120 MHz target. Total license demand is 222 and 396 at 84 and 120 MHz, respectively.

effect by holding fixed the total broadcast volume of sold licenses. The price effect alone accounts for \$1.48 billion (89%) or \$5.83 billion (86%) of the additional payouts, implying that the primary mechanism is an increase in closing price as opposed to a substitution towards surrendering higher-volume licenses in the auction.

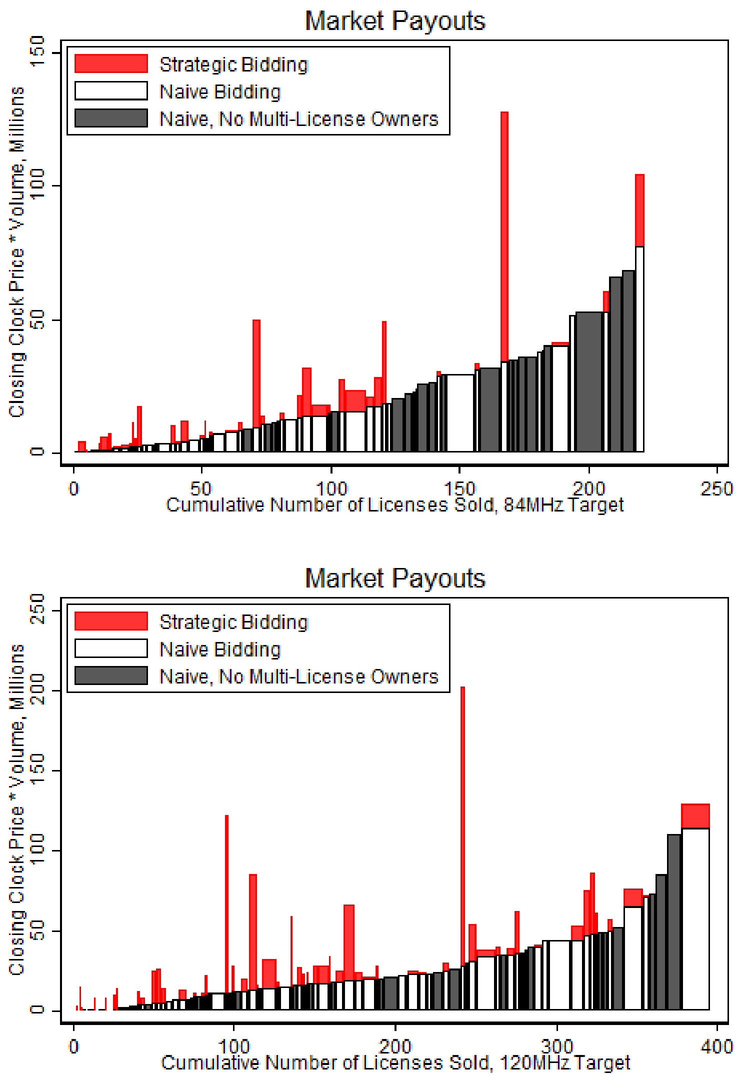
Our simulation allows us to determine the profitability of strategic supply reduction for the three private equity firms. Panel A of Table 5 presents the results. As discussed in Section 4.2 these firms have acquired TV stations with high broadcast volume but low valuations. Even under naive bidding, the firms stand to profit as their payouts in the reverse auction plus the value of any unsold licenses substantially exceed their total acquisition costs for both clearing targets. The private equity firms have carefully chosen their acquisition targets: as Appendix Table 17 shows, the private equity firms would fare much worse if they had instead acquired the same number of licenses randomly from the set of all transacted auction-eligible UHF licenses in our sample. This rejects that the firms' strategy is the same as that of other acquirers. Importantly, however, we see that profits go up under strategic bidding, sometimes very significantly. This reinforces our contention that in addition to speculative motivations behind reselling broadcast TV licenses in the reverse auction, there is the potential for rent-seeking through strategic supply reduction. It is further possible the three private equity firms engage in the multi-market strategies that we discuss in Section 6.6.

Panel B of Table 5 shows the total surplus from the auction for all participants. As we do not observe the original purchase prices for all licenses, we calculate surplus here as proceeds from licenses that sell in the auction less reservation values. The results show that the strategic behavior of multi-license owners benefits those owners, but also creates a large positive externality for single-license owners, who see a surplus increase of 34% to 62%, without changing their own behavior.

The simulations bear out the implication of the model in Section 3 that a multi-license owner sells stations with higher broadcast volume into the auction but withholds stations with lower broadcast volume. Table 6 shows the average broadcast volume, interference count, covered population, and reservation value of the licenses that multi-license owners decide to keep and sell under naive and strategic bidding. Comparing attributes of unsold stations under naive and strategic bidding, we see that owners on average keep stations of lower value and sell stations of higher value under strategic bidding. This is counter-intuitive, until one sees that the stations kept have lower broadcast volume, and so are less valuable in the auction, while those sold have higher broadcast volume, making them particularly attractive to sell into the auction.

Our analysis has a number of limitations. First, we focus exclusively on the full surrender of UHF licenses into the auction in line with the FCC's repacking simulations. We thus set aside VHF licenses and, similarly, do not model a TV station's additional option of moving from a higher to a lower frequency band in order to free up more desirable parts of the spectrum. The price that a VHF station is offered for going off the air and the price that a UHF or a VHF station is offered to move channels are fixed fractions of the price that a UHF station is offered for going off the air. For this reason, the FCC itself focuses solely on the number of UHF licenses required to

Figure 7: DMA-Level Closing Prices



Notes: The width of each column represents the number of licenses demanded in a DMA, implying that the area of a column is the total payout in a DMA. The change in height from naive to strategic bidding reflects both an increase in clock price, as well as potentially a higher broadcast volume for the set of licenses sold in the auction.

Table 5: Firm Profits and Auction Surplus

Panel A: Private Equity Firms	# Stations	Total Purchase Price ($M)	Total Profits: 84 MHz Clearing Target Naive ($M)	Total Profits: 84 MHz Clearing Target Strategic ($M)	Total Profits: 120 MHz Clearing Target Naive ($M)	Total Profits: 120 MHz Clearing Target Strategic ($M)
NRJ	14	235.51	284.72	298.50	576.00	636.20
OTA	20	77.05	238.52	250.07	322.30	571.97
LocusPoint	9	54.75	119.80	122.56	182.01	189.99

Panel B: All Firms	# Stations	Total Purchase Price ($M)	Auction Surplus: 84 MHz Clearing Target Naive ($B)	Auction Surplus: 84 MHz Clearing Target Strategic ($B)	Auction Surplus: 120 MHz Clearing Target Naive ($B)	Auction Surplus: 120 MHz Clearing Target Strategic ($B)
Multi-License Owners	279 / 386	-	0.80	1.42	2.47	4.63
Single-License Owners	491 / 685	-	2.52	3.38	6.27	10.16

Notes: Profits are averages over 1000 auction simulations. Total profits are defined as total proceeds from the auction for stations that sell, plus the reservation values of stations that do not sell, less the purchase prices paid by the firms for the stations. Auction surplus is total proceeds for stations that sell less their reservation values. In calculating outcomes, we exclude DMAs where the auction closes immediately under naive bidding (2 markets under 84 MHz clearing target, 9 markets under 120 MHz).

Table 6: Station Characteristics for Multi-License Owners

	84 MHz				120 MHz			
	Naive		Strategic		Naive		Strategic	
Averages	Unsold	Sold	Unsold	Sold	Unsold	Sold	Unsold	Sold
Broadcast Volume (000s)	184.66	253.04	183.67	269.33	180.36	238.35	177.80	258.22
Interference Count	68.81	102.20	68.96	105.45	66.45	95.90	66.36	101.13
Covered Population (M)	2.17	2.65	2.15	2.85	2.16	2.50	2.12	2.70
Reservation Value ($M)	61.87	7.33	60.83	8.05	68.26	9.17	65.45	10.84

Notes: Data are averages of station characteristics for selling and non-selling licenses in each of 1000 auction simulations. We include 244 firms that own multiple licenses (588 in total) within a given DMA.

meet a given clearing target in its repacking simulations. Second, we do not consider the option of channel-sharing arrangements. Channel-sharing refers to a situation where two TV stations enter into a private agreement to share a license to 6 MHz of spectrum and split the proceeds from selling the other license into the auction. It is unclear how attractive this option is and there are technological constraints.[29] Channel-sharing arrangements are likely to boost participation in the reverse auction, thereby effectively reducing the number of UHF licenses required from regular auction participants to meet a given clearing target. Third, we do not model the repacking process explicitly, but instead rely on the FCC's repacking scenarios to capture the effect of repacking: introducing correlations in demand across DMAs. This thus reflects implicitly that licenses in neighboring DMAs may be (imperfect) substitutes in the repacking process because the reverse auction is run at the national level. To show that our results are not particularly sensitive to these issues, we present two robustness checks. First, in Appendix Table 18 we repeat our main analysis with the demand for spectrum reduced by one license in all positive demand DMAs and second, in Appendix Table 19 we draw from the joint distribution of DMA-level demand in the FCC repacking simulations. We continue to find significant effects from strategic supply reduction.

6.3 Case study: Philadelphia, PA

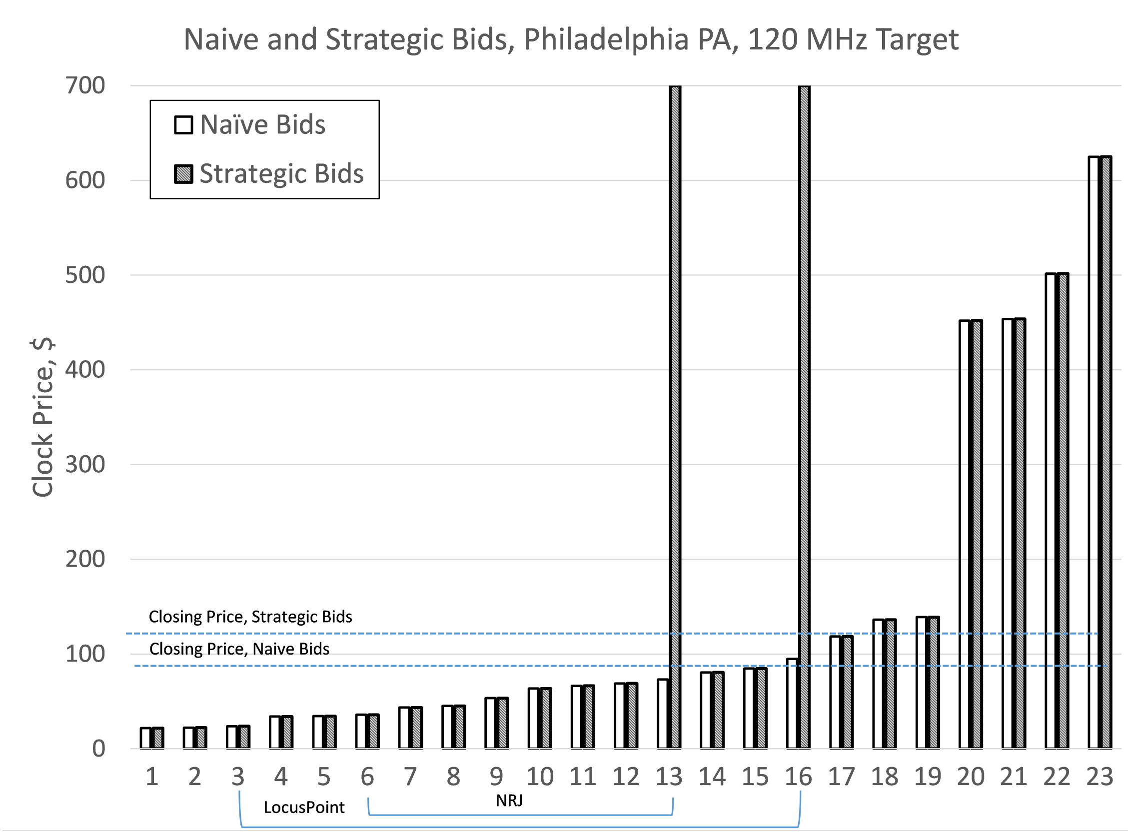
We next examine the Philadelphia, PA, DMA, in detail. There are 23 auction-eligible UHF stations in the DMA; Figure 8 shows their naive bid, $\frac{v_j}{\varphi_j}$, and strategic bid in a particular simulation run in increasing order of naive bids. The private equity firm NRJ owns licenses 6 and 13 and Locus Point owns licenses 3 and 16. Licenses 12 and 19 are jointly owned by Univision, licenses 1 and 5 by the New Jersey Public Broadcasting Authority, licenses 9 and 20 by NBC, and licenses 11 and 23 by CBS. The median number of licenses the FCC intends to acquire in order to clear 120 MHz of spectrum is 14.

Under naive bidding, the 15^{th} lowest bid sets the closing base clock price of \$84.69. Under strategic bidding, however, in this simulation run LocusPoint and NRJ withhold stations 16 (WPHA-CD) and 13 (WPHY-CD) from the reverse auction to increase payouts from their remaining licenses. Hence, the 17^{th} lowest valuation sets the closing base clock price of \$118.42. As a result, payouts to broadcast TV license holders in the DMA for the 14 licenses increase substantially from \$607 million to \$849 million. While all license holders benefit from strategic supply reduction, LocusPoint and NRJ find it individually profitable to withhold stations 16 and 13. In this particular simulation run, it is not profitable for any other multi-license owner to withhold licenses from the auction.[30] We revisit the case of Philadelphia, PA, in Section 6.5.

[29] 6 MHz of spectrum is insufficient for two high-definition video streams. The FCC has piloted a channel-sharing arrangement in Los Angeles, CA, showing that it is technologically feasible for one high-definition video stream and one or more standard-definition video streams to share 6 MHz of spectrum. 6 MHz of spectrum may no longer suffice if a TV station eventually transitions from a high-definition to a ultra-high-definition (4K) video stream.

[30] We emphasize that simulation runs may be quite different: in 36% of simulation runs, no licenses are withheld, in 36% one license is withheld, in 21% two licenses are withheld, and in 7% three or more licenses are withheld.

Figure 8: Case Study: Philadelphia PA DMA



Notes: Plotted is one simulation of the order of play and reservation values of the Philadelphia DMA. Stations are ranked by their naive bids. We indicate auction non-participation as a clock price of $700. In addition to NRJ and Locus Point's jointly owned stations, the remaining jointly-owned stations are those ranked: 12 and 19 by Univision, 1 and 5 by the New Jersey Public Broadcasting Authority, 9 and 20 by NBC, and 11 and 23 by CBS.

6.4 Misallocation and efficiency losses

The strategic behavior by multi-license owners in the reverse auction is rent-seeking in that funds are diverted from the government's general funds to broadcast TV license holders. In addition, the strategic behavior changes the composition of TV stations that remain in operation and those that surrender their licenses. Figure 9 presents a Venn diagram of the average (across simulation runs) number of licenses sold in positive demand DMAs. The population is the set of licenses in positive demand DMAs. We group licenses by whether they sell only under naive, only under strategic bidding, or under both. As can be seen, there are a large number of stations that sell under both scenarios at both clearing targets. However, strategic supply reduction by multi-license owners causes an average of 30 licenses at the 84 MHz target and 60 licenses at the 120 MHz target to be misallocated. These licenses are surrendered under naive bidding but continue to operate under strategic bidding or vice versa.

In addition, stations differ in their value as a going concern. We estimate that the average reservation value for licenses that sell under both naive and strategic bidding is \$9.75 or \$12.43 million depending on the clearing target. Importantly, the licenses that only sell under strategic bidding have an average reservation valuation that is \$10 or \$20 million higher, depending on the clearing target, than the licenses that sell only under naive bidding. Multi-license owners find it profitable to withhold low-value stations from the auction resulting in the surrender of licenses with higher values. This misallocation has a direct efficiency cost: an asset worth \$6 million could be surrendered instead of an asset worth \$29 million, to free up the same 6 MHz of spectrum. Our estimates imply that the efficiency loss is approximately \$701 million (\$176 million) at the 120 MHz (84 MHz) clearing target.

6.5 Partial remedy

We have so far shown that strategic supply reduction may lead to increased payouts and efficiency losses in the reverse auction. We next propose a change to the auction rules and show how it limits the potential for rent-seeking. The model in Section 3 shows that strategically reducing supply is more likely to be profitable if the increase in the closing base clock price from withholding a license can be leveraged by selling a license with high broadcast volume into the auction. Our proposal aims to weaken this mechanism by limiting the strategy space of multi-license owners. In particular, we stipulate that a multi-license owner must first withdraw his highest broadcast volume license. Only once that has been withdrawn from the reverse auction, the owner may withdraw his second highest broadcast volume license, and so on.

Table 7 shows how the rule change affects our main results. In general, the increase in payouts from strategic bidding are 33-65% less than in Table 4. The average number of misallocated licenses falls from 30.2 (14.9) to 17.6 (10.0) at 120 MHz (84 MHz), and the corresponding efficiency loss falls 81% (69%) to \$120M (\$54M).

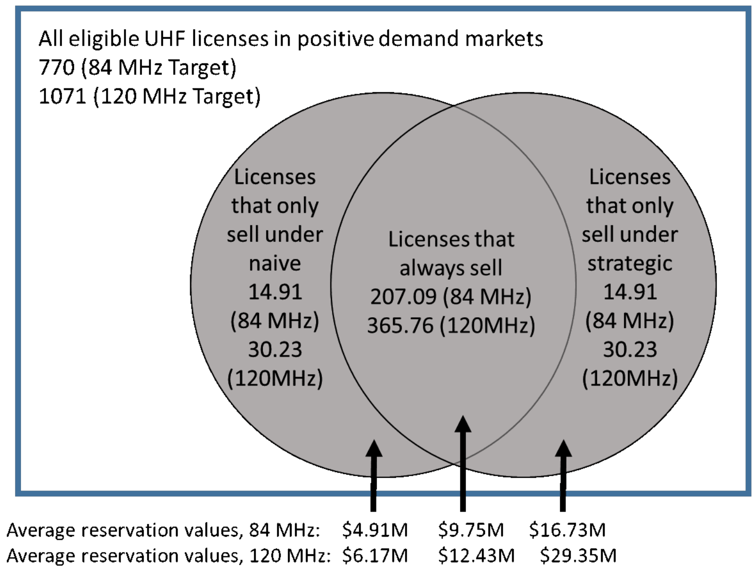
Interestingly, the rule change undoes the example of strategic supply reduction in Section 6.3. Recall that in a particular simulation run NRJ withdrew license 13 and sold license 6 into the

Table 7: Clock Prices and Total Payments by DMA Type under Rule Change

		Avg. Clock Price ($)		Total Payment ($B)		Payment
Types of DMAs	# DMAs	Naïve	Strategic	Naïve	Strategic	Increase %
		84 MHz Clearing Target				
Positive demand	81	90.52 (3.68)	109.53 (4.22)	5.41 (0.24)	6.53 (0.27)	20.68 (4.06)
Multi-License Owners	55	70.42 (3.38)	93.52 (4.38)	3.46 (0.18)	4.57 (0.22)	32.44 (6.54)
Two or more Multi-License Owners	37	70.78 (3.74)	92.82 (4.71)	3.03 (0.17)	3.95 (0.21)	30.57 (7.02)
Private equity active	14	73.33 (4.55)	75.76 (4.98)	2.13 (0.14)	2.20 (0.15)	3.17 (3.80)
		120 MHz Clearing Target				
Positive demand	121	129.01 (4.53)	151.81 (6.27)	13.48 (0.51)	15.83 (0.69)	17.53 (4.21)
Multi-License Owners	81	116.62 (4.22)	142.80 (6.41)	10.60 (0.41)	12.96 (0.61)	22.29 (5.39)
Two or more Multi-License Owners	50	117.80 (4.72)	141.16 (7.17)	8.90 (0.39)	10.62 (0.56)	19.45 (5.74)
Private equity active	17	119.85 (5.84)	130.33 (8.89)	6.00 (0.32)	6.52 (0.46)	8.74 (6.16)

Notes: Data are averages over 1000 auction simulations. Standard deviations across 1000 simulations are in parentheses. Auction mechanism assumes that multi-license holders withdraw license with highest broadcast volume first. See Notes to Table 4. Differences in naive prices and payouts from Table 4 are due to convergence failure of the auction in 1-3% of simulation runs.

Figure 9: Allocative Effects of Strategic Behavior



Notes: Diagram includes all UHF licenses eligible in the auction in DMAs with positive demand. Excludes 2 (9) markets, or 2 (18) licenses, that close immediately under naive bidding at the 84 MHz (120 MHz) target. Data are averages over 1000 auction simulations.

reverse auction. Under the rule change, NRJ is unable to withdraw license 13 before withdrawing license 6. As a result, Locus Point no longer finds it profitable to withdraw license 16, and the outcome is the same as under naive bidding.[31] Table 8 compares the outcomes for that simulation under unrestricted bidding and under the proposed rule change.

Efficiency requires that the licenses with the lowest reservation values are sold into the auction. In the spirit of the literature on regulation where effort is not verifiable (Laffont and Tirole, 1986), the rule change leverages the fact that broadcast volume, unlike cash flows, is observed and contractible. Our estimates imply that broadcast volume is positively correlated with reservation

[31] Once again simulation runs may be quite different: in 50% of simulation runs, no licenses are withheld, in 35% one license is withheld, and in 15% two or more licenses are withheld. This compares to 41%, 36%, and 23% prior to the rule change, see footnote 30.

Table 8: Case Study: Philadelphia PA DMA Under Rule Change

Owner	Station	Broadcast Volume (000s)	Reservation Value ($M)	Naive Bid Rank ($\frac{v_j}{\varphi_j}$)	Outcome: Base	Outcome: Rule Change
LocusPoint	WMGM-TV	159.42	3.80	3	Sold	Sold
LocusPoint	WPHA-CD	222.35	21.10	16	Withdrawn	Not Sold
NRJ	WTVE	570.17	20.45	6	Sold	Sold
NRJ	WPHY-CD	326.13	23.84	13	Withdrawn	Sold

Notes: Reservation value based on a single simulation draw. Under the rule change, NRJ would have to pull Station WTVE before Station WPHY-CD, and LocusPoint would have to pull WPHA-CD before WMGM-TV.

value: averaged across simulation runs the correlation is 0.47 overall and 0.44 within DMA.[32] The rule change therefore mitigates efficiency losses by requiring that licenses with higher broadcast volumes, and likely higher reservation values, are withdrawn first from the reverse auction.

The rule change has two potential shortcomings. First, a multi-license owner may be able to circumvent the rule change by selectively entering his licenses into the reverse auction in the first place. However, the rules of the auction may be further rewritten to compel a multi-license owner to either participate with all his licenses in the auction or not at all. Second, and perhaps more importantly, forcing lower broadcast volume licenses to sell before higher broadcast volume licenses may complicate the repacking process to the extent that licenses with higher broadcast volume and potentially also higher interference count may have to be repacked.

6.6 Multi-market strategies

Strategic bidding may extend beyond market borders if multi-license owners exploit the fact that the repacking process ties together all DMAs by withholding a license in a DMA from the reverse auction to drive up the closing base clock price in a neighboring DMA where they also own a license. Without modeling the repacking process, it is difficult to further assess the likely impact of such a multi-market strategy. However, an example makes the point.

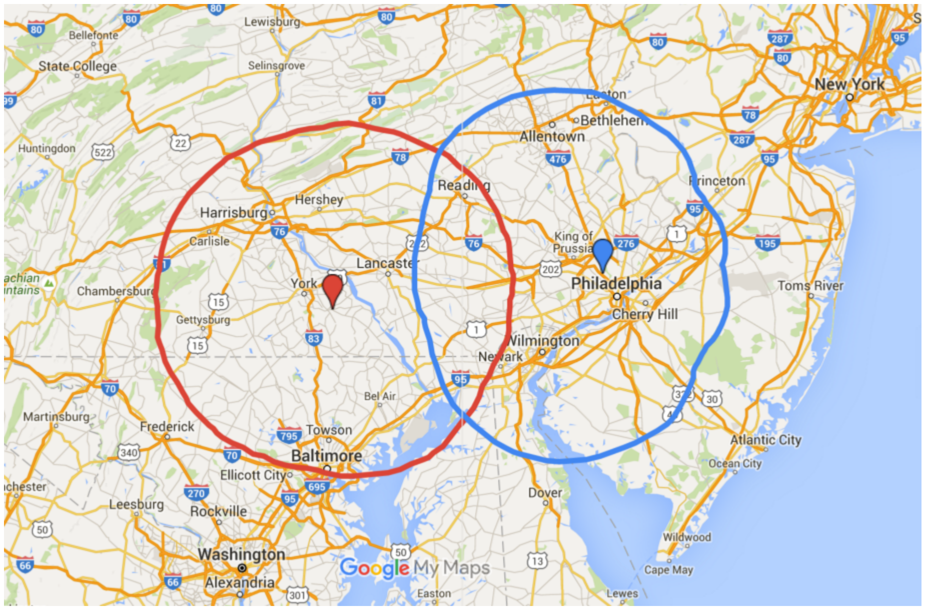
In late 2012 NRJ purchased WGCB-TV in the Harrisburg, PA, DMA for $9 million. While NRJ owns no other TV stations in the Harrisburg, PA, DMA they had previously purchased WTVE in the Philadelphia, PA, DMA in late 2011 for $30.4 million. WGCB-TV has a very high interference count and may interfere with 161 stations in the repacking process. A closer look shows that WGCB-TV is not actually located in Harrisburg, PA, but in Red Lion, PA, towards both the Philadelphia, PA, and Baltimore, MD, DMAs. Figure 10 shows how the broadcast contours of WGCB-TV and WTVE overlap. Hence, if NRJ withdraws WGCB-TV from the reverse auction, this may sufficiently complicate the repacking process to increase demand in the Philadelphia, PA, DMA, and potentially other DMAs, by one or more licenses.

Table 9 shows the effect of increasing demand in the Philadelphia, PA, DMA by one or two licenses on the closing base clock price and payouts to broadcast TV license holders. NRJ is expected to capture 1/14th of the payout increase in the Philadelphia, PA, DMA for each license it sells there, with the rest going to other auction participants. This highlights both the positive externality of strategic supply reduction for other auction participants and the potential for multi-market strategies.

More generally, cross-market ownership can be seen as positive for the auction, as selling licenses should be complementary across markets if it allows a larger clearing target to be attained. However, in this context, it has the potential to be negative if withdrawing WGCB-TV from the auction sufficiently complicates repacking in Philadelphia: NRJ may not find it worthwhile to withdraw WGCB-TV from the auction if either the closing price in the Harrisburg DMA is high, or if NRJ's share of the price increase in Philadelphia is small.

[32] Within DMA correlations are averaged over 184 DMAs that have three or more stations.

Figure 10: Multi-Market Strategy in the Mid-Atlantic



Notes: Map plots reception contours from FCC TV Query database for WGCB (Harrisburg) in red and WTVE (Philadelphia) in blue. Contour plots reflect reception of DTV signals from the broadcast towers. Image via Google Maps.

Table 9: Case Study: Philadelphia PA DMA Under Multi-Market Strategy

	Avg. Clock Price ($)		Total Payment ($M)	
	Naïve	Strategic	Naïve	Strategic
	84 MHz Clearing Target			
FCC Median Demand	64.26	69.04	343.42	370.87
FCC Median Demand ...				
+ 1 license	72.27	80.05	421.09	469.24
+ 2 licenses	81.45	93.78	513.37	595.89
	120 MHz Clearing Target			
FCC Median Demand	92.30	109.88	625.01	751.41
FCC Median Demand ...				
+ 1 license	105.06	140.61	759.62	1041.62
+ 2 licenses	119.39	200.86	923.39	1601.49

Notes: Data are averages over 1000 auction simulations. We depict average clock prices and total payouts under strategic bidding in Philadelphia under the FCC's estimated median demand, and under demand that is increased by one or two licenses beyond the median.

7 Conclusions

In this paper we explore ownership concentration as a means to seek rents in the context of the U.S. government's planned acquisition of broadcast TV licenses in the upcoming incentive auction. We argue that firms may engage in rent-seeking by attempting to reduce supply of broadcast TV licenses in the reverse auction. Our prospective analysis conducts a large-scale valuation exercise for all auction-eligible broadcast licenses in order to highlight the potential for strategic supply reduction and quantify the resulting increases in payouts and efficiency losses. The effect of ownership concentration can be substantial.

Ownership concentration is an important policy concern as the FCC has worried about encouraging a healthy supply of licenses in the reverse auction and has viewed outside investors as more likely to part with their licenses than potentially "sentimental" owners. Our analysis shows that this is likely to give rise to strategic supply reduction and raise the cost of acquiring spectrum. We propose a partial remedy that mitigates the impact of strategic supply reduction by a small change in the auction rules; we hope this proves useful is designing future auctions.

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A Appendix: Data

A.1 Sample construction and primary variables

In this appendix, we describe how we construct the sample of DMAs and TV stations used and discuss several details of the data sources we rely on. Our objective is to infer a TV station's reservation value going into the auction from its cash flow or population coverage scaled the appropriate multiple. While the auction is scheduled for March 2016, we infer a TV station's reservation value as of 2012 as the latest year of availability for both the BIA and NAB data. Our analysis is further made difficult by the fact that different data sources cover different TV stations.

A.1.1 DMAs

The U.S. is divided into 210 DMAs. DMAs are ranked annually according to market size as measured by the total number of homes with at least one television (henceforth, TV households, measured in thousand). Table 10 lists the top ten DMAs in 2012 along with some characteristics from the BIA data.

Table 10: Top Ten DMAs (2012)

Rank	DMA	TV Households	Station Count	Income ($)
1	New York, NY	7,388	19	49,518
2	Los Angeles, CA	5,570	24	36,972
3	Chicago, IL	3,493	18	40,500
4	Philadelphia, PA	2,993	19	42,034
5	Dallas-Ft. Worth, TX	2,571	17	37,215
6	San Francisco-Oakland-San Jose, CA	2,507	18	53,448
7	Boston, MA	2,380	16	48,294
8	Washington, DC	2,360	11	49,495
9	Atlanta, GA	2,293	13	33,726
10	Houston, TX	2,185	14	40,704

Notes: Includes all auction-eligible commercial full-power and low-power (class-A) TV stations. Income is average per capita disposable personal income. Source: BIA.

A.1.2 TV stations

Table 11 shows counts of auction-eligible TV stations as of 2012, broken down by power output, type of use, and type of service. There are a total of 2,166 auction-eligible TV stations. We focus on the 1,672 UHF stations that the FCC includes in its repacking simulations.

A.1.3 BIA data

After restricting to full-power (primary and satellite) and low-power (class-A) stations, the BIA data provides us with 24,341 station-year observations from 2003 to 2013. Commercial stations make up 19,595 observations and non-commercial stations, including dark stations, for 4,746 observations.

Table 11: TV station counts by power output and type of use and service (2012)

	Type of Use and Service						
	Commercial		Non-commercial				
	UHF	VHF	UHF	VHF	UHF	VHF	Total
Full-power							
Primary	950	292	281	104	1,231	396	1,627
Satellite	57	55	0	0	57	55	112
Low-power (Class-A)	376	42	8	1	384	43	427
Total	1,772		394		1,672	494	2,166

Notes: Only stations that are eligible for participation in the incentive auction included. Primary stations denote the owner's main station in the DMA. Satellite stations are full-power relay stations re-broadcasting for the primary stations. Non-commercial stations carry educational or public broadcast programming.

For commercial stations, advertising revenue is missing for 6,058, or 30.9%, station-year observations. Table 12 shows the share of station-year observations with missing advertising revenue for commercial stations. Advertising revenue is missing for almost all satellite stations because BIA subsumes a satellite's advertising revenue into that of its parent primary station.[33] Missings are further concentrated among low-power (Class-A) stations, among stations affiliated with Spanish-language networks (Azteca America, Independent Spanish, Telemundo, Unimas, and Univision) and other minor networks, and among independent stations. There are no discernible patterns in missings along other dimensions of the data such as the market size.

We impute advertising revenue for commercial stations where it is missing by regressing the log of advertising revenue (in \$ thousand) $\ln AD_{jt}$ on station, owner, and market characteristics X_{jt}. We run this regression separately for each year from 2003 to 2013 and use it to predict advertising revenue AD_{jt}. We include in X_{jt} the log of the station's population coverage (in thousand), an indicator for whether the TV station has multicast sub-channels, power output fixed effects (primary and class-A), fixed effects for the eleven affiliations in Table 12, fixed effects for the interaction of affiliation groups (see Section A.2.1) with U.S. states, an indicator for whether the owner owns more than one TV station in the same DMA, ownership category fixed effects (whether the owner owns one, between two and ten, or more than ten TV stations across DMAs), the number of TV stations in the DMA, the number of major network affiliates in the DMA, the wealth and competitiveness indices for the DMA (see Section A.2.1), and the log of the number of TV households (in thousand) in the DMA. Finally, we account for the contribution of any satellite stations to advertising revenue by including in X_{jt} the number of satellite stations that belong to the primary station N_{jt}^{SAT}.The adjusted R^2 is 0.99 in all years in logs and 0.75 on average in levels, suggesting that we capture most of the variation in advertising revenue across stations and years.

[33] We enforce this convention for the 36 station-year observations where a satellite has non-missing advertising revenue. We manually link satellite stations to their parent primary stations because BIA does not provide this information. The 114 satellite stations in Table 11 belong to 80 primary stations.

With the estimates in hand, we predict advertising revenue AD_{jt} as $\widehat{AD}_{jt} = e^{\ln \widehat{AD}_{jt} + \frac{\hat{\sigma}^2}{2}}$ to account for the non-zero mean of the log-normally distributed error term with estimated variance $\hat{\sigma}^2$. We proceed as follows: First, for a primary station we impute advertising revenue AD_{jt} where missing as $\widehat{AD}_{jt}$. Second, we compute the contribution of satellite stations (if any) to the advertising revenue of their parent primary station as $AD_{jt} - AD_{jt}/e^{\hat{\beta}_{SAT} N_{jt}^{SAT}}$, where $\hat{\beta}_{SAT}$ is the estimated coefficient for the number of satellite stations. For a primary station we net out the contribution of satellite stations by replacing advertising revenue AD_{jt} with $AD_{jt}/e^{\hat{\beta}_{SAT} N_{jt}^{SAT}}$. Third, for a satellite station we impute advertising revenue AD_{jt} by allocating the contribution of satellite stations to the advertising revenue of their parent primary station in proportion to the population coverages of the satellite stations.

Table 12: Missing advertising revenue for commercial stations

		Missing advertising revenue	
	Station-year count	Station-year count	%
Full-power			
Primary	13,490	937	6.95
Satellite	1,252	1,216	97.12
Low-power (Class-A)	4,853	3,905	80.47
Major networks			
ABC	2,497	420	16.82
CBS	2,423	314	12.96
Fox	2,272	318	14.00
NBC	2,445	376	15.38
Minor networks			
CW	850	99	11.65
MyNetwork TV	745	133	17.85
United Paramount	269	37	13.75
Warner Bros	267	24	8.99
Spanish-language networks	1,747	563	32.23
Other	3,159	1,781	56.38
Independent	2,921	1,993	68.23
Total	19,595	6,058	30.92

Notes: United Paramount and Warner Bros merged in 2006 to form CW. Spanish-language networks include Azteca America, Telemundo, Univision, UniMas, and Independent Spanish stations.

A.1.4 NAB data

NAB collects detailed financial information for commercial full-power stations. In 2012, NAB received 785 responses on 1,288 originated questionnaires, corresponding to a response rate of 60.9%.

NAB reports the data at various levels of aggregation. Table 13 shows the resulting 66 tables for 2012.[34] The number of tables fluctuates slightly year-by-year because NAB imposes a minimum of ten TV stations per aggregation category to ensure confidentiality.[35] Note that a TV station may feature in more than one table. For example, WABC-TV is the ABC affiliate in New York, NY. Its data is used in calculating statistics for (1) markets of rank 1 to 10; (2) major network affiliates; (3) all ABC affiliates; and (4) ABC affiliates in markets with rank 1 to 25.

For each aggregation category, NAB reports the mean, 1^{st}, 2^{nd}, and 3^{rd} quartiles for cash flow and detailed revenue source categories. We define non-broadcast revenue as the sum of total trade-outs and barter, multicast revenue, and other broadcast related revenue. We further define advertising revenue as the sum of local, regional, national, and political advertising revenues, commissions, and network compensations. Because we do not observe correlations between the detailed revenue source categories, we can construct the mean of non-broadcast revenue and advertising revenue but not the quartiles. We present sample moments of cash flow and non-broadcast revenue for select aggregation categories in Table 14.[36]

A.2 Cash flows

A.2.1 Functional forms

We parameterize $\alpha\left(X_{jt};\beta\right)$, $RT\left(X_{jt};\gamma\right)$, and $F\left(X_{jt};\delta\right)$ as a function of station and market characteristics X_{jt} as

$$\begin{aligned}
\alpha\left(X_{jt};\beta\right) =& \sum_{a=1}^{9}\beta_0^a I(\mathit{Affiliation}_{jt}=a) + \sum_{s=2003}^{2012}\beta_0^s I(t=s) + \beta_1 Fox_{jt}\cdot t + \beta_2 CompIndex_{jt},\\
RT\left(X_{jt};\gamma\right) =& \exp\left(\gamma_0+\gamma_1 t+\gamma_2\ln(MktSize_{jt})\right),\\
F\left(X_{jt};\delta\right) =& \delta_0+\delta_1\, WealthIndex_{jt} + \sum_{h=1}^{3} I(Group_{jt}=h)\cdot\left(\delta_2^h\ln(MktSize_{jt})+\delta_3^h\ln(MktSize_{jt})^2\right),
\end{aligned}$$

where $I(\cdot)$ is the indicator function. $Affiliation_{jt}$ refers to nine of the eleven affiliations[37] in Table 12 and $Group_{jt}$ to groupings of affiliations (detailed below). $MktSize_{jt}$ is the number of TV households in the DMA and $WealthIndex_{jt}$ and $CompIndex_{jt}$ are the wealth and competitiveness indices for the DMA.[38]

[34] We exclude 15 aggregation categories that are defined by total revenue from each year's NAB report because the BIA data is restricted to advertising revenue.

[35] Some years, in particular, break out United Paramount and Spanish-language networks but not other minor networks. We conclude that the response rate of other minor networks is very low and thus exclude other minor networks from most of the subsequent analysis.

[36] To validate the data, we compare the mean of advertising revenue from the NAB data to suitably averaged advertising revenue from the BIA data. The resulting 662 pairs of means from the two data sources exhibit a correlation of 0.92.

[37] We normalize the parameter on the indicator for Spanish-language networks to zero. We exclude any TV station affiliated with other minor networks from the estimation, see footnote 35. To predict the cash flow for such a TV station from our parameter estimates, we use its station and owner characteristics X_{jt} and the parameter on the indicator for Independent.

[38] To parsimoniously capture market characteristics, we conduct a principal component analysis of the market-level variables prime-age (18-54) population, average disposable income, retail expenditures, advertising revenues,

Table 13: NAB Tables (2012)

Table	Description	Table	Description
1	All Stations, All Markets	34	ABC, CBS, FOX, NBC, Markets 176+
2	All Stations, Markets 1-10	35	ABC, All Markets
3	All Stations, Markets 11-20	36	ABC, Markets 1-25
4	All Stations, Markets 21-30	37	ABC, Markets 26-50
5	All Stations, Markets 31-40	38	ABC, Markets 51-75
6	All Stations, Markets 41-50	39	ABC, Markets 76-100
7	All Stations, Markets 51-60	40	ABC, Markets 101+
8	All Stations, Markets 61-70	41	CBS, All Markets
9	All Stations, Markets 71-80	42	CBS, Markets 1-25
10	All Stations, Markets 81-90	43	CBS, Markets 26-50
11	All Stations, Markets 91-100	44	CBS, Markets 51-75
12	All Stations, Markets 101-110	45	CBS, Markets 76-100
13	All Stations, Markets 111-120	46	CBS, Markets 101+
14	All Stations, Markets 121-130	47	FOX, All Markets
15	All Stations, Markets 131-150	48	FOX, Markets 1-50
16	All Stations, Markets 151-175	49	FOX, Markets 51-75
17	All Stations, Markets 176+	50	FOX, Markets 76-100
18	ABC, CBS, FOX, NBC, All Markets	51	FOX, Markets 101+
19	ABC, CBS, FOX, NBC, Markets 1-10	52	NBC, All Markets
20	ABC, CBS, FOX, NBC, Markets 11-20	53	NBC, Markets 1-25
21	ABC, CBS, FOX, NBC, Markets 21-30	54	NBC, Markets 26-50
22	ABC, CBS, FOX, NBC, Markets 31-40	55	NBC, Markets 51-75
23	ABC, CBS, FOX, NBC, Markets 41-50	56	NBC, Markets 76-100
24	ABC, CBS, FOX, NBC, Markets 51-60	57	NBC, Markets 101+
25	ABC, CBS, FOX, NBC, Markets 61-70	58	CW, All Markets
26	ABC, CBS, FOX, NBC, Markets 71-80	59	CW, Markets 1-25
27	ABC, CBS, FOX, NBC, Markets 81-90	60	CW, Markets 26-50
28	ABC, CBS, FOX, NBC, Markets 91-100	61	CW, Markets 51-75
29	ABC, CBS, FOX, NBC, Markets 101-110	62	MNTV, All Markets
30	ABC, CBS, FOX, NBC, Markets 111-120	63	MNTV, Markets 1-50
31	ABC, CBS, FOX, NBC, Markets 121-130	64	MNTV, Markets 51+
32	ABC, CBS, FOX, NBC, Markets 131-150	65	Independent, All markets
33	ABC, CBS, FOX, NBC, Markets 151-175	66	Independent, Markets 1-25

Notes: Data comes from NAB annual directory for 2012. Market numbers refer to a market's rank in terms of size. NAB rules prohibit aggregation when there are too few respondents in a particular grouping, which determines the market size ranges. Tables with total revenue breakouts are excluded.

Table 14: Sample moments for cash flow and non-broadcast revenue for select aggregation categories (2012)

	Cash Flow ($ million)				Non-broadcast Revenue ($ million)
		Percentile			
	Mean	25th	50th	75th	Mean
All Stations	7.798	1.243	3.752	9.178	2.977
All Stations, Markets 101-110	4.120	1.704	3.619	6.444	2.102
All Major Affiliates	9.244	1.936	4.929	10.901	3.326
ABC Affiliates, Markets 1-25	32.400	15.090	27.150	42.460	7.596
NBC Affiliates, Markets 101+	3.652	1.293	3.283	5.901	1.883
All CW Affiliates	3.929	0.355	1.798	3.224	2.884
MyNetwork TV Affiliates, Markets 1-50	3.124	1.270	1.799	3.215	2.507
All Independent Stations	2.786	-0.020	1.288	4.327	2.195

Notes: Data comes from NAB annual directory for 2012. A select few categories are reported (see Table 13 for all categories). Non-broadcast revenues are constructed as the sum of total trade-outs and barter, multicast revenues, and other broadcast related revenues. We thus only obtain the mean as we lack information on the correlations of the respective distributions.

We allow the share $\alpha(X_{jt};\beta)$ of advertising revenue retained as cash flow to vary flexibly by year and network affiliation. We allow for a separate time trend for Fox affiliates as their profitability grew substantially over time. The competitiveness index $CompIndex_{jt}$ accounts for differences in the competitive environment across DMAs.

We specify $RT(X_{jt};\gamma)$ as an exponential function of a time trend and market size in light of the rapid growth of retransmission fees. We make no attempt to separately estimate an error term for non-broadcast revenue and assume it is one part of ϵ_{jt} in equation 6 due to additivity.[39]

Lastly, we let fixed cost $F(X_{jt};\delta)$ vary flexibly with market size and the network affiliation. To streamline the specification, we subsume the affiliations in Table 12 into three groups with similar cost structures: (1) ABC, CBS, and NBC; (2) Fox, CW, and Warner Bros; (3) My Network TV, United Paramount, Spanish-language networks, and Independents. We include the wealth index $WealthIndex_{jt}$ in the fixed cost to reflect the differential cost of operating in different DMAs.

A.2.2 Data

We combine the station-level data on advertising revenue from BIA with the aggregated data from NAB. The NAB data yields 3,313 moments across aggregation categories and the years from 2003 to 2012 as shown in Table 16.[40] There are a total of 11,801 station-year observations from the BIA data that meet NAB's data collection and reporting procedure and therefore map into a table of a

number of primary TV stations, and number of major network affiliates. The first principal component, denoted as $CompIndex_{jt}$, loads primarily on to prime-age population, advertising revenues, number of primary TV stations, and number of major network affiliates. The second principal component, denoted as $WealthIndex_{jt}$ loads primarily on to average disposable income and retail expenditures.

[39] We obtain very similar estimates when we separately estimate such an error term.

[40] We drop the year 2013 from the BIA data as 2012 is the latest year of availability for the NAB data. We further drop TV stations affiliated with other minor networks from the BIA data, see footnotes 35 and 37.

NAB report.

A.2.3 Estimation

We use a simulated minimum distance estimator. We draw $S = 100$ vectors of cash flow error terms $\epsilon^s = \left(\epsilon^s_{jt}\right)$, where ϵ^s_{jt} is the cash flow error term of TV station j in year t in draw s. Denote by $\overline{CF}_{gt}$, CF^1_{gt}, CF^2_{gt}, and CF^3_{gt} the mean, 1^{st}, 2^{nd}, and 3^{rd} quartiles of the cash flow distribution reported by NAB in year t for aggregation category $g = 1, \ldots, G_t$, where G_t is the number of aggregation categories in year t. Similarly, denote by $\widehat{\overline{CF}}_{gt}(\theta;\epsilon^s)$, $\widehat{CF}^1_{gt}(\theta;\epsilon^s)$, $\widehat{CF}^2_{gt}(\theta;\epsilon^s)$, and $\widehat{CF}^3_{gt}(\theta;\epsilon^s)$ the analogous moments of the predicted cash flow distribution for the TV stations that feature in aggregation category g in year t. Our notation emphasizes that the latter depend on the parameters $\theta = (\beta, \gamma, \delta, \sigma)$ and the vector of cash flow error terms ϵ^s in draw s. We use similar notation, replacing $\overline{CF}$ with $\overline{RT}$, for the mean of the non-broadcast revenue distributions. To estimate θ, we match the moments of the predicted and actual distributions across aggregation categories and years. Formally,

$$\hat{\theta} = \arg\min_{\theta} \sum_{t=2003}^{2012} \sum_{g=1}^{G_t} \left(\overline{CF}_{gt} - \frac{1}{S}\sum_{s=1}^{S} \widehat{\overline{CF}}_{gt}(\theta;\epsilon^s)\right)^2 + \sum_{q=1}^{3} \left(CF^q_{gt} - \frac{1}{S}\sum_{s=1}^{S} \widehat{CF}^q_{gt}(\theta;\epsilon^s)\right)^2 + \left(\overline{RT}_{gt} - \widehat{\overline{RT}}_{gt}(\theta)\right)^2.$$

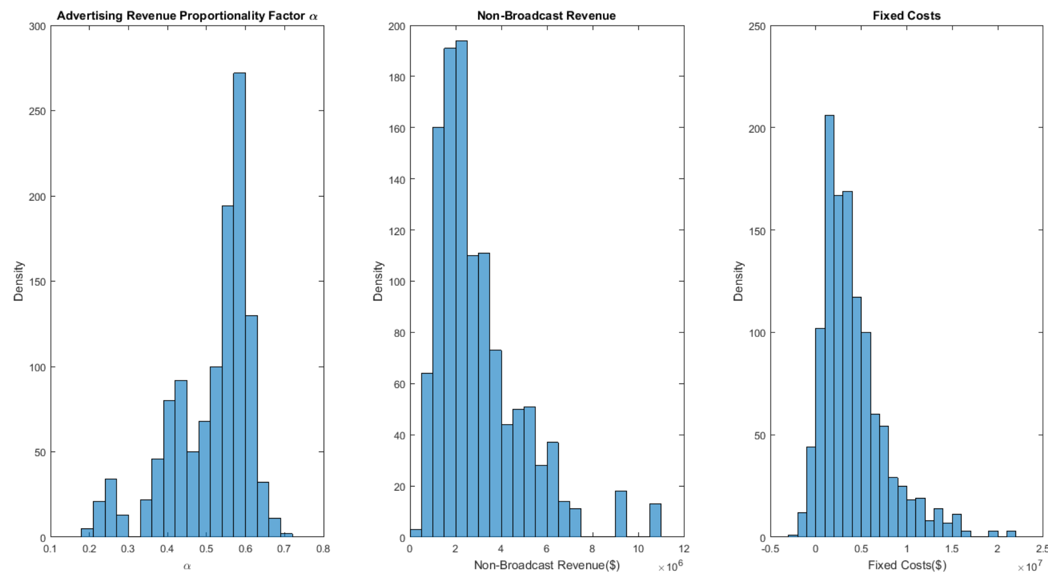
We constrain the standard deviation of the error term to be positive. Our interior-point minimization algorithm terminates with a search step less than the specified tolerance of 10^{-12}. We use multi starts to guard against local minima. Our estimates are robust to different starting values.

A.2.4 Results

Table 15 reports the parameter estimates. The estimates are in line with our expectations: major network affiliates retain a higher share of advertising revenue than minor networks, with Fox having a positive trend; independent and WB stations retain the highest share of advertising revenues, albeit with the smallest revenue base; the retained share falls over time, bottoming out in 2009 before bouncing back in recent years; the retained share is lower in more competitive markets. Finally, non-broadcast revenue has grown significantly in recent years and there are economies of scale in fixed cost.

Figure 11 plots the distributions of the estimated retained share $\alpha(X_{jt};\beta)$, non-broadcast revenue $RT(X_{jt};\delta)$, and fixed cost $F(X_{jt};\delta)$. Reassuringly, without imposing restrictions, we estimate α to be between 0.2 and 0.7 in 2012, with an average of 0.51; non-broadcast revenue is estimated to be between \$0.21 million and \$10.9 million; fixed cost is estimated to be contributing negatively to cash flow in 95% of cases, averaging \$4.12 million, with the highest fixed cost estimated to be up to \$21.9 million in 2012.

Figure 11: Estimated Retained Share of Advertising Revenue $\alpha(X_{jt};\beta)$, Non-Broadcast Revenue $RT(X_{jt};\delta)$, and Fixed Cost $F(X_{jt};\delta)$ (2012)



Notes: Plots are distributions of estimated retained share of advertising revenue α (left), non-broadcast revenue in dollars (middle), and fixed cost in dollars (right) in 2012. Includes 1,172 commercial full-power stations in 2012 used in the cash flow estimation.

Table 15: Cash Flow Parameters Estimates

	Estimates
Retained share $\alpha(X_{jt};\beta)$ of advertising revenue	
ABC	-0.035
CBS	-0.062
Fox	-0.382
NBC	-0.054
CW	-0.113
MyNetwork TV	-0.356
United Paramount	-0.364
Warner Bros	0.013
Spanish-language networks (normalized)	0
Independent	-0.210
Fox $\times$ Trend	0.018
2003	0.692
2004	0.666
2005	0.642
2006	0.630
2007	0.599
2008	0.567
2009	0.529
2010	0.600
2011	0.619
2012	0.636
$CompIndex$	-0.021
Non-broadcast revenue $RT(X_{jt},\gamma)$ (log \$)	
Intercept	6.513
ln(MktSize)	0.527
Trend	0.135
Fixed cost $F(X_{jt};\delta)$ (\$ million)	
Intercept	63.941
$WealthIndex$	1.052
Group 1 $\times$ ln(MktSize)	-12.851
Group 2 $\times$ ln(MktSize)	-11.696
Group 3 $\times$ ln(MktSize)	-10.210
Group 1 $\times$ ln(MktSize)^2	0.643
Group 2 $\times$ ln(MktSize)^2	0.535
Group 3 $\times$ ln(MktSize)^2	0.419
σ (\$ million)	1.030

Notes: Group 1 is ABC, CBS, and NBC; group 2 is Fox, CW, and Warner Bros; and group 3 is My Network TV, United Paramount, Spanish-language networks, and Independents.

The cash flow model fits the data well. Figure 12 plots the predicted distributions of cash flow and non-broadcast revenue, superimposed with the corresponding moments from the NAB data for all TV stations in 2012. Cash flow is estimated to be between -$6.4 million and $127 million across

Table 16: Cash Flow and Non-Broadcast Revenue Moments and Fit Measures

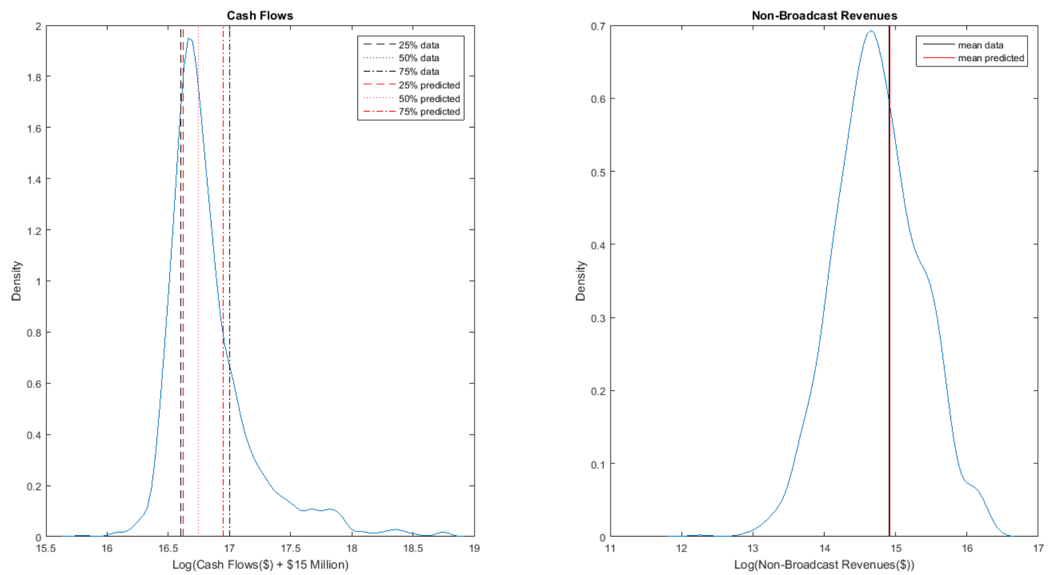
		Number of Moments	Correlation	Mean Abs Deviation $ million	Mean Abs Deviation %
All		3313	0.98	0.91	18.11
Type	Cash flow, mean	663	0.99	0.89	13.16
	1^{st} quartile	662	0.97	0.90	35.24
	2^{nd} quartile	663	0.98	0.90	17.73
	3^{rd} quartile	663	0.98	1.36	15.16
	Non-broadcast revenue, mean	662	0.84	0.49	28.65
Affiliation	Major network	1995	0.98	1.00	16.13
	Minor network	350	0.93	1.00	38.55
	Independent	110	0.73	0.95	62.31
Year	2003	329	0.98	1.03	19.52
	2004	325	0.99	0.87	15.05
	2005	330	0.98	0.95	19.17
	2006	310	0.99	0.96	16.26
	2007	344	0.98	0.90	19.68
	2008	350	0.98	0.86	20.43
	2009	330	0.98	0.66	23.08
	2010	330	0.98	0.84	16.30
	2011	335	0.97	0.90	18.68
	2012	330	0.98	1.11	16.51
Market Rank	1-25	460	0.98	2.37	14.74
	26-50	385	0.96	0.94	15.97
	51-100	930	0.93	0.63	19.98
	101+	799	0.87	0.47	32.21

Notes: Correlations refer to correlations between predicted and observed dollar magnitudes for a particular subsample of distribution moments. Percent mean deviations measured as a share of observed dollar magnitudes.

TV stations in 2012, with an average of $7.2 million (compared to $7.8 million reported by NAB). The 25^{th} ($1.6 million), 50^{th} ($3.6 million), and 75^{th} ($7.8 million) percentiles of the predicted distribution are overlaid in red lines (dashed, dotted, and dash-dotted, respectively). The black lines of the same patterns refer to the corresponding moments in the NAB data. Non-broadcast revenue is estimated to average $3.0 million (compared to $3.0 million reported by NAB).

To further assess the fit of the cash flow model, Table 16 compares the cash flow and non-broadcast revenue moments as reported in NAB to the corresponding predicted moments, broken down type of moment, affiliation, year, and market rank. It provides three different measures of fit, namely the correlation between actual and predicted moments as well as the absolute deviation in millions of dollars and in percent magnitudes, and percent of absolute deviations. Overall, our cash flow model predicts the 3,313 moments with a 0.98 correlation. Of the 330 moments from 2012, our predicted moments have a 0.98 correlation with the actual moments reported by NAB; on average, our predicted moments miss the actual moments by $1.11 million, or 16.5%.

Figure 12: Estimated Cash Flow and Non-Broadcast Revenue with Moments (2012)



Notes: Plots are kernel densities of estimated cash flows (left) and non-broadcast revenues (right) in 2012 in log terms. Cash flows (in dollars) are shifted by $15 million to avoid negative numbers. Black lines indicate data moments and red lines indicate model-predicted moments. Data moments are from the all-station category in NAB (year 2012, table 1). Includes 1,172 commercial full power stations in 2012 used in the cash flow estimation procedure. The cash flow distribution is plotted from one simulation with station-specific errors.

A.3 Multiples

A.3.1 Priors

Industry analysts give a range of \$0.15 to \$0.40 per MHz-pop for the stick multiple and a range of 10 to 12 for the cash flow multiple.[41] Therefore, our prior is that the stick multiple is distributed log-normally with mean $\mu_{prior}^{Stick} = -1.4$ and standard deviation $\sigma_{prior}^{Stick} = 0.5$ (corresponding to a mean of \$0.25 per MHz-pop and a standard deviation of \$1 per MHz-pop, thereby covering \$0.15 to \$0.40 per MHz-pop with probability 0.68). According to industry analysts, while the stick multiple is believed to be much larger for larger markets, the cash flow multiple is believed to be symmetrically distributed. Our prior is therefore that the cash flow multiple is distributed normally with mean $\mu_{prior}^{CF} = 11$ and standard deviation $\sigma_{prior}^{CF} = 1$.

A.3.2 Data

As discussed in Section 5.1, our data consists of 136 transactions between 2003 and 2012 based on cash flow and 201 transactions between 2003 and 2013 based on stick value. For cash flow transactions, we infer the cash flow multiple from the transaction price and the estimated cash flow $\widehat{CF}_{jt}$ using equation 4. For stick value transactions, we infer the stick multiple from the transaction price using equation 5.

A.3.3 Estimation

For cash flow transactions, we estimate the following model for the multiple to construct its conditional likelihood function:

$$Multiple_{jt}^{CF} = \beta X_{jt} + \epsilon_{jt}, \tag{7}$$

where X_{jt} includes owner, station, and market characteristics. Specifically, we include in X_{jt} an indicator of whether a station has multicast sub-channels, the station's population coverage (in thousand), the wealth and competitiveness indices for the DMA, power output fixed effects (primary, satellite, and class-A), ownership category fixed effects (whether the owner owns one, between two and ten, or more than ten stations across markets), fixed effects for the eleven affiliations in Table 12, and a full set of year fixed effects. The adjusted R^2 is 0.68 and we take $\hat{\sigma}_{likelihood}^{CF} = 4.52$ to be the standard deviation of the 136 estimated residuals.

For stick value transactions, we estimate the following model:

$$\ln Multiple_{jt}^{Stick} = \beta X_{jt} + \epsilon_{jt}, \tag{8}$$

[41] See "Opportunities and Pitfalls on the Road to the Television Spectrum Auction," Bond & Pecaro white paper, December 12, 2013, available at http://www.bondpecaro.com/images/Bond_Pecaro_Spectrum_White_Paper_12122013.pdf, accessed on November 15, 2015.

where we include in X_{jt} the log of the station's output power, the log of the station's population coverage, the wealth and competitiveness indices for the DMA, power output fixed effects, ownership category fixed effects, affiliation fixed effects, and year fixed effects. The adjusted R^2 is 0.67 and we take $\hat{\sigma}^{Stick}_{likelihood} = 0.97$.

A.3.4 Posteriors

With the estimates in hand, we can predict multiples for any TV stations. To obtain the posterior for the cash flow, respectively, stick multiple, we update our prior with the conditional likelihood function using Bayes rule as

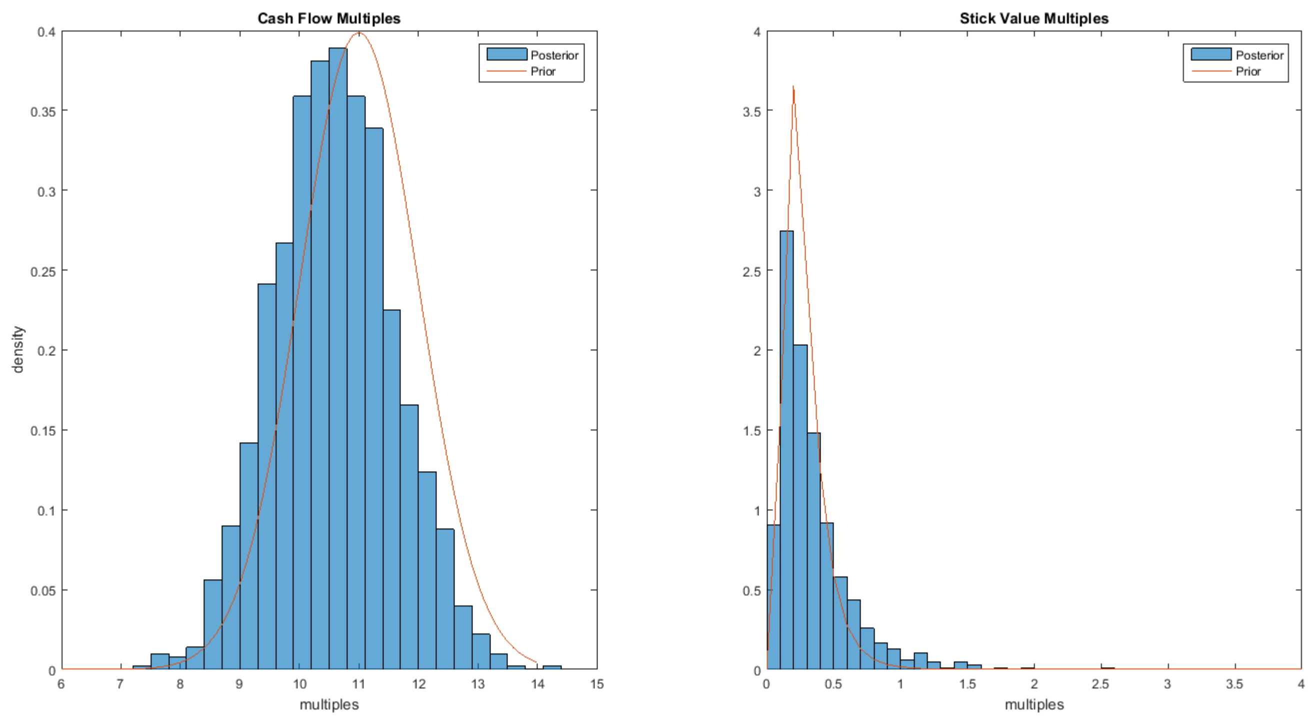
$$\mu_{posterior} = \frac{\mu_{prior}\sigma^2_{likelihood} + \mu_{likelihood}\sigma^2_{prior}}{\sigma^2_{prior} + \sigma^2_{likelihood}},$$

$$\sigma^2_{posterior} = \frac{\sigma^2_{likelihood}\sigma^2_{prior}}{\sigma^2_{prior} + \sigma^2_{likelihood}},$$

where $\mu^{CF}_{likelihood} = \widehat{Multiple}^{CF}_{jt_0}$ for cash flow transactions and $\mu^{Stick}_{likelihood} = \ln \widehat{Multiple}^{Stick}_{jt_0}$ for stick value transactions and we set $t_0 = 2012$. The posterior standard deviation of the cash flow multiple is 0.98 and that of the stick multiple is 0.44. Because the posterior mean depends on X_{jt}, Figure 13 illustrates the estimated posterior distribution for the cash flow, respectively, stick multiple in one particular simulation run for the 1,672 UHF licenses that the FCC includes in its repacking simulations. The prior distributions are overlaid in red dashed lines.

B Appendix: Additional results

Figure 13: Prior and Posterior Distributions of Cash Flow Multiple and Stick Multiple



Notes: Probability density function for the prior distributions and estimated posterior distributions. Plotted from one simulation (one station-specific draw for each station).

Table 17: Counterfactual random assignment of private equity firm license purchases

	# Stations	Total Purchase Price ($M)	Auction Profits Naive ($M)	Auction Profits Strategic ($M)
			84 MHz Clearing Target	
NRJ	14	679.04	-76.35	-71.96
OTA	20	934.24	-69.85	-65.23
LocusPoint	9	425.83	-48.74	-46.55
			120 MHz Clearing Target	
NRJ	14	676.73	-15.23	12.31
OTA	20	934.54	18.97	58.57
LocusPoint	9	424.37	-7.36	11.64

Notes: Private equity firms' purchases of licenses are randomized across 1000 simulations, sampled from the 529 auction-eligible UHF stations transacted between 2003-2013. The auction is then re-simulated under the counterfactual ownership scenario in each simulation. Auction profits are averages over 1000 auction simulations. Auction profits are defined as: total proceeds from the auction for stations that sell, plus the reservation values of stations that do not sell, less the purchase prices paid by the firm for the stations. Total purchase prices differ slightly across clearing targets due to convergence failures of the auction in 1-3% of simulation runs.

Table 18: Robustness Check: Decrease Demand by 1 License in All DMAs

Types of DMAs	# DMAs	Avg. Clock Price ($) Naïve	Avg. Clock Price ($) Strategic	Total Payment Amount ($B) Naïve	Total Payment Amount ($B) Strategic	Payment Increase %
		84 MHz Clearing Target				
Positive demand	57	66.95 (3.68)	90.26 (8.32)	2.81 (0.17)	3.85 (0.36)	37.55 (13.47)
Multi-License Owners	39	58.73 (3.64)	86.13 (9.64)	2.10 (0.14)	3.15 (0.36)	50.19 (18.11)
Two or more Multi-License Owners	30	59.03 (3.82)	85.32 (10.37)	1.95 (0.14)	2.87 (0.35)	47.59 (19.30)
Private equity active	12	60.61 (4.17)	64.19 (4.75)	1.46 (0.11)	1.55 (0.12)	6.71 (5.51)
		120 MHz Clearing Target				
Positive demand	87	102.33 (3.87)	143.98 (6.00)	8.58 (0.35)	12.41 (0.55)	44.77 (7.15)
Multi-License Owners	63	93.66 (4.08)	140.80 (6.64)	6.96 (0.32)	10.79 (0.54)	55.28 (9.05)
Two or more Multi-License Owners	41	94.45 (4.51)	139.16 (7.51)	6.02 (0.31)	9.08 (0.52)	51.12 (10.01)
Private equity active	16	104.89 (5.66)	129.86 (7.90)	4.66 (0.27)	5.85 (0.38)	25.83 (8.36)

Notes: The row "Positive demand" excludes DMAs where the new demand is zero. No DMAs close at the starting price. Total license demand is 293 at 120 MHz and 143 at 84 MHz. Data are averages over 1000 auction simulations. Standard deviations across 1000 simulations are in parentheses. See Notes to Table 4.

Table 19: Robustness Check: Demand from Full FCC Repacking Simulations

		Avg. Clock Price ($)		Total Payment Amount ($B)		Payment
Types of DMAs	# DMAs	Naïve	Strategic	Naïve	Strategic	Increase %
		84 MHz Clearing Target				
Positive demand	73.18 (5.38)	98.56 (12.45)	136.75 (24.47)	5.73 (0.61)	8.10 (1.17)	41.28 (12.57)
Multi-License Owners	51.51 (4.76)	78.41 (10.11)	124.59 (26.33)	3.81 (0.40)	6.18 (1.03)	62.11 (18.91)
Two or more Multi-License Owners	33.73 (4.37)	76.76 (10.25)	119.47 (26.03)	3.14 (0.37)	4.95 (0.80)	58.17 (20.52)
Private equity active	14.52 (0.57)	74.10 (9.52)	81.93 (11.30)	2.10 (0.37)	2.34 (0.44)	11.83 (9.88)
		120 MHz Clearing Target				
Positive demand	106.24 (7.43)	142.13 (9.64)	212.41 (32.99)	14.71 (1.18)	22.52 (2.88)	53.38 (18.37)
Multi-License Owners	77.65 (6.46)	131.08 (9.22)	211.38 (36.62)	11.91 (1.02)	19.72 (2.74)	66.15 (23.32)
Two or more Multi-License Owners	49.19 (4.70)	125.09 (10.65)	190.78 (24.27)	9.48 (1.55)	14.77 (2.68)	56.41 (18.51)
Private equity active	16.18 (0.72)	126.04 (9.29)	175.38 (31.18)	6.30 (0.64)	8.93 (1.78)	41.53 (24.14)

Notes: DMAs that close at the starting price are excluded. Data are averages over 20,000 auction simulations. Standard deviations across 20,000 simulations are in parentheses. Total license demand is 215.1 (17.3) and 389.4 (25.5) at 84 and 120 MHz, respectively. See Notes to Table 4.