Empirical Model of Dynamic Merger Enforcement – Choosing Ownership Caps in U.S. Radio *

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Abstract

The paper introduces a method to conduct a forward-looking antitrust review of horizontal mergers. The method utilizes a dynamic oligopoly model in which mergers, entry/exit and product repositioning are endogenous. The model provides long-run industry trajectories with and without the merger under review, which enables the regulator to obtain dynamically robust welfare comparison. The paper demonstrates the application of the framework to regulate U.S. radio broadcasting industry. In particular, it investigates long-run efficacy of two commonly used merger heuristics: radio station ownership caps (see Telecom Act (1996)) and static merger simulations (see Nevo (2000)). The paper finds that raising the ownership cap results in higher total welfare, and demonstrates that myopic merger simulations may be ineffective in preventing the losses to consumer welfare.

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1 Introduction

Enforcement of horizontal merger policy involves assessing the trade-off between market power and cost synergies resulting from mergers (see Williamson (1968)). Traditionally, the economic literature on antitrust policy studies this trade-off in a static environment, assuming that the set of competing firms and their product characteristics, other than prices, remain perpetually constant (see structure-conduct-performance, as in Bain (1968), equilibrium analysis, as in Farrell and Shapiro (1990), and more recently, merger simulations, as in Nevo (2000)). In practice, the above assumptions rarely hold, as markets experience merger waves as well as entry, exit and product repositioning. In case these assumptions are indeed not satisfied, the static merger enforcement heuristics may lead to inefficient or erroneous regulation. The inefficiency is hard to quantify theoretically and can manifest itself as Type I error, in which the regulator rejects the merger that should be approved, or as Type II error, in which the regulator approves the merger that should be rejected.

An instance of Type I error (merger overblocking) is recognized in the Horizontal Merger Guidelines published by the United States Department of Justice. Specifically, the competitive pressure generated by an effective entry of new competitors or product repositioning by existing ones can mitigate the effects of the merger by lowering the post-merger market power to the pre-merger level. In such cases, a myopic enforcement agency may overestimate market power and reject an efficient merger that should be approved. In more subtle cases, myopic regulation can lead to Type II error (merger underblocking). For example, an efficiency enhancing merger can lead to future monopolization by forcing less efficient competitors to exit or reposition. A myopic regulator who does not account for such exit will underestimate the post-merger market power and may approve a merger that should be rejected. Another source of Type II error is a selection bias that can arise if forward-looking companies attempt to circumvent the myopic regulations by proposing mergers strategically. For example, companies may attempt a merger which leads to excessive market power only if followed by the repositioning of consolidated products. In such case a myopic regulator, who presumes that product characteristics are perpetually constant, would allow a merger that should be blocked.

The above examples suggest that in order to make a robust decision, the regulator should employ a forward-looking approach and compare the trajectory of the industry in the presence of the merger in question to the counterfactual trajectory in the absence of that merger. Computing such industry trajectories requires solving and estimating a forward-looking model in which mergers, entry/exit and product characteristics are endogenous. Such approach is scarce in the literature because dynamic models of endogenous mergers and product characteristics pose theoretical and econometric challenges. In the general dynamic model of mergers, profit-maximizing players consider every feasible merger possibility, as well as predict which mergers will be executed by competitors in the future. However, the number of merger possibilities, among even a handful of active players, grows exponentially, making the computation of Nash equilibrium extremely burdensome. The model becomes even more complex when allowing for differentiated products, as it needs to keep track of the product portfolios of all active players. Past attempts to solve the aforementioned issues resulted in complicated frameworks that are impractical for estimation and counterfactual predictions (see Gowrisankaran (1999), Stahl (2011) and Jeziorski (2014b)). Thus, designing a simple, but empirically relevant, endogenous merger model seems necessary.

This paper proposes a general empirical framework that can be used to conduct a dynamically robust antitrust merger review. The framework is easily estimable using commonly obtainable panel data on mergers, and the associated prices, market shares and product characteristics. It is also easily computable which enables experiments evaluating counterfactual merger enforcement policies. The key component of the proposed methodology is a dynamic model with endogenous mergers, entry/exit and product repositioning. The model is an extension of static merger simulations and aims at three objectives: (i) allow the regulator to be forward looking by providing industry trajectories with and without the merger in question, (ii) minimize Type I and Type II error by allowing the set of competitors and characteristics of all products to change as a result of the merger, and (iii) limit the Type II error from merger selection bias by allowing the attempted mergers to be endogenous.

The model is a natural continuous time generalization of Rubinstein's 1982 bargaining model (for earlier applications of continuous time to dynamic oligopoly, see Kryukov (2008), Arcidiacono et al. (2010), Doraszelski and Judd (2012)). The pivotal feature of reframing the bargaining process in continuous time is that the probability that more than one company would attempt a merger or repositioning at the same instant is negligible. Such simplification dramatically lowers the conceptual and computational burden of predicting which mergers and repositioning events occur in the equilibrium. Consequently, it enables a modeling compromise that maintains the necessary economic complexity that is required to conduct a robust dynamic merger review, while alleviating the computational obstacles.

I apply the proposed model to analyze retrospective and hypothetical antitrust policy changes in the U.S. radio broadcasting industry and demonstrate inefficiencies in myopic regulation. The radio industry presents a natural experiment for studying the consequences of changes in antitrust policy. The 1996 Telecom Act doubled local radio station ownership caps and abolished the national ownership cap resulting in the deregulation of the industry. These changes facilitated over 6,000 acquisitions within the period of 1996-2006, constituting a major structural change from a fragmented into a consolidated market (see Leeper (1999)). The Act aimed to enable realization of cost efficiencies created by joint operation of multiple radio stations. However, it generated controversy concerning the increase in radio owners' market power over listeners and advertisers (see Drushel (1998)). The coexistence of cost synergies and market power raises questions about the efficiency of the 1996 deregulation and it complicates an assessment of whether further deregulation would be socially beneficial. This paper answers these two questions by applying the proposed empirical framework to conduct antitrust policy counterfactuals.

First, I investigate the consequences of the doubling of local ownership caps mandated by the 1996 Telecom Act. For that purpose, I compute the hypothetical industry path under the pre-Telecom-Act local caps and compare it to the actual post-Telecom-Act industry path. I find that, in the long run, the 1996 deregulation increases total surplus.[1] In particular, under the actual industry path, producer surplus is greater by 10.1%, listener surplus is greater by 0.07%, and advertiser surplus is lower by 1.7% as it compares to the hypothetical industry path. These numbers are significantly smaller than corresponding results obtained by Jeziorski (2014a) using a static model. To explain this difference, I demonstrate that in more than 72% markets mergers

[1] I use static measured of consumer and producer surplus based on the snapshots of the industry along the path predicted by the model. The consequence is that the welfare numbers do not account for dynamic cost shocks. There are two reasons for this choice. First, the dynamic cost shocks could be interpreted as behavioral shocks, and in such case they should not be included in welfare calculations. Second, the variance of the dynamic cost shocks is usually not separately identified from the frequency of moves (see Section 5 for details). Choosing static welfare measures makes the results invariant to rescaling of the move frequency.

are followed by entry of competitors, which is not accounted for by static models. Further, I show that static analysis overpredicts the impact of deregulation on variety provision.

I also investigate the consequences of further deregulation. Specifically, I explore the possibility of raising the local ownership cap from between three to five FM stations (depending on the market size) to a uniform cap of seven FM stations. I find that this change would lead to an additional 4% increase in producer surplus, 0.01% increase in listener surplus and 1% decrease in advertiser surplus. I note that this policy would have a smaller impact on the industry than the Telecom Act.

The thus far considered policy changes, based on increasing local ownership caps, increase total surplus. However, the increase is predominantly in the form of greater profits to radio station owners. Thus, a regulation agency could consider complementing the increase in the ownership caps with measures that directly focus on consumer surplus. In particular, the recent version of Horizontal Merger Guidelines (2010) recommends using merger simulations as introduced by Nevo (2000), and Ivaldi and Verboven (2005). These simulations compute unilateral price effects of proposed mergers allowing the regulator to reject mergers that lead to substantial price increases. Nevertheless, existing versions of such simulations are inherently static. Thus, similarly to ownership caps, their efficiency is likely to be affected by industry dynamics.

To investigate the robustness of static merger simulations I consider two exemplary simulation-based policies. In the first policy, the agency raises the ownership cap to seven FM stations and additionally rejects all mergers that lower static listener surplus. In the long run, this leads to 2.24% increase in producer surplus, a 0.08% increase in listener surplus, and a 0.66% decrease in advertiser surplus. I note that using a combination of ownership caps and merger simulations results in a larger listener surplus than using ownership caps alone.

In the second policy, the regulator raises the ownership cap to seven FM stations and rejects the mergers that lower advertiser surplus. This policy aims to prevent the losses to advertiser surplus that result from all thus far considered deregulatory measures. Unfortunately, it presents only a short term solution. Specifically, in the first 5 years the policy leads to a 0.1% increase in advertiser surplus. However, in 20 years, this policy results in a 0.79% decrease in advertiser surplus, which is the same as in the policy without any merger simulations. [2] This counterintuitive result is a

[2]This result is consistent with the fact, that according to judicial documents, a version of advertiser-centered pol-

direct consequence of the myopic nature of merger simulations and exemplifies the Type II error mechanism described earlier. The companies, being forward looking, strategically propose mergers that are acceptable to the regulator and reposition the products after the merger is approved. As a result, in the long run, the companies are able to extract advertiser surplus circumventing the simulation-based antitrust criteria. This example of the failure of merger simulations shows that static heuristics should be applied with caution in the industries that experience considerable amount of post-merger activity, such as product repositioning.

The closest empirical work to this paper is that of Benkard et al. (2010), who study the long run effects of mergers in the airline industry using a dynamic model of entry and exit with exogenous mergers. They find that the mergers between major airlines lead to increased entry by low cost carriers. Similarly, Collard-Wexler (2014) examines the duration of the merger effects in the ready-mix concrete industry and finds that a merger from duopoly to monopoly generates between 9 and 10 years of monopoly.

This paper extends the theoretical analysis by Nocke and Whinston (2010), who show that myopic merger rules are dynamically optimal when applied in a simplified environment with homogenous products and when possible mergers are disjoint (no firm has the possibility of being part of more than one merger). However, their paper does not cover markets with differentiated products and overlapping mergers, such the ones studied in this paper. Similarly, this paper extends Cabral (2003) who examines impact of free entry on the outcomes of the merger between two firms in a spatially differentiated oligopoly. Cabral shows that post-merger cost efficiencies can have detrimental effects on consumers by lowering entry. The possibility of such effects is allowed within the framework used in this paper.

The model utilized in this paper has features in common with the theoretical model by Armstrong and Vickers (2010), who examine a static principal and agent problem. The agent proposes projects to a principal, but the principal does not observe full characteristics of unproposed projects and commits to the acceptance policy ex-ante. Nocke and Whinston (2013) extend these results to merger review, allowing for bargaining among firms and multiple agents. Furthermore, the present study extends the arguments of Lyons (2002), who emphasizes that regulators cannot

icy was sporadically applied between 1996 and 2000 but did not prevent losses to advertiser surplus, as documented by Jeziorski (2014a).

choose which mergers to execute, but rather they can only approve or reject mergers from the set chosen by strategic players. Lyons offers examples in which the regulator should announce a consumer surplus criterion instead of a total surplus criterion even if the goal is to maximize the total surplus.

The proposed model is also compatible with a vast theoretical and numerical literature on endogenous mergers and product repositioning. For example, as in Kamien and Zang (1990), Rodrigues (2001), and Gowrisankaran and Holmes (2004), the model assumes that both sellers and buyers are fully forward looking. This work is also related to the literature on merger waves (see Harford (2005) and Qiu and Zhou (2007)) allowing mergers to be strategic compliments. Another related study is Mazzeo et al. (2012), who numerically demonstrate, through the use of a static model, that post-merger repositioning can significantly alter the welfare assessment of the merger. In my present effort, I provide an empirical demonstration of a similar phenomena utilizing a dynamic model. Finally, the model is this paper builds on Sweeting (2013), who considers endogenous repositioning without considering mergers.

The study is organized as follows. In the next section, I provide a description of the U.S. radio broadcasting industry. In the third section, I present the dynamic model. The fourth section provides a description of the data, the fifth section describes the estimation algorithm, the sixth section contains results, the seventh section presents counterfactual, and I conclude in the eighth section.

2 Industry background

Between 1996 and 2006 the radio broadcasting industry in the United States underwent major structural changes. Prior to 1996 the industry was heavily regulated. In particular, Federal Communication Commission limited the joint ownership of radio stations through the imposition of national and local ownership caps. The restrictions were significantly relaxed with the enactment of the 1996 Telecom Act. This legislative change spurred a massive wave of ownership consolidation and product repositioning in which about a half of the 12,000 active radio stations changed ownership and a similar fraction of radio stations changed the type of broadcast content. These changes significantly affected both the demand and supply side of the radio industry by creating market power over advertisers and listeners as well as fixed and marginal cost efficiencies. Because of these developments, radio has become a viable case study for evaluating the consequences of antitrust policy changes.

The American radio broadcasting industry is composed of more than 300 relatively separated geographical markets. The broadcast spectrum in each market is partitioned into a set of discrete frequencies each hosting a single radio station. The number of frequencies does not change significantly over time; thus, most of the entry is executed though the acquisition of one of the assigned frequencies (between 1996 and 2006 FCC granted less than 60 new licenses nationwide which constitutes approximately 0.5% of active radio stations). Due to the geographical fragmentation the competition between radio stations is localized. For example, according to the Radio Advertising Bureau national advertising contributed only 15% of overall advertising revenue in 2009. As a result of this convenient fact, restricting attention to the competition for local listeners and advertisers captures first order revenue sources in this industry. In particular, for the purpose of modeling the demand side, the 300 local markets might be regarded as distinct, although the existence of some cross-market fixed cost synergies is possible.

Prior to the 1996 Telecom Act the industry was limited by national and local ownership caps. The national cap prevented any company from owning over 45 stations which effectively prevented the formation of large cross-market chains. The local cap was determined on the number of allocated frequencies, as described in Table 1. The 1996 Telecom Act abolished the national cap, nearly doubled the local cap, and over the following decade the industry moved from fragmented local ownership (about 1.64 station per owner in 1996) to a market in which fewer than 10 parent radio companies dominate two-thirds of both revenues and listeners nation wide (as of 2010). Furthermore, according to the 2010 data by BIA/Kelsey, the two largest companies, Clear Channel and Viacom, account for about 42% of listeners and 45% of advertising revenues. In particular, Clear Channel grew from 40 stations to over 1,200, executing about 15% of all 1996-2006 industry acquisitions. Thus, it is reasonable to expect that the first order magnitude of market power and cost synergies can be captured from an examination of a handful of large owners.

An extensive product repositioning followed the aforementioned consolidation of ownership. In the case of radio market such repositioning is relatively easy to identify because each radio station is uniquely categorized into a distinct programming format. Each format describes the overall type of programming and is directly related to the demographics of the potential listenership base. Thus, local radio markets can be categorized as differentiated product oligopolies in which the degree of differentiation is endogenous and is measured by the variety of supplied formats (see Berry and Waldfogel (2001)). The formats are announced on a biannually basis by Arbitron, a consulting company, and are frequently utilized as marketing tools for targeting advertising. Importantly, the formats frequently change, with approximately 10% of all stations switching formats annually, and these changes can be regarded as a generalized version of entry and exit into and out of particular industry niches; therefore, they affect the amount of market power and cost synergies. Thus, format changes are likely to have first order impact on the antitrust policy evaluation and should be incorporated in the analysis. This point is demonstrated numerically in the online appendix.

The next section contains the model of the industry that captures the above features.

3 Model

Consider a market over an infinite continuous time horizon. The market consists of a maximum of K active radio owners and N possible broadcast frequencies. Each frequency has an assigned owner and can host one radio station. This technical restriction effectively caps the number of active stations to N. I assume the radio station can be fully characterized by a programming format from a finite type space $\mathcal{F} = \{1, \ldots, F\}$.

The market is modeled as a dynamic among between radio-station owners. The portfolio of the radio-station owner k is characterized by a vector $\omega_k^t = (\omega_{k1}^t, \ldots, \omega_{kF}^t)$, where ω_{kf}^t is the number of radio stations of format f owned by a player k. The state of player k is given by the vector $\mathcal{J}_k^t = (\omega_k^t, z_k^t)$, where z_k^t are the remaining payoff-relevant variables. For convenience, I denote the total number of stations owned by player k as n_k^t. The instantaneous variable profits and fixed cost for firm k are given by $\pi_k(\mathcal{J}^t)$ and $F_k(\mathcal{J}^t)$, respectively.

The model is composed of two parts: (i) a model of endogenous mergers in which acquisition prices are determined by non-cooperative bargaining game, and (ii) a model of product repositioning, which is a continuous time version of Sweeting (2013). Both of these models are versions of dynamic discrete choice (see Miller (1984), Pakes (1986), Rust (1987), and Wolpin (1984)). Mergers and product repositioning can happen concurrently, with mergers leading to subsequent repositioning and *vice versa*. This feature makes this model distinct from alternative static models and from two-period models in which merger stage is followed by a repositioning stage. Allowing for concurrent mergers and repositioning is pivotal when conducting a robust antitrust review. Besides, it keeps the realistic by reflecting the dynamics of the market structure in the radio industry. To simplify the exposition I discuss mergers and repositioning separately.

3.1 Mergers

Merger model can be summarized as a multi-agent version of a Rubinstein (1982) model with a random right to move. Each company is associated with a Poisson process that determines the arrival of the right to acquire a competitor. These Poisson processes are independent and share a common arrival rate λ^A. Once the company obtains a right to acquire, it chooses an acquisition target that maximizes its discounted stream of profits. Before making this choice an acquirer observes a vector of stochastic merger costs denoted by $\zeta^{A,t}(\cdot)$, where $\zeta^{A,t}(k')$ is the cost of acquiring competitor k'. I consider a flexible form of merger costs:

$$\zeta_k^{A,t}(\mathcal{J}^t, k') = \mu_k^A(\mathcal{J}^t, k') + \sigma_k^A(\mathcal{J}^t, k')\epsilon_k^{A,t}(k'). \tag{3.1}$$

The term $\mu_k^A(\mathcal{J}^t, k')$ is a persistent part of the cost which is a deterministic function of the industry state and is commonly known. The term $\epsilon_k^{A,t}(k')$ is a stochastic idiosyncratic shock to the cost and is private information of the acquirer.

The acquirer makes a single take-it-or-leave-it merger proposal that maximizes the continuation value or makes no merger offer. The potential acquiree instantaneously accepts or rejects the offer taking into account his opportunity cost. Once the offer is rejected it cannot be accepted in the future unless the same offer is received again or counteroffer is made.[3] If the merger offer is accepted, it is reviewed by an antitrust authority. During the review, the regulator blocks the merger of k and k' with a commonly known probability $\mathbf{G}(\mathcal{J}^t, k, k')$.[4] If the merger fails the

[3]This assumption is particularly difficult to relax because withholding offers would require a model in which multiple offers can be made at the same time. This assumption should not be pivotal if the frequency of making offers/counteroffers is assumed to be sufficiently high.

[4]I focus on the commitment of the regulator to the policies, that is, the regulator cannot renege on the announced policy at any point. I also focus on Markov policies of the regulator, which is without any loss to efficiency if the firms play a Markov Perfect Equilibrium.

review, it is not implemented and neither party incurs merger costs. If the merger passes the review, the merger offer is implemented, that is, the following 3 things occur simultaneously: (i) the acquirer incurs merger cost $\zeta^A(k')$, (ii) the merger bid P is transferred to the acquiree, and (iii) the companies merge their portfolios of products. The industry continues with a new market structure.

A major advantage of a continuous time bargaining model is that it resolves the issue of merger conflicts as it appears when using discrete time models. Consider the possibility of conflicting merger attempts a_k, $a_{k'}$ (e.g., when two companies bid to acquire the same firm), and let $\mathrm{CON}_{k,k'}$ be the probability that the deal k would be executed. Over a short period of time Δ, the probability of execution of an attempt a_k is equal to:

$$\lambda^A\Delta(1-\lambda^A)\Delta + \mathrm{CON}_{k,k'}\lambda^A\Delta\lambda^A\Delta + O(\Delta^2) = \lambda^A\Delta + O(\Delta^2)$$

Doraszelski and Judd (2012) show that only the linear terms of the arrival rates matter for optimality; therefore, in the equilibrium, the conflicting events would not play any role. By contrast, when using discrete time, one usually has to model conflicting mergers explicitly. Because such events are rarely observed in the data, identifying this component of the model would be difficult. In practice, it would force the modeler to assume such events away, for example, by putting a structure on a sequence of moves (see Gowrisankaran (1999), Gowrisankaran and Holmes (2004) and Jeziorski (2014b)).

The model of mergers allows for entry through acquisition of other active firms. Potential entrants are firms that hold empty portfolios of stations; that is, $\omega_k^t = \overrightarrow{0}$. [5] Modeling of entry and exit through acquisitions endogenizes entry cost and scrap value, which are usually assumed to be primitives (see Ericson and Pakes (1995)). Specifically, in my model, acquisition involves paying an endogenous acquisition price, which acts as an endogenous sunk entry cost for the acquirer and an endogenous scrap value for the acquiree. Due to this endogenous sunk cost and the fact that large players operate in multiple markets simultaneously, potential entrants frequently delay entry into a particular local market waiting for favorable market conditions. Consequently, the common assumption that potential entrants are short-lived needs to be modified. Instead, I assume the

[5] One way to allow the possibility of more traditional entry is to endow the type space $\mathcal{F}$ with an inactive state. This extension is possible but is not implemented because traditional entry is insignificant in the radio industry.

potential entrants to be long-lived, which allows for postponing entry as well as re-entry. Similarly to entry, exit is modeled as selling off all owned stations.

Bargaining with take-it-or-leave-it determines the split of bargaining power depending on the outside option of the acquiree. This outside option is determined by many dynamic factors, which include: (i) the value of waiting until the market becomes more concentrated, (ii) the value of making a counter offer in the future, and (iii) the value of repositioning. The value of outside option effects bargaining power in a natural way, that is, the larger the outside option, the larger part of surplus the acquiree receives in case of the merger. For the industries with few large companies and many relatively homogenous smaller companies (radio industry included), the model is likely to allocate most of the surplus to the large acquirers. However, in the industries where the number of firms is small and the frequency of offers is large, the model can allocate a significant amount of the bargaining power to the acquirees. In this sense, a cooperative alternative, such as Nash Bargaining solution should be regarded as a reduced form of this model (see (Collard-Wexler et al., 2014)).

The above model of mergers is versatile and can incorporate alternative methods of soliciting merger offers. One alternative is a model in which nature chooses an acquisition target. After being selected, the target is auctioned off and acquired by highest bidder. Such auction process is relatively straightforward to incorporate within the current framework, however, it may be inappropriate for an analysis of radio industry. In the radio industry there are many potential acquisition targets and acquisition bidding wars are rare. Consequently, if the move (auction) frequency λ^A is large enough, large proportion of auctions will have only one bidder. In such case, the auction would be equivalent to making a take-it-or-leave-it offer.

Another possible extension of the model is allowing the move arrival rate λ^A be different (and possibly larger) when making a counteroffer. Such extension is theoretically possible, but has insignificant consequences if the overall frequency of moves is large.

3.2 Repositioning actions

Repositioning is modeled as a dynamic discrete choice with a random arrival of a right to reposition. In addition to a Poisson process gathering merger actions, each company is endowed with a Poisson process with an arrival rate λ^R, which determines the timing of possible repositioning actions. Upon the arrival of the right to reposition the company observes a vector of repositioning costs

$$\zeta_k^{R,t}(\mathcal{J}^t, r) = \mu_k^R(\mathcal{J}^t, r) + \sigma_k^R(\mathcal{J}^t, r)\epsilon_k^{R,t}(r), \tag{3.2}$$

where $r = (f, f')$ and represents repositioning a product from type f to type f'. Similarly to merger costs, μ_k^R is deterministic function of the state and is common knowledge, while $\epsilon_k^{R,t}$ is a private idiosyncratic shock. After observing the cost the company makes a single repositioning action r or makes no repositioning action. The repositioning is instantaneous and the new state of the industry becomes common knowledge. Repositioning action cannot be delayed.

3.3 Timing

As mentioned before, the merger and repositioning actions are interrelated and are executed concurrently. The joint model of merger and repositioning includes the following sequence of events:

(1) All players observe the state variables $\mathcal{J}^t$.

(2) Players collect the payoff $\pi_k(\mathcal{J}^t) - F_k(\mathcal{J}^t)$ until a merger/repositioning opportunity arises.

(3a) If a merger opportunity arrives for player k, then:

- (i) Player k observes a vector of costs ζ_k^A of merging with any of the active competitors.
- (ii) Player k chooses whether to make a merger bid. If he chooses to make the bid, he puts forward a single take-it-or-leave-it acquisition offer to the chosen acquisition target.
- (iii) The acquisition target accepts or rejects the bid.
- (iv) In case of acceptance the merger review is conducted and the new market structure is determined. The flow returns to (1).

(3b) If a repositioning opportunity arises for player k, he observes payoff shocks ζ_k^R for the repositioning of any owned station to a different format. Next, he makes an immediate decision to reposition a single station or not to reposition at all. Relevant switching costs are paid, the state space is updated, and the flow goes back to stage (1).

3.4 Strategies and equilibrium

This section contains a formal definition of the strategies and defines an equilibrium. A strategy consists of four components: a merger strategy, a pricing strategy, a strategy to accept or reject the merger bid, and a repositioning strategy. A merger strategy has the following form: $\mathbf{a}_k(\mathcal{J}^t, \zeta^{A,t}) \in \{0, \ldots, K\}$. This formula specifies which merger bid (if any) is proposed, conditional on the arrival of a merger opportunity. The set of feasible acquisitions $\Gamma_k^A(\mathcal{J}^t)$ is the set of active competitors and action 0, which represents no merger bid. Upon deciding to make a merger bid k', the buyer makes a take-it-or-leave-it offer to seller k', given by the pricing strategy $\mathbf{P}_k(\mathcal{J}^t, \zeta^{A,t}, k') \in \mathbb{R}_+$. Temporarily suppose all merger bids are accepted, so that the accept/reject function is constant for all players and can be omitted (I relax the assumption later in this study). The repositioning strategy $\mathbf{r}_k(\mathcal{J}^t, \zeta^{R,t}) \in (F \times F) \cup \{0\}$ prescribes which station would be repositioned. The feasible repositioning actions $\Gamma_k^R(\mathcal{J})$ allow for remaining idle or for repositioning any currently owned station to any possible format.

Let $\mathbf{g}_k = (\mathbf{a}_k, \mathbf{P}_k, \mathbf{r}_k)$ be a strategy of player k. For every initial state $\mathcal{J}^0$, a strategy profile $(\mathbf{g}_k, \mathbf{g}_{-k})$ and regulator's enforcement rule $\mathbf{G}$ prescribe a continuous time jump Markov process on states $\mathcal{J}^t$, actions (a_k^t, P_k^t, r_k^t), decisions of the regulator $G_k^t \in \{0,1\}$, and private shocks $(\zeta^{A,t}, \zeta^{R,t})$. The jumps in the process occur if a move opportunity arrives for any of the players, and a non-empty action is implemented.

Let $\tau_k^{A,(l)}$, $\tau_k^{R,(m)}$ be stopping times that represent arrivals of the l-th merger and the m-th repositioning opportunity for player k, respectively. With some abuse of notation, denote by $\zeta_k^{A,(l)}$ and $\zeta_k^{R,(m)}$ cost shocks revealed at $\tau_k^{A,(l)}$ and $\tau_k^{R,(m)}$. Similarly, denote the prescribed actions by $a_k^{(l)}$, $P_k^{(l)}$, $G_k^{(l)}$, and $r_k^{(m)}$. Because the moves are implemented immediately, the resulting Markov process on $\mathcal{J}^t$ would have right-continuous paths. However, note the actions are prescribed by the strategies evaluated at the left-side limit of the state space process; for example, $a_k^{(l)} = \mathbf{a}_k(\mathcal{J}^{\tau_k^{A,(l)}-}, \zeta_k^{A,(l)})$. The value function for company k is given by the following equation (I temporarily ignore the events by which company k is acquired):

$$V_k(\mathcal{J}^0; \mathbf{g}_k, \mathbf{g}_{-k}, \mathbf{G}) = E_{\mathbf{g}} \Bigg\{ \int_0^{\infty} e^{-\rho t} \left[\pi_k(\mathcal{J}^t) - F_k(\mathcal{J}^t) \right] dt + \\ \sum_{l=1}^{\infty} e^{-\rho \tau_k^{A,(l)}} \left[\zeta_k^{A,(l)} \left(a_k^{(l)} \right) - G_k^{(l)} P_k^{(l)} \right] + \sum_{m=1}^{\infty} e^{-\rho \tau_k^{R,(m)}} \zeta_k^{R,(m)} \left(r_k^{(m)} \right) \Bigg\}. \tag{3.3}$$

The equilibrium of the game is defined as follows.

Definition 3.1 (Markov Perfect Equilibrium)**.** *A strategy profile* $\mathbf{g}^*$ *is a Markov perfect equilibrium (for a given enforcement rule* $\mathbf{G}$*) if the strategies maximize a stream of discounted profits at any state,*

$$\mathbf{g}_k^*(\mathcal{J}, \zeta_k) \ \in \arg\max_{\mathbf{g}_k} V_k(\mathcal{J}; \mathbf{g}_k, \mathbf{g}_{-k}^*, \mathbf{G}); \quad \forall k, \mathcal{J}, \zeta_k. \tag{3.4}$$

The first equation states that each player best responds to the opponents' strategies and a pre-announced enforcement rule. The second condition specifies equilibrium acquisition prices. An acquiree must be compensated for an option value for rejecting the merger bid and continuing as a separate company until a new merger bid arrives, which dynamically endogenizes the bargaining position of a seller.

In this study, I examine only equilibria in which the acquisition price is equal to the acquiree's value function, that is,

$$\mathbf{P}_k^*(\mathcal{J}, \zeta_k^A, k') = V_{k'}(\mathcal{J}; \mathbf{g}^*, \mathbf{G}); \quad \forall k' > 0, k, \mathcal{J}, \zeta_k^A.$$

Under this condition acquisition events do not affect the acquiree's value function and can be ignored in the acquiree's Bellman equation. This restriction is without much loss of generality for two reasons: (i) acquirees do not have private information at the moment of receiving a merger bid, and (ii) acquirees receive only one merger offer at a time, almost surely. In such a case, knowing there are no other outstanding offers at each particular instant, the acquirer would propose the acquisition price equal to the reservation value of the acquiree (value function) or would not make an offer if this reservation value is too large.

The discussion of the existence of an equilibrium and computational strategy is contained in the Appendix B. In summary, similarly to dynamic discrete choice in discrete time, the merger and repositioning strategies in the model can be expressed in terms of instantaneous conditional choice probabilities, denoted by $\text{CCP}^A(\mathcal{J})$, and $\text{CCP}^R(\mathcal{J})$. These probabilities gather merger and repositioning actions conditional on the arrival of the right to move. After this reformulation one can directly apply the existence result and computational tools from Doraszelski and Judd (2012).

4 Data

The data used to estimate a dynamic model covers the period of 1996-2006 and consists of (i) a complete set of radio station acquisition transactions with monthly time stamps, and (ii) formats of every radio station in the United States with half-year time stamps. Additionally, the study uses a pre-estimated static mapping, $\pi_k(\mathcal{J}_t)$, between market structure and station revenues. The mapping is estimated for a subset of 88 non-overlapping markets, using a panel data set on listenership shares, advertising quantities, advertising prices and revenues. In order to avoid modeling cross-market interactions I drop the overlapping markets in a way following the method of Sweeting (2013); that is, I drop markets "where more than 6% of listening was to stations based in other markets". I also drop markets that do not have data on advertising prices. On-line appendix contains the details on the price/quantity data used for static estimation. The reminder of this section concerns the data used to estimate the dynamic model.

During the estimation, I introduce several data simplifications that reflect the main features of the radio industry described in section 2. Primarily, I divide the set of players into three groups: dominant owners, local owners, and fringe. Dominant owners include companies such as Clear Channel, ABC, or Viacom, which own complicated network of stations nationwide. I allow these companies to own multiple stations in local markets as well as acquire new stations. I also allow dominant owners to reposition stations within their portfolios. The second group of companies consists of local owners. These companies are not allowed to own multiple stations; however, they are allowed to reposition. Both dominant and local owners are forward looking about repositioning and bargaining about the acquisition prices. The remainder of companies compose the fringe. Companies in the fringe group are myopic and cannot reposition or be acquired, but they do participate in the static competition for advertisers and listeners.

In each local market, I label three active companies with the largest national revenue share in

2006 (the last year of the data set) as dominant owners.[6] Consequently, each local market may have a different set of potentially active dominant owners, however this set almost always contains Clear Channel, accompanied by ABC, Viacom, Citadel or Cumulus (see Table 2). According to the data, during and immediately after 1996, when the ownership was still fragmented, the dominant owners were initially inactive in many local markets, and then subsequently entered through acquisitions.

In addition to tracking dominant owners, in each local market, I label 22 of the remaining radio stations with the highest local listenership share as local owners. All other radio stations, which are small and usually have less than 0.5% listenership, are labeled as fringe stations. An exception to the above rule consists the markets with more than 15 active stations, where I label all AM stations as fringe because in such markets FM stations generate a dominant part of total revenues. In rural markets with less than 15 active stations, AM stations become important, so I allow both AM and FM stations to be outside of the fringe.

Dividing owners into the aforementioned groups has some important consequences. The upside is that it captures the important features of the radio market and reduces the complexity of the estimation. In particular, it enables estimating acquisition price, that is, a value function the acquiree, without tracking the possibility that the acquiree can make merger offers himself. This procedure enables me to use a simple two-step estimator to recover the parameters of the dynamic model. I note that dividing players into groups is not a limitation of the model per se and can be relaxed if the application requires it. Relaxation is also possible when computing counterfactuals and when using a nested-fixed-point estimator; but, given my data, these extensions would require further assumptions and have not been implemented.[7]

Modeling dominant owners, local owners, and the fringe is a minimum necessary compromise chosen to capture first-order dynamics of the radio industry. For example, putting all local owners in the fringe would be a strong assumption. First, as shown in examples 1 and 2 in the online appendix, the regulator must track the product repositioning of smaller players in response to the

[6] Labeling a subset of firms as national using future growth introduces an implicit assumption that all players have correct expectations about which firms will become large. In case of the radio industry this distinction is quite clear because firms such as Clear Channel, ABC, or Viacom were expected to execute many merger transactions after the deregulation. In other industries such distinction may be less clear.

[7] I did not use a nested-fixed-point algorithm for two reasons: (i) it requires strong assumptions on equilibrium selection, and (ii) it would require further and unrealistic simplifications to the model.

merger. Also, as shown in example 3 in the online appendix, the acquirees should be modeled forward-looking. However, at the same time, the smallest stations rarely change formats and are almost never acquired by larger owners as indicated in the data. Thus, in practice, while increasing the complexity of the estimation, modeling the forward-looking decisions of every small owner has little benefit. Nevertheless, dropping the smallest owners altogether is unrealistic because they collectively affect markups in the pricing game. Therefore, fully tracking only large and medium owners, and partially tracking smallest firms is a realistic compromise.

One artifact of not allowing smaller players to make merger bids is the prohibition of spin offs. I do observe spin offs in the data, but they are mostly a consequence of lumpy cross-market mergers that violate local ownership caps. Consequently, the owners must spin off certain stations to stay within the regulatory rules; according to the anecdotal evidence, the candidates for spin offs are determined in advance and are unlikely to be fully integrated into the new owner's portfolio in the first place. Thus, counting spun off stations in the new owner's portfolio would most likely overestimate the market power of the merged entity. I use this convenient fact and ignore acquisition of stations that were spun off subsequently.

The data contains information about more than 100 possible formats. I aggregate these formats into three meta formats: (i) "Adult Music," containing such formats as Adult Contemporary, Jazz, Rock, and Country, (ii) "Hits Music," containing such formats as Contemporary Hit Radio, Urban, and Alternative, and (iii) "Non-music," containing such formats as Talk, News, Ethnic and Religious formats. This choice is dictated by the consideration of the substitution patterns described by Jeziorski (2014a). The "Adult Music" format caters to a more mature population of listeners, while the "Hits Music" attracts a mostly younger crowd. The aggregation trades off a static realism for a dynamic realism. Namely, I sacrifice some accuracy in capturing within-period behavior by dropping second order format designations. However, such aggregation allows me to describe cross-period behavior in greater detail. At the same time, I note that the inaccuracy in describing within-period behavior can translate into inaccurate cross-period predictions. Keeping this caveat in mind, I proceed to estimate the model and come back to this issue when discussing the results.

5 Estimation

The estimator used in this paper belongs to the class of two-step methods pioneered by Hotz and Miller (1993). These methods enable the estimation of large dynamic systems without re-solving for an equilibrium at each parameter value. Hotz and Miller (1993) developed their estimator for discrete-time single-agent problems, and many studies have extended their method to discrete-time dynamic games (see Pakes et al. (2007), Bajari et al. (2007), Aguirregabiria and Mira (2007) and Arcidiacono and Miller (2011)). The present paper develops a new two-step Instantaneous Pseudo Maximum Likelihood (IPML) estimator that maximizes an objective function based on the instantaneous choice probabilities described by equations (B.2) and (B.3) in the Appendix B. An IPML is can be regarded as an extension of the 0-iteration Pseudo Maximum Likelihood introduced in Aguirregabiria and Mira (2007) for discrete time games. The estimation procedure builds on the previous work by Arcidiacono et al. (2010), but does not rely on the existence of the terminal state with a normalized terminal value, and relaxes the functional form of payoff shock distribution.

Suppose one has the data on H players' actions and states of the game an instant prior to taking these actions $\{(g_h, \mathcal{J}_h) : h = 1, \ldots, H\}$, where g_h is either a merger or repositioning action. If the full solution to the game is available, then the game can be estimated using a full information maximum log-likelihood (FMLE). Because state transitions conditional on actions are deterministic an FMLE is obtained by plugging a computed value function $V(\cdot;\theta)$ into the equations (B.2) and (B.3); that is,

$$L_H(\theta) = \sum_{h=1}^{H} \log \mathrm{CCP}(g_h | \mathcal{J}_h; V(\cdot;\theta), \theta).$$

However, there are two reasons why $V(\cdot;\theta)$ is difficult to obtain: (i) the state space of the game is large, so it is infeasible to recompute the value function for many candidate values of θ; and, (ii) the game is likely to have multiple equilibria so obtaining $V(\cdot;\theta)$ for every possible equilibrium may be necessary. The IPML estimator is designed to solve these issues. It replaces the value function $V(\cdot;\theta)$ with its uniformly consistent estimator $\hat{V}(\cdot;\theta)$, and maximizes the instantaneous pseudo likelihood

$$Q_H(\theta) = \sum_{h=1}^{H} \log \mathrm{CCP}(g_h | \mathcal{J}_h; \hat{V}(\cdot;\theta), \theta). \tag{5.1}$$

I follow the usual way of obtaining a uniformly consistent estimator of the value function; that is, I first pre-estimate CCPs and subsequently simulate the value function using equation (3.3). The details are presented in the four remaining parts of this section. The first part describes the pre-estimation of a one-shot profit function; the second contains the description of the state space of the model; the third explains the estimation of acquisition and repositioning strategies; and the fourth describes the simulated pseudo-likelihood estimation of structural parameters.

In the remainder of the paper I presume that the static profits $\pi(\mathcal{J})$ are known. The estimation procedure to obtain $\pi(\mathcal{J})$ is very similar to the one employed by Jeziorski (2014b). The details of this procedure are contained in the On-line Appendix.

5.1 Description of the state space

After the simplifications the state variables are: the identity of the market (because the profit functions vary from market to market), station portfolios of 3 dominant owners and station portfolio of fringe owners. Because the markets are assumed to have no interactions the game can be solved market by market. Table 3 shows the number of states of the game with post 1996 ownership caps and in the game with a uniform ownership cap of 7 stations. The largest market in the game with post 1996 ownership caps has 21 million states, and the smallest has about 700,000 states. The number of states increases by an order of magnitude of the ownership caps are increased to 7. In particular, the largest market has nearly 100 million states.

I find that solving the game market by market does not provide direct savings in terms of computation time because evaluating the Bellman equation is relatively cheap and the number of these evaluations grows linearly in the overall number states for all markets. However, separating markets is still crucial for the feasibility of the exercise because it enables significant memory savings. In particular, memorizing a value function for one market at a time, lowers the requirements from approximately 800GB to approximately 17GB of Random Access Memory (RAM).

As mentioned above, overall computation time is determined by the total number of states in all markets, which amounts to 4.5 billion. Consequently, despite heavy optimizations, such as, using compiled C-code, precomputing profits for all states, and using look-up tables for state transitions, the counterfactual with a cap of 7 requires more than 6,000 Central-Processing-Unit-Hours (CPUh) to compute. It is crucial that the solution algorithm is "embarrassingly parallelizable", that is, it delivers linear efficiency gain with the number of the CPUs used. Consequently, the counterfactual with a cap of 7 requires about a week to compute on a 48 CPUs server.[8] Increasing the number of product types (formats) in my application is infeasible with today's computers, however it is likely to be possible in a near future. Also, analyzing more product types for other industries with less active firms than radio should be possible.

Both stages of dynamic estimation involve imposition of current FCC ownership caps while assuming that there is no other and meaningful antitrust scrutiny. Such assumption largely reflects the reality of the radio industry, but can be easily relaxed if needed. In fact, having more antitrust restrictions makes the analysis easier by lowering the set of possible industry configurations (for example, larger ownership caps have higher computational complexity that smaller ownership caps).

5.2 Estimation of acquisition and repositioning strategies

The data I use to estimate the dynamic model is summarized by two sets. The first set describes merger decisions

$$X^A = \{a^{mhi} \subset K \times K : 1 \leq i \leq 6, h \in H, m \in M\},$$

a^{mhi} is an observed set of mergers, m is a local market, h is a half-year period, and i is the month in which the mergers took place. Several instances of multiple mergers exist in the same half-year, as well as multiple mergers in the same month. I can observe the sequence of mergers across months; however, I do not observe the sequence of mergers within the month. Therefore, for the periods that have multiple mergers within the same month, the state space at the time of taking an action is only partially observed.

The second set describes repositioning decisions:

$$X^R = \{b^{mh} \subset J \times F \times F : h \in H, m \in M\},$$

[8] The server setup used in this paper consists of 48 CPUs sharing the same RAM. Sharing the RAM is crucial, because when running on non-shared RAM setups (such as clusters or cloud) the algorithm is not embarrassingly parallelizable. In particular, one needs to accommodate an extra overhead from communicating the new value function to the nodes in each iteration. For this reason, comparable performance (in the year 2014) would require hundreds of cloud nodes instead of 48 units.

where b^{mhd} is the observed set of repositioning events during half-year h. The formats are observed once every half a year, as opposed to the mergers, which are observed monthly. Therefore, multiple merger and repositioning actions during the same data period create complications. For example, if the station was acquired and repositioned in the same half-year, I do not see which player took a repositioning action. Furthermore, I do not know how many active players were present during a repositioning action. For these reasons, the state, set of players, and players' actions are only partially observed, which must be taken into account during the estimation.

Equilibrium CCPs, given by equations B.2 and B.3, depend on the state through unknown value functions requiring semi-parametric estimation. In particular, the acquisition CCPs are given by

$$\widehat{\mathrm{CCP}}^{A}(k'|k,\mathcal{J},\theta^{A}) = \frac{\exp\left\{\Upsilon^{A}(k,k',\mathcal{J})\right\}}{\sum_{k''}\exp\left\{\Upsilon^{A}(k,k'',\mathcal{J})\right\}}, \tag{5.2}$$

where $\Upsilon^{A}(k,k'\mathcal{J})$ are unknown functions of the state $\mathcal{J}$. The unknown functions Υ^{A} and Υ^{R} are approximated through the use of polynomial sieves (see Ai and Chen (2003)) described below.

I denote the fraction of the total number of active non-fringe stations in format f and owned by player k as $\eta_{f,k}$. Formally,

$$\eta^{t}_{f,k} = \frac{\omega^{t}_{fk}}{J}.$$

Additionally, I denote a set of dominant owners as $\mathbf{K^{N}}$ and a set of local owners as $\mathbf{K^{L}}$. These sets must meet an adding-up constraint given by $K = \#\left(\mathbf{K^{N}} \cup \mathbf{K^{L}}\right)$,where $\#$ denotes the number of elements in the set. The above notation is useful for expressing statistics from the state that determine acquisitions and repositioning. For example, a fraction of stations that are locally owned and have format f is given by $\sum\limits_{k\in\mathbf{K^{L}}} \eta_{k,f}$.

After introducing the above notation, I define the approximations of Υ^{A} and Υ^{R} by polynomials of η. I postulate that the coefficients of these polynomials satisfy a certain set of restrictions imposed by the availability of the data, namely: (i) symmetric equilibrium and (ii) no mergers across the dominant owners. With additional data, I could potentially relax the first restriction by estimating Υ^{A} and Υ^{R} separately for each player. Similarly, if I observed many mergers of dominant owners, I could potentially estimate Υ^{A} separately for those types of actions. In practice, despite the fact that the merger data is rich, relaxing either of these restrictions is infeasible. Imposing the above restrictions, I approximate the above indices with polynomials

$$\Upsilon^{A}(k,k',\mathcal{J}) \approx \mathcal{P}(\theta^{A}_{f(k')},\eta),$$

where $\mathcal{P}$ is a polynomial of the statistics η, and $\theta^A_{f(k')}$ are coefficients specific to the format $f(k')$ of the only radio station owned by a local owner k'. Similarly, the repositioning policy index function could be written as

$$\Upsilon^R(k, f, f', \mathcal{J}) \approx \mathcal{P}(\theta^R_{f,f'}, \eta).$$

Note that dominant and local owners have different primitives for the model (possibly different fixed cost structures and local companies cannot acquire other firms), thus, equilibrium strategies have to be allowed to differ across these two types of players. For this reason, I utilize a different polynomial Υ^R to approximate the repositioning strategies of dominant and local firms. Despite the use of two different Υ^R, the coefficients of all polynomials are interrelated and require joint estimation because, as mentioned before, the state is only partially observed.

If the industry states were perfectly observable at the instant of the actions were takes, the sieves estimator would choose the θ^A and θ^R that maximize the data's pseudo-likelihood. However, as explained earlier, the data is imperfect, and full information likelihood cannot be computed. Instead one could use a simulated likelihood or a generalized method of moments. Unfortunately, both methods are impractical for my application. The former would require too many simulations to obtain a reasonably precise likelihood; the latter would lead to a substantial loss in efficiency. Another option is to perform an analytical integration of unobsevables using Chapman-Kolmogorov equations describing state transitions, as suggested by Arcidiacono et al. (2010). However, this method cannot be applied directly, because the full intensity matrix (a continuous time equivalent of a transition matrix) for my largest markets can contain up to 4 million by 4 million entries. Although this matrix is quite sparse, it would not be sufficiently sparse to either store in the computer memory, or to recompute "on the fly." Instead, I develop a method of integrating the likelihood based on partial Chapman-Kolmogorov equations. These partial equations take advantage the fact that only a small subset of feasible latent industry states are relevant for the estimation. This simplification relies on two facts: (i) I obseve all merger events, thus, no latent mergers have to be intergrated out, (ii) two repositioning events by the same station are extremely unlikely and are assumed away.[9] The details of this method are presented in the Appendix C.

I do not observe events in which players take no action, therefore, in the first stage, I am only

[9] I verify this assumption using a subset of the data for which I observe formats quarterly. Particularly, none of the stations in this subsample repositioned twice in the same half-year.

able to identify the product of the move arrival rate λ and CCPs. However, as long as the true move arrival rate is not excessively small, I can estimate the first stage by choosing a reference value of λ set to 1. Relevant CCPs for a desired value of an arrival rate could be obtained by dividing the estimates by λ.

5.3 Estimation of structural parameters

This subsection details the remaining parts of the estimation; namely, the parametrization of the model and the simulation of the value function.

Fixed cost. The fixed cost of player k to operate a station j in format f is parametrized as follows:

$$F_{kj}^{m}(\mathcal{J}^t|\theta^F) = \bar{F}_f^m \times F^S(\omega_{kf}^t, z_k|\theta^F) \times F^E(n_k^t, z_k|\theta^E). \tag{5.3}$$

The cost is composed of three terms: (i) term $\bar{F}_f^m$ is a fixed cost of owning a single station of format f in market m, without owning additional stations in this or any other market; (ii) the function F^S represents a fixed cost discount caused by synergies of operating multiple stations in the same format and the same local market; and (iii) the function F^E represents a fixed cost discount caused by within- and cross-market economies of scale.[10] Note that for local owners, F^E and F^S are equal to 1.

The market-level fixed cost of owning one station $\bar{F}_f^m$ is assumed to be proportional to average variable profits (before fixed cost) in the market, calculated separately for each format. I compute this average by simulating an industry path for each observed data point and averaging over time. The simulation is done using the first-stage estimates.

I postulate that for dominant owners:

$$F^S(\omega_{kf}^t, z_k = N|\theta^F) = \frac{\left(\omega_{kf}^t\right)^{\theta^F}}{\omega_{kf}^t}.$$

[10] I include cross-market economies of scale, but I do not model the joint decision to acquire multiple stations across markets. The implications of this assumption depend of the form of cross-market synergies. In my particular case, I use a simple specification in which large owners are assumed to have cost discount that does not increase with number of stations owned in other markets. In such specification, most joint decisions to acquire multiple stations can be disaggregated into market-by-market decision without losing generality. The disaggregation may matter if the multiple stations are acquired from the same owner and if there are economies of scale while bargaining.

Parameter θ^F captures the synergy and is expected to lie between 0 and 1. I allow for economies of scale by setting F^E as follows[11]

$$F^E(n_k^t, z_k = N|\theta^E) = \theta_N^F \frac{(n_k^t)^{\theta^E}}{n_k^t},$$

where θ_N^F is a discount for being a dominant owner and θ^E is a parameter that captures local economies of scale.

Acquisition cost. The acquisition cost has a persistent part $\mu_k^A(\mathcal{J}^t, k'|\theta^A)$ and an idiosyncratic part with volatility $\sigma_k^A(\mathcal{J}^t, k'|\theta^A)$. The persistent part is parametrized as follows:

$$\mu_k^{A,m}(\mathcal{J}^t, k'|\theta^A) = \theta^{A,m} + \theta_\pi^A \pi_k(\mathcal{J}^t).$$

The acquisition cost may depend on the company's size because integrating into a bigger company can be more costly, which is captured by the dependence of μ_k^A on the variable profits as a proxy for size. I postulate a similar relationship for the idiosyncratic volatility:

$$\sigma_k^{A,m}(\mathcal{J}^t, k'|\theta^A) = \theta_\sigma^{A,m} + \theta_{\sigma,\pi}^A \pi_k(\mathcal{J}^t).$$

Because acquisition cost is likely to be heterogeneous across markets, I allow the intercepts $\theta^{A,m}$ and $\theta_\sigma^{A,m}$ to vary across four market categories. The first category consists of markets in which a single station has average variable profits greater than \$150,000, the second category has half-yearly variable profits in the range \$150,000-\$60,000, the third in the \$60,000-\$20,000, range, and the fourth less than \$20,000.[12] Additionally, $\theta^{A,m}$ may vary across formats, because layoff costs as well as other integration costs (human and physical resources reallocation) may vary with the type of programming. I try this specification and find that the differences are economically small (less than 5%) and statistically (1%-size test) insignificant.

[11] I also try other specifications, such as fixed effects for discounts when n_k^t is greater than 3 or 4, and arrive at similar results.

[12] The variable profits are small for two reasons. First, they are an average across a relatively small number large stations and a larger number of fringe stations. Second, the variable profits are net of variable cost. Overall evidence on radio station profitabily is scarce; According to Federal Communications Commission (2003), Figure VI, net profit margin of the radio industry was actually negative in 33% of quarters from 1995 to 2003. Moreover, radio industry was found to underperform relative to S&P-500 companies. Small average profits are also consistent with Jeziorski (2014b).

Repositioning cost. Similarly to the acquisition cost, the repositioning cost has a persistent part $\mu_k^R(\mathcal{J}^t, k'|\theta^R)$ and an idiosyncratic part with volatility $\sigma_k^R(\mathcal{J}^t, k'|\theta^R)$. It is reasonable to expect that dominant owners face different repositioning costs than local owners. For example, voice-tracking technology can allow the dominant owners to temporarily bring announcers from other markets to streamline format switching. However, local owners may have better access to local labor markets and a more flexible workforce. Differences may additionally vary by format. One example is the Hits Music format, which requires a large tower and costly marketing to gain sufficient listenership. For this reason, switching to the Hits format is likely to require greater capital investments and access to specialized production factors. Thus I expect dominant owners to have lower cost when switching into this format. To accommodate that expectation, I postulate the following parametrizations:

$$\mu_k^{R,m}(\mathcal{J}^t, f, f'|\theta^R) = \theta^{R,m}\left[\mathbf{1}(z_k = L)\theta^R_{L,f',f} + \mathbf{1}(z_k = N)\theta^R_{N,f',f}\right] + \theta^R_\pi \pi_k(\mathcal{J}^t)$$

and

$$\sigma_k^{R,m}(\mathcal{J}^t, f, f'|\theta^A) = \theta^R_{\sigma,m} + \theta^R_{\sigma,\pi}\pi_k(\mathcal{J}^t).$$

The intercepts of repositioning costs are allowed to be from-to format specific and vary by the company type. In addition, I allow for the mean shifts and heteroscedasticity by size, which are captured by parameters θ^R_π and $\theta^R_{\sigma,\pi}$, respectively. To control for differences in switching costs across markets, I allow for market-category multiplicative fixed effects in the mean $\theta^{R,m}$, and the variance $\theta^R_{\sigma,m}$. I find that allowing for such flexibility in the specification is critical in fitting the model to the data.

The above specification is used to simulate the value function

$$\begin{aligned} V_k(\mathcal{J}^t|\theta) = \int_{s=t}^{\infty} e^{-\rho s}\pi_k(\mathcal{J}^s)ds - \int_{s=t}^{\infty} e^{-\rho s}F_k(\mathcal{J}^s|\theta)ds + \sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}} P(a_k^{(l)}, \mathcal{J}^{\tau_k^{A,(l)}}|\theta) + \\ \sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}} W^A_{a_k^{(l)}}(\mathrm{CCP}^A_k, \mathcal{J}^{\tau_k^{A,(l)}}|\theta) + \sum_{m=1}^{\infty} e^{-\rho\tau_k^{R,(m)}} W^R_{r_k^{(m)}}(\mathrm{CCP}^R_k, \mathcal{J}^{\tau_k^{R,(m)}}|\theta). \end{aligned} \tag{5.4}$$

The acquisition prices $P_k^{(l)}$ (value functions of the local firms) are simulated using a nested routine, which is triggered upon the arrival of a merger action at time $\tau_k^{A,(l)}$ and simulates the continuation value of the local owner conditional on rejecting the merger bid. This value includes future mergers between rivals, as well as the potential repositioning of the firm and its rivals. By backward induction on the number of active rivals, it is possible to show that the option value of the local firm must be equal to the value of rejecting all subsequent merger bids. The nested-simulation routine arrives at this value with the following formula:

$$V_k(\mathcal{J}^t|\theta) = \int_{s=t}^{\infty} e^{-\rho s}\pi_k(\mathcal{J}^s)ds - \int_{s=t}^{\infty} e^{-\rho s}F_k(\mathcal{J}^s|\theta)ds + \sum_{m=1}^{\infty} e^{-\rho\tau_k^{R,(m)}} W^R_{r_k^{(m)}}(\text{CCP}^R_k, \mathcal{J}^{\tau_k^{R,(m)}}|\theta).$$

The closed-form solution for the conditional expected value of shocks W is unknown for the number of alternatives larger than 1 (not including empty actions), which is a consequence of the fact that idiosyncratic shocks are not distributed as type-1 extreme value random variables. Instead, I simulate the idiosyncratic part of W on the grid of CCPs and fit the 4^{th}-degree complete Chebyshev polynomial. Likewise, I fit a separate polynomial for each number of feasible alternatives. Such interpolation provides a good approximation along the equilibrium path, with a maximum error of about 1% and lower.

Having the estimators of the value function $\hat{V}$ at hand, I maximize an expected version of the pseudo-likelihood (equation (5.1)), obtained using the procedure described in Appendix C. Note that the value function must be simulated for every potentially feasible latent state as well as for any state attainable by a single action from any feasible latent state. For example, in the case of Los Angeles, there are 46 feasible latent states, which generate $1,208$ potentially accessible states. Overall, 88 markets contain $106,304$ accessible states. Each simulation is composed of $1,000$ draws, so the procedure involves obtaining $106,304,000$ industry paths, which are assumed to evolve for 40 years and are kept constant thereafter. Because the number of industry paths is large the simulation procedure must be efficient. Two features facilitate this efficiency: (i) Using my functional-form specification, one can simulate the industry path once and compute the value function for different candidate values of structural parameters θ by using a set of sufficient statistics (details in Appendix D). In such a case the computation of the pseudo-likelihood takes about as much as computing first-stage likelihood. (ii) Continuous time enables updating the industry state only at the arrival of the executed move, which saves computing power when simulating relatively infrequent actions such as mergers and product repositioning. In an extreme case, when the draw of the waiting time for the first executed move exceeds 40 years, the state is never updated and the draw of the value function collapses to perpetual static profits.

Several components of the model must be identified: (i) the repositioning cost θ^R, (ii) merger cost θ^A, (iii) cost efficiencies from mergers (θ^F, θ^E), (iv) level of the fixed cost $\bar{F}_j^m$, and (v) arrival rate λ. The identification strategy relies on the fact that revenues of radio owners at each industry state can be predicted by a pre-estimated static model. As in Sweeting (2013) and Jeziorski (2014b), the repositioning cost is identified as the residual from endogenizing format repositioning. In other words, pre-estimated revenue predictions and the estimated repositioning cost must rationalize the repositioning actions observed in the data. I identify the merger cost and cost efficiencies from consolidation in a similar way. Specifically, I use the convenient fact that entry is possible only though acquisition and choose the merger cost that rationalizes observed timing of such entry decisions. Similarly, the estimates of the cost efficiencies have to rationalize subsequent acquisitions. Lastly, the level of the fixed cost (or the fixed cost of owning one station) is bounded from above by the fact that the entry is profitable in all markets, and from below by the level of cost discount required to justify the mergers.

Identifying rate λ separately from other structural parameters is difficult without observing move opportunities that were not executed. Such identification may still be possible with an exclusion restriction that shifts the continuation value but does not affect current payoffs. One candidate for such exclusion are ownership caps. If an owner is below the cap, the cap does not affect current profits from a merger; however, it shifts future profits through the ability to execute mergers. I tried this approach and found it infeasible, because the variation in the ownership caps in my data is not sufficient. Note that the difficulty of identifying λ is not specific to continuous time and is present, but not prominently exposed, in discrete-time games. Specifically, an arrival rate in a continuous-time game is analogous to a period length in a discrete-time game. Identifying this period length is similar to identifying a discount factor, which is known to be difficult (see Rust (1994)). For this reason, the length of the period is usually not estimated but fixed, for example, to one action per year. I make a similar simplification and set the arrival rate to once per month; however, I estimated the model with an arrival rate of once per year and obtained similar results, both qualitatively and quantitatively.

6 Results

In this section, I report the estimates of the structural parameters of the model and discuss the first- and the second-stage estimates of the dynamic model. The discussion of the static part is contained in the On-line Appendix.

6.0.1 First stage estimates

The merger and repositioning strategies are estimated jointly as described in section 5.2. I group the results into multiple tables to facilitate the exposition. Table 4 contains the estimates of format-acquisition dummies and interactions between format acquisition and demographic composition of the local market. The format-acquisition dummies contained in the first row of the table are large and negative, which reflects the fact that mergers are relatively rare events. The values of these dummies are similar across formats, which suggests that other observable covariates explain most of the variation in acquisition across formats. I find that the interactions between the demographic composition and acquisition propensity represent the listeners' substitution patters reported in the On-line Appendix. For example, the Adult Music format has a positive (however statistically insignificant) interaction with age, Hits Music has a positive interaction with Black, and Non-music interacts positively with Hispanic.

Tables 5 and 6 present the coefficients describing the relationship between the industry state and a propensity to acquire a particular format f. Specifically, Table 5 contains coefficients on the state variables corresponding to the format f of a potential acquiree. The term $\eta_{f,k}$ represents the coefficient on the number of owned stations in the format of the acquiree. The positive number suggests that firms acquire in the formats they already own, which could be the result of demand- or supply-side complementarities. By contrast, Sweeting (2013) and Jeziorski (2014b) find that owners avoid acquiring stations similar to their current portfolios. The reason for this discrepancy is the broader definition of the format used in this study. For example, an owner of a Rock station might not acquire another Rock station; however, he might acquire another station in the Adult music format, such as Country or Adult Contemporary. The coefficient on the square of $\eta_{f,k}$ is negative, which indicates that the payoffs from mergers have decreasing returns.

The third column of Table 5 contains a coefficient that captures the impact of the number of national competitors in the same format as a potential acquiree on the propensity to acquire. I find that a larger number of national competitors in a particular format correlates with a higher propensity to acquire in this format; however, the result is not statistically significant. The fourth column reports a coefficient on ownership concentration (similar to the Herfindahl index) of stations in the acquiree's format. In general, the less concentrated the ownership in the acquiree's format, the greater the propensity to acquire. The last two columns describe the impact of the portfolios of the local owners. I find that, unlike the number of national competitors, the number of local competitors in the acquiree's format is negatively correlated with an acquisition.

Table 6 contains further state covariates explaining the acquisition decision. I find that larger numbers of owned stations correlate positively with a greater likelihood of acquisition. Also, the more stations are held by competing national owners, the less probable the acquisition. The last two numbers in the table contain higher-order terms representing concentration of ownership across competitors and the distribution across formats of nationally owned stations.

The acquisition strategy includes the dummies reflecting the proximity to the ownership cap. If the acquisition should result in coming closer to the maximum set by the cap, that acquisition becomes less probable. This means that as owners approach the cap, they become more selective in order to maintain an option value. In particular, if the acquiree is one station from the ownership cap, the estimated dummy is -0.47 (0.14).

The extended discussion of the estimates of format switching CCPs is contained in the On-line Appendix. The results are largely consistent with discrete time estimates of Sweeting (2013) and Jeziorski (2014b). This consistency suggests that format switching modeled in continuous time yields similar dynamics to format switching modeled in discrete time.

I relevant part of the format switching strategy is its interaction with merger strategy. Specifically, I find that the proximity to the ownership cap impacts format switching. The closer the owners are to the limits imposed by the cap, the more probable is the format switching. The dummies indicating "one more station to reach the cap" and "at the cap" states are positive and amount to 0.436(0.457) and 0.593(0.094), respectively. It suggests that companies are forward looking and treat format switching as a substitute for acquisitions. For example, if the owner is at the cap and wants to respond to changing market conditions, the only choice is to reposition because mergers are prohibited by the regulator.

6.0.2 Goodness of fit

To evaluate goodness of fit of the first-stage estimation I use a pseudo R^2 measures proposed by McFadden (1973). In particular, I compute $R^2 = 1 - \frac{\log(\text{likelihood of a full model})}{\log(\text{likelihood of a benchmark model})}$. This statistic delivers a test for significance of the first-stage estimation equation, when a benchmark model has constant merger and repositioning propensities and the full model has logistic structure (see equation (5.2)). Alternatively, the statistic can be interpreted as a "mean square error" of the "variance" explained by the model, which is analogous to a Multiple Correlation Coefficient (R) in the linear regression. The model used as a first stage in this study can be regarded as a generalization of the static logit model, that is, it is composed of discrete choice problems arriving with exponential arrival times. Thus, McFadden's R^2 should be informative about the goodness of fit. Since the merger and repositioning strategies are estimated jointly, I compute a joint R^2 measure using a model with two constants (one for merger strategy and one for repositioning strategy) as a benchmark. The statistics are presented in Table 12. I obtain $R^2 = 0.1$, which indicates that the model can explain about 10% of variation in merger and repositioning activity in the data. The unit of observation is a merger-month, thus, it is expected to have a reasonable amount of the residual variance, because it is difficult to predict the exact month the merger takes place. Further information can be obtained by looking at the fit of the model over time. I observe a sharp decrease in the merger activity after the year 2000 and it is important to verity if the first stage model can reasonably predict this qualitative change. For this purpose, I report the R^2 statistic for each year in the data. The R^2 statistic is always above 0.07 and stays above 0.1 for the pivotal years of 2000 and 2001.

The original McFadden's R^2 is designed to compare nested models, however, it can be extended to compare non-nested models. The purpose of such analysis is to investigate if relaxing certain assumptions of the model would lead to a better fit. A particularly relevant non-nested model is a non-stationary model that allows for time varying merger and repositioning propensity. Using this model as benchmark demonstrates how much explanatory power is gained when allowing for the main model to be non-stationary. Second row of Table 12 presents the results of using a model with year dummies for merger and repositioning propensities (20 parameters)[13] instead of using

[13]This alternative formulation allows both the arrival of moves λ and move execution probabilities to be non-stationary.

a model with constants as a benchmark. The results suggest that allowing for non-stationarity does not add significant amount of explanatory power. In particular, I observe that the main (stationary) model has more explanatory power than then the alternative non-stationary model. Moreover, since the R^2 computed using the model with the constant probabilities is quite similar to the one computed using the non-stationary model, I conclude that allowing a simple time trend does not capture a significant amount of variation in data.

6.1 Second stage estimates

In this subsection, I present estimates of the structural parameters, including fixed cost, as well as persistent and variable components of the acquisition and repositioning costs.

According to equation (5.3), the fixed cost of operating a portfolio of stations is composed of three parts: a market-level fixed-cost multiplier $\bar{F}_f^m$, a multiplier representing cost synergies of owning multiple stations in the same format $F^S(\mathcal{J}_{kf}^t|\theta^F)$, and a multiplier representing the economies of scale for owning multiple stations of any format $F^E(n_k^t|\theta^E)$.

Table 7 presents the fixed cost estimates of owning a single station averaged across formats. The level of the fixed cost varies across markets and is roughly proportional to the population. Table 9 contains the estimates of the within-market economies of scale resulting from owning multiple stations. I find that operating two stations together is 14% cheaper than operating them separately regardless of their formats. The last column contains the estimate of the cost advantage of being a national owner, a status that captures cross-market cost synergies. I find that national owners have a 4% lower fixed cost than local owners, but the result is not statistically significant. I also document further cost synergies of operating stations in the same format. According to Table 8, the operation of stations in the same format is additionally 14% cheaper on top of the economies of scale indicated in Table 9.

Table 10 presents the estimates of the merger cost. I find that the mean acquisition cost varies by market type and company size. Moreover, I find that this acquisition cost has a relatively high volatility, which is homoscedastic. Firms obtain a new draw from the idiosyncratic component every month, and mergers are tail events. Thus, the combination of large mean and high volatility usually leads to low cost for realized mergers.

I allow the repositioning costs to depend on the market category, source-target formats, and the ownership structure of the firm. I operationalize the estimation by using multiplicative fixed effect for market category, source-target format, and being a national owner. Estimates of repositioning for Category 1 are reported in Table 11, and the remaining categories are contained in the Online Appendix. I find that the repositioning cost varies considerably across market categories. In particular, I find higher switching cost in more profitable markets. Similar to the merger actions, switching is a tail event, and the estimates reveal high average switching costs with fairly high volatility over time. Additionally, the costs are statistically different depending on the source and target formats, suggesting that switching is cheaper between some formats than between others. These differences in switching costs are driven by the format switching patters in the raw data. For example, Hits stations are quite profitable, but I do not observe much switching into this format, which can be rationalized by high switching costs. One can explain the other switching-cost estimates similarly.

7 Counterfactuals

Using the estimates of the structural parameters of the model, I perform several counterfactuals, which study alternative merger enforcement policies.[14]. In order to minimize the impact of the estimation error, I compare the simulations of counterfactual policies to a simulation of the current policy (not to the actual outcomes).

7.1 Impact of the 1996 Telecom Act

The first set of experiments investigates the impact of the 1996 Telecom Act on producer, listener, and advertiser surplus. Table 13 presents counterfactuals that evaluate the impact of the looser post-1996 local ownership caps. In particular, I recompute the equilibrium merger and repositioning strategies for the pre-1996 ownership caps and compute the relevant surpluses for 5, 10, and

[14] The model of mergers is likely to have multiple equilibria. I use a selection rule that involves starting the best response dynamics algorithm from the equilibrium played currently in the data. While I cannot exclude the existence of other stable equilibria, I try many other starting points, including a value function equal to zero, and could not obtain any other equilibrium. Keeping this caveat in mind, all results in the counterfactual section should be interpreted as "there exists an equilibrium such that...", and should not be interpreted as "in all equilibria it holds that...".

20 years into the future. I use static measures of producer and consumer surplus for the following reasons: (i) the results are easily comparable with static analysis, and (ii) the static measures do not contain payoff shocks ζ, whose variance is difficult to identify separately from the move arrival rate λ. I find that radio-station owners benefit from the deregulation, because under the old caps the producer surplus is 10% lower. Approximately 6% of this decrease results from loss of market power and 4% results from lost cost efficiencies. Moreover, the deregulation leads to lower advertising supply and higher per-listener prices. Consequently, reverting to the old caps lowers listener surplus by 0.07% and increases advertiser surplus by 1.7%.

The above exercise addresses the changes in the local cap without imposing a national cap (the post-1996 conditions). An additional exercise aims to partially address changes in the national cap by nullifying the cross-market cost benefits. In general, a lack of national synergies leads to fewer mergers, which lowers the negative impact of the deregulation on advertiser surplus. However, mergers are also less efficient because cross-market synergies are not internalized. As a consequence, the realized mergers generate smaller gains in producer surplus. The overall effect is presented in the bottom three rows of Table 13.

It is useful to compare the findings of dynamic analysis with those obtained using static analysis. In particular, Jeziorski (2014a) finds that over the course of the decade between 1996 and 2006, ownership consolidation decreased advertiser welfare by 21%, whereas the present study determines that decrease to be 1.7%. I investigate two factors that are mismeasured or omitted in a static analysis and contribute to this difference: (i) post-merger product repositioning, which could correct the negative effect of the mergers; and (ii) equilibrium provision of variety with and without the Telecom Act.

When assessing market power after an acquisition of of a station in a particular format, it is particularly relevant to investigate the incentives of competitors to reposition into that format. Namely, because the acquisition generates higher rents for all stations of the focal format (as demonstrated numerically in the On-line Appendix), it invites repositioning by competitors. Such repositioning creates more competition and mitigates the effect of the merger. [15]

I measure the repositioning using *net entry rate* defined as the difference between entry and exit rate of competitors in and out of the focal format. I demonstrate the impact of mergers on entry

[15]This process is equivalent to post-merger entry mentioned in Horizontal Merger Guidelines.

by comparing the net entry rates before and after an acquisition of a station of the focal format. I compare the net entry rates using two methodologies: (i) using raw data summarized by first-stage estimates (in the spirit of Benkard et al. (2010)),[16] and (ii) using conditional choice probabilities obtained numerically from a model. These two methodologies of assessing post-merger entry are complementary. Using the model keeps the other market forces constant, beyond the merger in question, which is similar to running a field experiment. It is particularly attractive when studying mergers because actual field experiment is extremely hard to execute in such context. However, the quasi-experimental properties come with the cost of relatively strong modeling assumptions.

I compute before and after net entry rates using the first-stage CCPs averaged across mergers observed in the data. I find that in 72% percent of markets there is, on average, more net entry of fringe stations into a particular format after a station of the focal format was acquired. The average post-merger Poisson net entry rate equals 0.07 per month, which translates to about one year average waiting time for the repositioning of competitors.

I also compute net entry rates using the CCPs computed from the model. I compare average pre- and post-merger net entry on Figure 1 and I find that mergers lead to higher entry rates in all 88 markets. The average Poisson net entry rate predicted by the model amounts to 0.02 per month, which translates to about four year average waiting time for a post-merger repositioning of competitors. Both results, the one obtained from the raw data, and the one estimated model are mutually consistent, and suggest a significant increase in entry after the merger. The dynamic model accounts for such entry, whereas static model does not.

Next, I examine the effects of Telecom Act on the provision of variety. The reduced form evidence for the variety provision was provided by Berry and Waldfogel (2001), who find that mergers in radio markets generally lead to more variety. Jeziorski (2014a) further quantifies this effect and shows that the provision of more variety directly affects market power by increasing the surplus of the listeners and lowering the surplus of advertisers. These two papers compute the change in variety using temporal variation in formats before-and-after the Telecom Act. I supplement their analysis by comparing the provision of variety in the same year with and without the Telecom Act using counterfactual experiments.

[16] I thank Luis Cabral for helpful discussions about using the raw data to obtain evidence for post-merger entry and for proposing the statistics used in this paper.

I compute variety index that measures the concentration of formats in the market, defined as

$$\sum_f \left(\frac{\sum_k \omega_{kf}}{N}\right)^2,$$

which resembles Herfindahl index. If the variety index is 1, then all the stations have the same format (no variety). If the variety index is $\frac{1}{F}$, then the stations are distributed uniformly across formats (maximum variety). The variety index amounts to 0.45 in the year 1996 – the first year of my data. I replicate the result by Berry and Waldfogel (2001) and Jeziorski (2014a) by computing the change of variety index over time under the post-1996 ownership caps. I find that post-1996 mergers lead to increased variety generating a variety index of 0.39 and 0.381 in 2001 and 2006, respectively. I recompute the variety index under the old ownership caps and I find that the variety index amounts to 0.391 in 2001 and 0.388 in 2006. Relative to the changes in the variety index over time (comparing 0.45 in year 1996 to 0.39 in year 2001), counterfactual analysis reveals a negligible impact of Telecom Act on variety 5 years after it was introduced (comparing 0.39 and 0.391), and moderate impact 10 years after it was introduced (comparing 0.381 to 0.388). Thus, the static analysis, which uses only temporal variation, overstates an impact of Telecom Act on variety. Mismeasurement of the variety provision results in overstating antitrust implications on the Telecom Act.

7.2 Alternative merger policies

Ownership caps are rarely applied in markets other than radio broadcasting. Alternatively, the regulator applies policies based on concentration indices or direct measures of welfare. In the next experiment, I increase the ownership caps to seven FM stations, as before, but additionally I impose welfare criteria based on static merger simulations.

First, I evaluate the impact of increasing ownership caps to seven FM stations (subsequently CAP7)[17] and present the results in the first three rows of Table 14. I find that in the long run, the relaxation of the caps leads to about a 4.2% increase in producer surplus. Approximately one third of this gain comes from fixed cost efficiencies, and the remaining two thirds from market power. In

[17] Some results of the CAP7 counterfactuals rely on the functional form extrapolation of the cost synergies, that are by construction of the current regulation, not observed in the data.

the long run, market power is exercised predominantly on advertisers, which lose about 1% of their surplus. At the same time, the listeners gain 0.01%. Shorter-run analysis (over the first 5 to 10 years) demonstrates the tension between exercising market power on listeners versus advertisers. Namely, in the first five years after moving to CAP7, the companies exercise market power, on listeners, and in 10 to 20 years, on advertisers. The reason for this reversal is that the short-run welfare figures are driven by ownership consolidation, whereas the long-run welfare figures are driven by consolidation and post-merger product repositioning. These findings are in line with the previous literature on retrospective post-merger repositioning in the radio industry. In particular, post-merger repositioning can increase variety in the industry (see Berry and Waldfogel (1999), and Sweeting (2009)) benefiting listeners but hurting advertisers by thinning competition (see Jeziorski (2014a)). However, prior to this study, the applicability of these results to hypothetical and out-of-sample policies such as CAP7 has not been established.

Next, I imposed additional antitrust criteria and recompute the equilibrium of the dynamic game. Rows 4 to 6 of Table 14 present the results of experiments in which mergers that decrease static listener surplus are forbidden. On one hand, the policy is successful in selecting mergers that benefit listeners, raising their surplus by 0.03% in the long run, which is three times the gain from pure CAP7. On the other hand, the listener welfare criterion renders many mergers infeasible, leading to a smaller increase in producer surplus. However, because the executed mergers are in general more cost efficient compared to CAP7, much of the cost synergy is still realized.

Lastly, I evaluate the policy based on advertiser surplus and present the results in rows 7 to 9 of Table 14. Contrary to the listener surplus policy, advertiser surplus policy is unsuccessful in preventing mergers that harm advertisers in the long run. The welfare criterion does well in the short run, leading to an approximate 0.13% gain in advertiser surplus. However, post-merger repositioning reverts this trend in the long run and leads to a 0.77% loss in advertiser surplus. The reason for this reversal is that companies circumvent the regulation by proposing mergers that meet the static advertiser surplus criterion, and optimally repositioning to extract the advertiser surplus once the merger is approved. Consequently, in the long run, the impact of the enforcement policy on welfare depends more on how many mergers are approved and less on the type of mergers that are accepted. Moreover, contradictory to the static intuition, the static advertiser surplus criterion delivers a worse outcome for advertisers than the static listener surplus criterion, which demonstrates that myopic merger policy can be dynamically suboptimal and can have somewhat counterintuitive long-run consequences.

8 Conclusions

This paper proposes a model of industry response to different merger enforcement regimes. The regulator proposes and subsequently follows a merger enforcement policy, and companies respond to that policy via mergers, entry/exit and product repositioning. The merger transfer prices are endogenous and are an outcome of a dynamic bargaining process. This model aims at providing a tool to conduct antitrust merger review that accommodates the distortions created by endogeneity of mergers, entry/exit and product repositioning.

I demonstrate the applicability if the procedure by examining the wave of consolidation in U.S. radio broadcasting industry that occurred from 1996 to 2006. I find substantial fixed and marginal cost synergies from joint ownership. Namely, operating multiple stations together within the local markets is cheaper than operating them individually. Additionally, significant cost synergies arise from the operation of multiple similar stations withing a local market. Specifically, the operation of two stations by the same owner in a given local market is up to 14% cheaper than the operation of similar stations by different owners. Moreover, if the two stations that are operated jointly have the same programming format, the fixed cost drops by an additional 14%.

After establishing the extent of cost synergies from mergers, I compute a merger retrospective that evaluates the 1996 Telecom Act. This retrospective compares the industry trajectory without the Act with the factual trajectory with the Act. I find that the deregulation enhanced total surplus by raising producer surplus and generating a negligible impact on listener and advertiser surplus. Small impact of the Act on advertisers contrasts with the large drop in advertiser surplus suggested by the static model and highlights the need to incorporate dynamics into the merger analysis.

Furthermore, I evaluate the counterfactual policy of using looser caps supplemented by welfare criteria. In general, I find that increasing ownership caps to seven stations increases total surplus. I demonstrate that the mergers in the radio industry are largely self-correcting because they invite a significant amount of repositioning, which mitigates the market power. However, I also demonstrate that static welfare criteria are not sufficiently safeguarding to all losses to advertiser surplus. Specifically, the criterion that rejects mergers lowering static advertiser surplus does not prevent long-run losses to that surplus. Such losses to the advertisers surplus are a consequence of the fact that companies can circumvent the welfare rule by proposing a merger that is acceptable to the myopic regulator and altering the product characteristics to extract advertiser surplus after the merger. Also, more generally, I show that in the industries where dynamic processes such as entry/exit or product repositioning are prevalent, the companies are able to extract consumer surplus despite the welfare criteria employed by the regulator. In such cases, the efficacy of a particular merger enforcement rule is predominantly driven by the raw number of merger this rule allows, and less by the exact types of merger this rule permits.

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Appendices

A Tables and Figures

# of active stations	Old ownership cap	New cap
45+	4	8
30-44	4	7
15-29	4	6
0-14	3	5

Table 1: Change in local ownership caps introduced by the 1996 Telecom Act.

Company	Number of active markets in 2006 (out of 88)
Clear Channel	79
ABC/Disney	35
Viacom Int'l Inc	23
Citadel Comm Corp	18
Cumulus Media Partners LLC	18
Forstmann Little	18
Davidson Media Group LLC	17
Family Stations Inc	16
Radio One Inc	16
Entercom	15
Cox Radio Inc	12
Multicultural Bcstg	12
CSN International	10
Crawford Broadcasting Company	10
Entravision Communications Corp	10
Univision	10

Table 2: Number of active local markets (out of 88) for the largest radio owners.

	Number of markets having states within							Total states
	0-1M	1M-5M	5M-10M	10M-20M	20M-50M	50M-90M	90M-100M	
Post 1996	5	35	14	12	22	0	0	792,557,073
Cap 7	3	7	8	11	14	18	27	4,577,183,777
	Average computation time in CPU-hours							Total time
States	0-1M	1M-5M	5M-10M	10M-20M	20M-50M	50M-90M	90M-100M	
CPUh	1.4	5.7	10.7	19.3	47.7	88.6	138.5	Post 1996: 1,098 Cap7: 6,342

Table 3: The table shows the number of markets having number states in a particular interval, the total number of states for all markets, and average equilibrium computation time.

	Adult Music	Hits Music	Non-Music
Dummy	−3.633 (1.046)	−3.609 (0.886)	−3.743 (1.747)
Age	1.963 (4.247)	0.659 (3.615)	−1.125 (3.069)
Education	0.906 (1.992)	−0.108 (1.697)	−0.539 (1.289)
Income	−0.696 (0.753)	−0.814 (0.662)	−0.623 (0.567)
Black	−0.205 (0.800)	1.475 (0.638)	0.507 (0.711)
Hispanic	−0.496 (0.786)	−0.817 (0.703)	0.608 (1.849)

Table 4: Acquisition CCP: Format dummies and format-demographics interactions; demographics variables are 1996-2006 market-level averages.

$\eta_{f,k}$	$\eta^2_{f,k}$	$\sum_{k' \in \mathbf{K^N} \setminus k} \eta_{k',f}$	$\sum_{k' \in \mathbf{K^N} \setminus k} \eta^2_{k',f}$	$\left(\sum_{k' \in \mathbf{K^N} \setminus k} \eta_{k',f}\right)^2$	$\sum_{k' \in \mathbf{K^L}} \eta_{k',f}$	$\left(\sum_{k' \in \mathbf{K^L}} \eta_{k',f}\right)^2$
2.447 (1.530)	−0.083 (17.924)	0.755 (9.757)	−0.513 (3.842)	−1.321 (3.524)	−0.515 (5.078)	0.076 (3.854)

Table 5: Acquisition CCP: Coefficients on the covariates related to the target acquisition format.

$\sum_{f' \neq f} \eta_{f',k}$	$\sum_{f' \neq f} \eta^2_{f',k}$
5.116	−1.224
(9.876)	(8.252)
$\left(\sum_{f' \neq f} \eta_{f',k}\right)^2$	$\sum_{k' \in \mathbf{K^N} \setminus k, f' \neq f} \eta_{k',f'}$
−0.353	−0.131
(5.247)	(4.912)
$\left(\sum_{k' \in \mathbf{K^N} \setminus k, f' \neq f} \eta_{k',f'}\right)^2$	$\sum_{k' \in \mathbf{K^N} \setminus k} \left(\sum_{f' \neq f} \eta_{k',f'}\right)^2$
−1.999	4.618
(3.845)	(0.940)
$\sum_{f' \neq f} \left(\sum_{k' \in \mathbf{K^N} \setminus k} \eta_{k',f'}\right)^2$	
−4.306	
(2.009)	

Table 6: Acquisition CCP: Coefficients on the covariates related to formats other-than-those of the acquiree.

Name	Pop. 2007	Intercept	Name	Pop. 2007	Intercept
Los Angeles, CA	13155.1	0.2324 (0.02413)	Omaha-Council Bluffs, NE-IA	740.3	0.0255 (0.00265)
Chicago, IL	9341.4	0.1138 (0.01182)	Knoxville, TN	737.4	0.0153 (0.00158)
Dallas-Ft. Worth, TX	5846.9	0.0924 (0.00959)	El Paso, TX	728.2	0.0797 (0.00827)
Houston-Galveston, TX	5278.5	0.0695 (0.00721)	Harrisburg-Lebanon-Carlisle, PA	649.4	0.0343 (0.00356)
Atlanta, GA	4709.7	0.0512 (0.00531)	Little Rock, AR	618.7	0.0074 (0.00077)
Boston, MA	4531.8	0.0941 (0.00977)	Springfield, MA	618.1	0.0098 (0.00102)
Miami-Ft. Lauderdale-Hollywood, FL	4174.2	0.1223 (0.01270)	Charleston, SC	597.7	0.0071 (0.00074)
Seattle-Tacoma, WA	3775.5	0.1137 (0.01181)	Columbia, SC	576.6	0.0105 (0.00109)
Phoenix, AZ	3638.1	0.0577 (0.00599)	Des Moines, IA	576.5	0.0046 (0.00048)
Minneapolis-St. Paul, MN	3155	0.0692 (0.00718)	Spokane, WA	569.1	0.0123 (0.00128)
St. Louis, MO	2688.5	0.0214 (0.00222)	Wichita, KS	563.9	0.0144 (0.00150)
Tampa-St. Petersburg-Clearwater, FL	2649.1	0.0768 (0.00797)	Madison, WI	539.5	0.0237 (0.00247)
Denver-Boulder, CO	2603.5	0.0686 (0.00712)	Ft. Wayne, IN	520	0.0077 (0.00080)
Portland, OR	2352.2	0.1153 (0.01197)	Boise, ID	509.9	0.0240 (0.00249)
Cleveland, OH	2133.8	0.0504 (0.00523)	Lexington-Fayette, KY	509	0.0050 (0.00052)
Charlotte-Gastonia-Rock Hill, NC-SC	2126.7	0.0279 (0.00289)	Augusta, GA	498.4	0.0024 (0.00025)
Sacramento, CA	2099.6	0.0415 (0.00431)	Chattanooga, TN	494.5	0.0077 (0.00080)
Salt Lake City-Ogden-Provo, UT	1924.1	0.0269 (0.00279)	Roanoke-Lynchburg, VA	470.7	0.0038 (0.00039)
San Antonio, TX	1900.4	0.0540 (0.00560)	Jackson, MS	468.6	0.0011 (0.00011)
Kansas City, MO-KS	1870.8	0.0432 (0.00448)	Reno, NV	452.7	0.0155 (0.00161)
Las Vegas, NV	1752.4	0.0710 (0.00737)	Fayetteville, NC	438.9	0.0060 (0.00063)
Milwaukee-Racine, WI	1712.5	0.0217 (0.00225)	Shreveport, LA	399.6	0.0018 (0.00019)
Orlando, FL	1686.1	0.0537 (0.00558)	Quad Cities, IA-IL	358.8	0.0115 (0.00119)
Columbus, OH	1685	0.0119 (0.00123)	Macon, GA	337.1	0.0022 (0.00023)
Indianapolis, IN	1601.6	0.0184 (0.00191)	Eugene-Springfield, OR	336.4	0.0137 (0.00142)
Norfolk-Virginia Beach-Newport News, VA	1582.8	0.0173 (0.00179)	Portland, ME	276.1	0.0112 (0.00116)
Austin, TX	1466.3	0.0812 (0.00842)	South Bend, IN	267	0.0226 (0.00234)
Nashville, TN	1341.7	0.0488 (0.00506)	Lubbock, TX	255.3	0.0271 (0.00281)
Greensboro-Winston Salem-High Point, NC	1328.9	0.0185 (0.00193)	Binghamton, NY	247.9	0.0041 (0.00043)
New Orleans, LA	1293.7	0.0195 (0.00202)	Odessa-Midland, TX	247.8	0.0040 (0.00042)
Memphis, TN	1278	0.0045 (0.00047)	Yakima, WA	231.4	0.0099 (0.00103)
Jacksonville, FL	1270.5	0.0112 (0.00116)	Duluth-Superior, MN-WI	200.3	0.0123 (0.00127)
Oklahoma City, OK	1268.3	0.0119 (0.00123)	Medford-Ashland, OR	196.2	0.0076 (0.00079)
Buffalo-Niagara Falls, NY	1150	0.0401 (0.00417)	St. Cloud, MN	191.2	0.0100 (0.00104)
Louisville, KY	1099.6	0.0311 (0.00322)	Fargo-Moorhead, ND-MN	183.6	0.0150 (0.00155)
Richmond, VA	1066.4	0.0082 (0.00085)	Abilene, TX	159.1	0.0059 (0.00061)
Birmingham, AL	1030	0.0104 (0.00108)	Eau Claire, WI	156.5	0.0061 (0.00063)
Tucson, AZ	938.3	0.0317 (0.00329)	Monroe, LA	149.2	0.0054 (0.00056)
Honolulu, HI	909.4	0.0311 (0.00323)	Parkersburg-Marietta, WV-OH	149.2	0.0049 (0.00051)
Albany-Schenectady-Troy, NY	902	0.0323 (0.00335)	Grand Junction, CO	130	0.0091 (0.00094)
Tulsa, OK	870.2	0.0137 (0.00142)	Sioux City, IA	123.7	0.0119 (0.00123)
Ft. Myers-Naples-Marco Island, FL	864.1	0.0712 (0.00739)	Williamsport, PA	118.3	0.0036 (0.00037)
Grand Rapids, MI	856.4	0.0124 (0.00129)	San Angelo, TX	103.8	0.0057 (0.00059)
Albuquerque, NM	784.9	0.0614 (0.00638)	Bismarck, ND	99.2	0.0024 (0.00025)
Omaha-Council Bluffs, NE-IA	740.3	0.0255 (0.00265)			()

Standard errors (corrected for the first stage) in parentheses

*** p¡0.01, ** p¡0.05, * p¡0.1

Table 7: Fixed cost of owning one station in each market (half-yearly, millions USD).

Number of stations owned in the format in the local market	1	2	3	4	5
Fixed cost discount	1.000 (–)	0.862*** (0.034)	0.790*** (0.064)	0.743*** (0.058)	0.708*** (0.049)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1, one-tail test

Table 8: Fixed cost: Table contains estimates of discounts to fixed cost resulting from local cost synergies of owning multiple stations in the same format.

Number of stations owned local market	1	2	3	4	5	National
Fixed cost discount	1.000 (–)	0.863** (0.063)	0.791** (0.120)	0.744*** (0.109)	0.709*** (0.092)	0.963 (0.178)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1, one-tail test

Table 9: Fixed cost: Table contains estimates of within- and cross-market economies of scale. The number reflects the per-station discount.

	Mean		Standard deviation	
	Intercept	Variable profits	Intercept	Variable profits
Category 1	7.203*** (1.374)	2.653*** (0.653)	2.039*** (0.290)	0.086 (0.091)
Category 2	3.917*** (0.720)		1.030*** (0.151)	
Category 3	3.724*** (0.793)		0.950*** (0.177)	
Category 4	2.061*** (0.424)		0.510*** (0.095)	

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1, two-tail test

Table 10: Estimates of the acquisition cost (in millions USD). The table contains an intercept of the mean and standard deviation of the acqusition distribution. It includes market-size fixed effects (relative to the smallest category) and a coefficient on the static variable profits of an acquistion target.

Owner	Source format	Mean				Std. deviation	
		Target format			Variable	Intercept	Variable
		Adult Music	Hits Music	Non-Music	profit		profit
National	Adult Music	-	18.799*** (1.863)	18.088*** (1.732)	2.084 (1.842)	3.654*** (0.330)	0.069 (0.329)
	Hits Music	14.723*** (1.419)	-	17.757*** (1.732)			
	Non-Music	16.125*** (1.568)	21.194*** (2.099)	-			
Local	Adult Music	-	18.828*** (1.819)	13.665*** (1.306)			
	Hits Music	10.791*** (1.121)	-	10.443*** (1.104)			
	Non-Music	17.160*** (1.606)	22.076*** (2.115)	-			

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1, two-tail test

Table 11: Market category 1: Estimates of format-switching costs (in millions USD). The table contains to-from format fixed effects for local and national owners.

	All years	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Pseudo R^2 constant probabilities	0.10	0.07	0.11	0.12	0.12	0.11	0.09	0.08	0.09	0.08	0.10
Pseudo R^2 year dummies	0.08	0.05	0.11	0.11	0.10	0.07	0.10	0.05	0.09	0.07	0.08

Table 12: Pseudo R^2 measures for the first stage estimation, defined as $1 - \frac{\log(\text{likelihood of a full model})}{\log(\text{likelihood of a benchmark model})}$. I use two benchmark models: (i) a model with a constant probability of acqisition and repositioning (2 parameters), (ii) a model with time dummies (20 parameters). The former R^2 measure avaluates a general goodness of fit, the latter investigates to which degree a non-stationary model would fit the data better.

Counterfactual regime		Total producer surplus	Variable profits	Fixed cost	Listener surplus	Advertiser surplus
Pre-1996 local caps	5 years	-4.44 (2.30%)	-2.62 (1.36%)	1.82 (0.94%)	0.00 (0.00%)	-0.89 (0.21%)
Pre-1996 local caps	10 years	-9.63 (4.87%)	-5.67 (2.87%)	3.97 (2.00%)	-0.04 (0.01%)	-0.63 (0.15%)
Pre-1996 local caps	20 years	-20.95 (10.13%)	-12.38 (5.99%)	8.57 (4.15%)	-0.21 (0.07%)	7.28 (1.73%)
Pre-1996 local caps No cross-market ownership	5 years	-4.32 (2.24%)	-2.62 (1.36%)	1.70 (0.88%)	-0.02 (0.01%)	-0.75 (0.18%)
Pre-1996 local caps No cross-market ownership	10 years	-9.37 (4.74%)	-5.62 (2.84%)	3.75 (1.89%)	-0.08 (0.03%)	-0.44 (0.10%)
Pre-1996 local caps No cross-market ownership	20 years	-20.41 (9.88%)	-12.24 (5.92%)	8.18 (3.96%)	-0.27 (0.09%)	7.37 (1.75%)

Table 13: Impact of different enforcement regimes on producer (half-yearly, millions USD), listener (day-minutes of advertising per listener; listener surplus cannot be easily expressed in dollars because there are no dollar transfers between listeners and radio station owners), and advertiser surplus (half-yearly, millions USD), cumulative in the 88 markets. The table reports differences between simulated future states using the equilibrium merger and repositioning strategies for the counterfactual and observed regimes. A positive number means that the counterfactual regime yields a higher value.

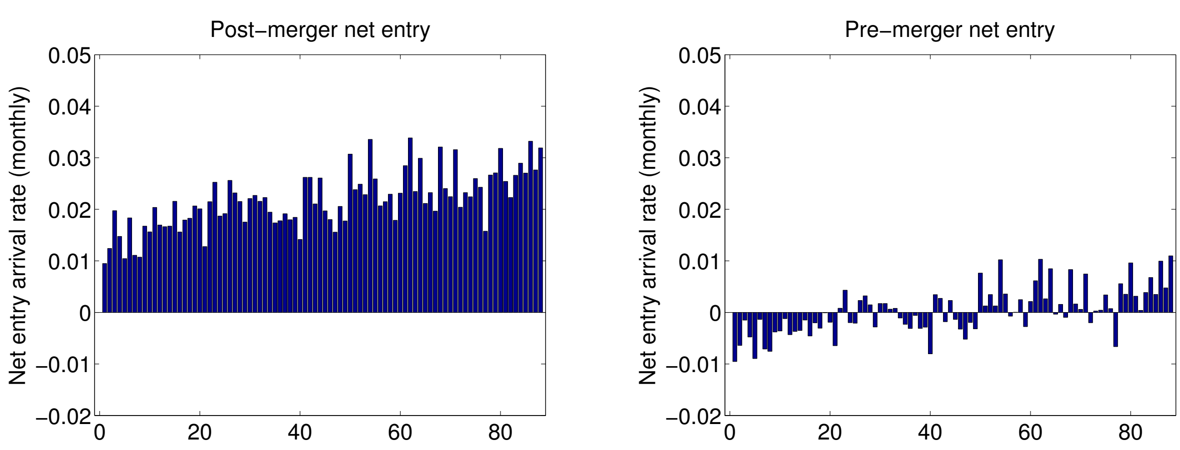

Figure 1: Post- and pre-merger net entry rates by market. Markets are sorted by population, from the smallest (Bismark) to the largest (Los Angeles).

Counterfactual regime		Total producer surplus	Variable profits	Fixed cost	Listener surplus	Advertiser surplus
Cap of 7	5 years	2.21 (1.14%)	1.66 (0.86%)	-0.55 (0.28%)	-0.03 (0.01%)	0.91 (0.22%)
Cap of 7	10 years	4.44 (2.24%)	3.18 (1.61%)	-1.26 (0.64%)	-0.00 (0.00%)	-1.20 (0.28%)
Cap of 7	20 years	8.59 (4.16%)	5.90 (2.86%)	-2.69 (1.30%)	0.03 (0.01%)	-3.71 (0.88%)
Cap of 7 Myopic Listener Surplus Criterion	5 years	0.59 (0.30%)	0.55 (0.28%)	-0.04 (0.02%)	0.05 (0.02%)	0.42 (0.10%)
Cap of 7 Myopic Listener Surplus Criterion	10 years	1.70 (0.86%)	1.20 (0.61%)	-0.50 (0.25%)	0.07 (0.02%)	-0.51 (0.12%)
Cap of 7 Myopic Listener Surplus Criterion	20 years	4.65 (2.25%)	2.80 (1.36%)	-1.85 (0.89%)	0.08 (0.03%)	-2.58 (0.61%)
Cap of 7 Myopic Advertiser Surplus Criterion	5 years	1.72 (0.89%)	1.16 (0.60%)	-0.56 (0.29%)	-0.07 (0.02%)	0.53 (0.13%)
Cap of 7 Myopic Advertiser Surplus Criterion	10 years	3.58 (1.81%)	2.25 (1.14%)	-1.33 (0.67%)	-0.10 (0.03%)	0.44 (0.10%)
Cap of 7 Myopic Advertiser Surplus Criterion	20 years	6.76 (3.27%)	4.12 (1.99%)	-2.64 (1.28%)	-0.05 (0.02%)	-3.25 (0.77%)

Table 14: Impact of increasing FM local ownership cap to 7 stations on producer (half-yearly, millions USD), listener (day-minutes of advertising per listener), and advertiser surplus (half-yearly, millions USD), cumulative in the 88 markets. The table reports differences between simulated future states using the equilibrium merger and repositioning strategies for the counterfactual and observed regimes. A positive number means that the counterfactual regime yields a higher value.

B Formulation using conditional choice probabilities

In order to apply an existence result from Doraszelski and Judd (2012), the game needs to be recast as one with continuous actions, which can be done by noting that choosing actions after observing payoff shocks $\zeta_k^{A,t}$ or $\zeta_k^{B,t}$ is mathematically equivalent to choosing the conditional choice probabilities (CCP) of actions (see Magesan and Aguirregabiria (2013)).

Let $\text{CCP}_k^A(a|\mathcal{J})$ be an ex-ante probability of company k acquiring a company k' conditional on the arrival of a merger opportunity. Similarly, define $\text{CCP}_k^R(r|\mathcal{J})$ to be an ex-ante probability of repositioning from f to f'. After a small adjustment to continuous time, the results contained in the proof of Theorem 1 from Hotz and Miller (1993) apply for this model. Following the notation in that paper, consider the expectation of $\zeta_k^{A,t}$, when the optimal action conditional on arrival of the right to merge at state $\mathcal{J}^t$ is

$$W_a^A(\text{CCP}_k^A, \mathcal{J}^t) = E[\zeta_k^{A,t}|\mathcal{J}^t, a_k^t = a].$$

A similar expression can be written for the repositioning action:

$$W_r^R(\text{CCP}_k^R, \mathcal{J}^t) = E[\zeta_k^{R,t}|\mathcal{J}^t, r_k^t = r].$$

The above expressions are equal to 0 if no action occurs. The key fact is that these expectations can be expressed as functions of CCPs. Hotz and Miller (1993) established this result for single-agent discrete-time models, and their proof can be repeated with minor adjustments for the continuous-time game studied in this paper. Subsequently, maximizing the value function with discrete choices is equivalent to solving the following Bellman equation with continuous actions:

$$\begin{aligned}
\rho V_k(\mathcal{J}) = \max_{\text{CCP}_k^A, \text{CCP}_k^R} \Bigg\{ & \pi_k(\mathcal{J}) - F_k(\mathcal{J}) - \left(\lambda_k^A(\mathcal{J}) + \sum_{k=1}^{K} \lambda_k^R(\mathcal{J})\right) V_k(\mathcal{J}) - \\
& \lambda_k^A(\mathcal{J}) \left[\sum_{a \in \Gamma_k^A(\mathcal{J})} \text{CCP}_k^A(a) \Big(V_k(\mathcal{J}'(k,a)) - V_a(\mathcal{J}) + W_a^A(\text{CCP}_k^A, \mathcal{J}) \Big) \right] + \\
& \lambda_k^R(\mathcal{J}) \left[\sum_{r \in \Gamma_k^R(\mathcal{J})} \text{CCP}_k^R(r) \Big(V_k(\mathcal{J}'(k,r)) - V_{a'}(\mathcal{J}) + W_r^R(\text{CCP}_k^R, \mathcal{J}) \Big) \right] + \\
& \sum_{k' \neq k} \lambda_{k'}^A(\mathcal{J}) \sum_{a \in \Gamma_{k'}^A(\mathcal{J})} \text{CCP}_{k'}^A(a) V_k(\mathcal{J}'(k',a)) + \\
& \sum_{k' \neq k} \lambda_{k'}^R(\mathcal{J}) \sum_{r \in \Gamma_{k'}^R(\mathcal{J})} \text{CCP}_{k'}^R(r) V_k(\mathcal{J}'(k',r)) \Bigg\},
\end{aligned} \tag{B.1}$$

where $\mathcal{J}'(k,k')$ is the future industry state after k,k' merger and $\mathcal{J}'(k,r)$ is the future industry state after company k takes a repositioning action r. Using this formulation, one can directly apply the existence result from Doraszelski and Judd (2012).

Equation B.1 can be used to compute the equilibrium of the game, and the algorithm has relatively low computational requirements. Suppose the idiosyncratic parts of the payoff shocks, as defined in equations (3.1) and (3.2), have the following structure: $\epsilon_k^{A,t}(a) = \tilde{\epsilon}_k^{A,t}(a) - \tilde{\epsilon}_k^{A,t}(0)$ and $\epsilon_k^{R,t}(r) = \tilde{\epsilon}_k^{R,t}(r) - \tilde{\epsilon}_k^{R,t}(0)$, where $\tilde{\epsilon}$s have IID type-1 extreme value distributions (recall that if no action occurs, $\epsilon_k^{A,t}(0) = 0$ and $\epsilon_k^{R,t}(0) = 0$). Then the optimal merger CCPs are given by a closed-form formula,

$$\text{CCP}_k^A(a|\mathcal{J}) = \frac{\exp\left\{\sigma_k^A(\mathcal{J},a)^{-1}\left[V_k(\mathcal{J}'(k,a)) - V_a(\mathcal{J}) + \mu_k^A(\mathcal{J},a)\right]\right\}}{\sum_{a' \in \Gamma_k^A(\mathcal{J})} \exp\left\{\sigma_k^A(\mathcal{J},a')^{-1}\left[V_k(\mathcal{J}'(k,a')) - V_{a'}(\mathcal{J}) + \mu_k^A(\mathcal{J},a')\right]\right\}}, \tag{B.2}$$

where V_a is the value function of the acquiree (equilibrium acquisition price) and μ_k^A is the persistent part of the acquisition payoff shock defined in (3.1). Repositioning CCPs are given by the following formula:

$$\text{CCP}_k^R(r|\mathcal{J}) = \frac{\exp\left\{\sigma_k^R(\mathcal{J},r)^{-1}\left[V_k(\mathcal{J}'(k,r)) + \mu_k^R(\mathcal{J},r)\right]\right\}}{\sum_{r' \in \Gamma_k^R(\mathcal{J})} \exp\left\{\sigma_k^R(\mathcal{J},r')^{-1}\left[V_k(\mathcal{J}'(k,r')) + \mu_k^R(\mathcal{J},r')\right]\right\}}. \tag{B.3}$$

The computational algorithm involves iterating on the value function using a Bellman equation (B.1) and equations (B.2) and (B.3). The procedure can be summarized as follows:

Initialization: Initialize the value function $V^{(0)}$.

(1) For every state $\mathcal{J}$,

(i) use $V^{(j)}$ to compute the CCPs of all players at $\mathcal{J}$, given by equations (B.2) and (B.3),

(ii) use the CCPs from (i) to obtain a new value function $V^{(j+1)}(\mathcal{J})$ by iterating a Bellman equation (B.1).

(2) Stop if $\|V^{(j)} - V^{(j+1)}\| <$ tolerance; otherwise, go to stage (1).

Several features of this algorithm facilitate the computation of large games. Primarily, iteration steps (i) are (ii) are relatively cheap because the integration in the Bellman equation is done on a player by player basis, instead of jointly (see discussion in Doraszelski and Judd (2012)). Therefore, its complexity does not grow exponentially but only linearly, as the number of active players increases. Additionally, best response CCPs depend on strategies of other players only through the value functions. In such a case, one does not need to remember a full set of CCPs at every state. Note that storing all CCPs in a reasonable amount of memory might be infeasible if the action space has large support (large support is frequently needed to match the data). Also, because only one player changes state at each instant, the state transitions $\mathcal{J}'(k,a)$ and $\mathcal{J}'(k,r)$ are relatively simple. Therefore, state encoding and decoding routines (which can take up to 60%-70% of the execution time depending on the problem) can be replaced with look-up tables. Lastly, a closed-form of conditional expectations $W_a^A(\mathrm{CCP}_k^A, \mathcal{J}^t)$ and $W_r^R(\mathrm{CCP}_k^R, \mathcal{J}^t)$ for more than two feasible actions is unknown. Instead, these expectations must be simulated (see section 5 for details).

C Time aggregation

The time aggregation is performed in steps. I will demonstrate the steps using a simple example contained at Figure 2. In this example

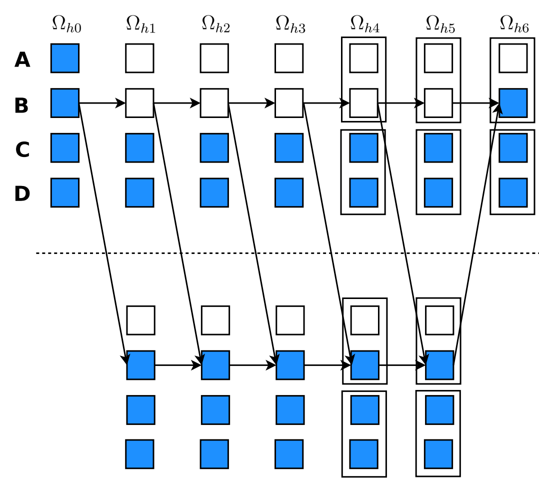

Figure 2: Feasible industry paths for a simple example with one repositioning event and two merger events.

there is one reposiotioning event and two merger events. The merger events happen during month 4 and the repositioning event happens some time between month 1 and month 6. First, I construct a set of feasible intermediate states during the half year h and denote it by Ω^h. This set contains the feasible latent states that do not contradict the observed data and a coffin state. Denote a set of feasible states at the end of month i by $\Omega^{hi} \subset \Omega^h$. States in Ω^{hi} incorporate all mergers that happened prior to and including month i, that is, $\{a^{hd} : d \leq i\}$, as well as any possible subset of repositioning events b^h that occurred during half-year h. At the simple example each end of the month month has only two feasible latent states, however the number of these sets grows quickly as the number of repositioning events increases. The special cases are: Ω^{h0}, which contains only the fully observed starting state at the beginning of a half-year h, and Ω^{h6}, which contains only the fully observed state at the end of half-year h. Apart from the states in Ω^{hi}, the set Ω^h contains all transitory states, between any states in Ω^{hi} and Ω^{hi+1}. For the simple example, the transitory states are presented in Figure 3. In particular, it is possible that upper merger happens before lower merger, and vice versa. It is also possible that repositioning happens at any point before, in between and after both mergers. The computation of the transitory states that determine feasible paths of the

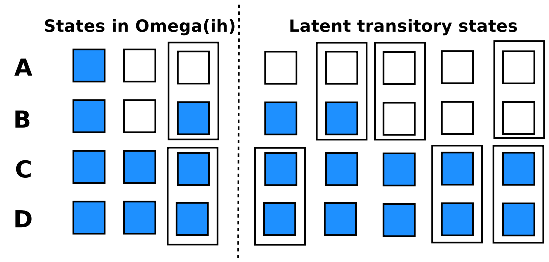

Figure 3: Feasible and transitory states for a simple example with one repositioning event and two merger events.

industry becomes quite budernsome if many mergers and repositionings happen in a particular half-year. For example, a computation of feasible paths for seven mergers and three repositioning events within a one half-year period can take up to a week and require up to 40GB of memory to store the temporary data (Matlab code on 2GHz AMD Opteron CPU). The exercise in this study is feasible because the process was parallelized. Despite a long preparation time, this computation must be done only once for each data set. The benefit of the this process is that the final augmented state space, Ω^h, is thousands times smaller than the full state, which dramatically reduces the size of the intensity matrix.

Upon arrival of the merger and repositioning actions at time t, the equilibrium strategies induce transitions according to instantaneous conditional choice probabilities of acquisition $\mathrm{CCP}^A(\mathcal{J}^t)$ or repositioning $\mathrm{CCP}^R(\mathcal{J}^t)$. Together with action arrival rates λ^A and λ^R, these CCPs generate an intensity matrix Q^h on the augmented state space Ω^h. The overall goal is to use the Markov process on Ω^h to compute the conditional likelihood of the data, that is, $L(\Omega^{h6}, \ldots, \Omega^{h1}|\Omega^{h0})$. The exact states from Ω^{hi} (expect for the beginning and the end of the half-year) as well as transitory states between the Ω^{hi}s are unobserved by the econometrician and must be integrated out.

Denote the time that passed since the beginning of h by $s \in [0, 6]$, and let $\iota^h(s)$ be a stochastic process of the latent state of the system conditional on $\{\Omega^{hi} : i < s\}$. Conditioning prevents the $\iota^h(s)$ from contradicting the data by eliminating the infeasible paths. Note that $\iota^h(0)$ is a degenerate distribution at Ω^{h0}. First, I compute the distribution after the initial month, $\iota^h(1)$, by numerically solving a Chapman-Kolmogorov system of differential equations

$$\frac{d\iota^h(s)}{ds} = \iota^h(s) Q^h, \tag{C.1}$$

subject to the initial condition of $\iota^h(0)$ being degenerate at Ω^{h0}. Knowing $\iota^h(1)$, I can obtain $L(\Omega^{h1}|\Omega^{h0})$ by taking the mass of states that belong to Ω^{h1}. The next step is obtaining $L(\Omega^{h2}|\Omega^{h1}, \Omega^{h0})$.[18] For this purpose, I compute $\iota^h(2)$ by solving equation (C.1) with

[18]Note that $L(\Omega^{h2}|\Omega^{h1}, \Omega^{h0}) \neq L(\Omega^{h2}|\Omega^{h1})$ even though the latent state ω^{hi} is Markovian, because Ω^{h1} is a set, and the value of Ω^{h0} is informative about the distribution of the latent states in Ω^{h1}.

$\iota^h(1)$ conditioned on Ω^{h1} used as an initial condition. The likelihood is the mass of the set Ω^{h2} obtained according to $\iota^h(2)$. By repeating the procedure, we can obtain any of $L(\Omega^{hi}|\Omega^{hi-1},\ldots,\Omega^{h1},\Omega^{h0})$, and as a result, I get the joint likelihood $L(\Omega^{h6},\ldots,\Omega^{h1}|\Omega^{h0})$ by using Bayes rule. By repeating the procedure for every h the expected likelihood of the data is obtained.

D Value function simulation details

The value function at $\mathcal{J}^s$ can be decomposed into four components according to

$$V_k = V^{(\pi)} + V^{(P)} + V^{(F)} + V^{(A)} + V^{(R)},$$

where

$$\begin{aligned}
V_k^{(\pi)} &= \int_{s=t}^{\infty} e^{-\rho s}\pi_k(\mathcal{J}^s)ds,\\
V_k^{(F)} &= -\int_{s=t}^{\infty} e^{-\rho s}F_k(\mathcal{J}^s|\theta)ds,\\
V_k^{(A)} &= \sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}} W^A_{a_k^{(l)}}(\mathrm{CCP}^A_k, \mathcal{J}^{\tau_k^{A,(l)}}|\theta),\\
V_K^{(R)} &= \sum_{m=1}^{\infty} e^{-\rho\tau_k^{R,(m)}} W^R_{r_k^{(l)}}(\mathrm{CCP}^R_k, \mathcal{J}^{\tau_k^{R,(m)}}|\theta),\\
V_k^{(P)} &= \sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}} - P(a_k^{(l)}, \mathcal{J}^{\tau_k^{A,(l)}}|\theta).
\end{aligned}$$

Each of these components can be expressed as a linear function of parameters θ and sufficient statistics about the simulated industry paths $\hat{\mathcal{J}}^{s,r}$ for $r = 1,\ldots,1000$. I discuss all components below.

The first component $V_k^{(\pi)}$ does not depend on dynamic parameters, so the sufficient statistic is simply an average of all draws, and the second component $V_k^{(F)}$ is a discounted sum of fixed costs. The sufficient statistic to compute this cost is a matrix

$$\mathrm{SIM}^F(f,x,y) = \int_{s=t}^{\infty} e^{-\rho s}\mathbf{1}(\omega^s_{kf} = x, n^s_k = y)ds.$$

Fixed cost can be obtained using

$$V_k^{(F)} = \sum_{f=1}^{F} \bar{F}^m_f \sum_{x,y} \mathrm{SIM}^F(f,x,y)F^S(x|\theta^F)F^E(y|\theta^E).$$

The third component consist of sum of discounted acquisition shocks, and it can be decomposed into

$$\begin{aligned}
V_k^{(A)} = \theta^{A,m}\sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}} + \theta^A_\pi \sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}}\pi_k(\mathcal{J}^{\tau_k^{A,(l)}}) + \\
\theta^{A,m}_\sigma \sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}} E[\epsilon^A(k')|a_k^{(l)}] + \theta^{A,m}_{\sigma,\pi}\sum_{l=1}^{\infty} e^{-\rho\tau_k^{A,(l)}}\pi_k(\mathcal{J}^{\tau_k^{A,(l)}})E[\epsilon^A(k')|a_k^{(l)}].
\end{aligned}$$

In such a case, I need four sufficient statistics to evaluate this part of the value function. One can similarly decompose the fourth component and obtain nine sufficient statistics. An extra five statistics come from the fact that I allow six different means of repositioning cost depending on the source and target format.

The last component is the sum of discounted acquisition spending. To obtain this figure, I make use of the fact that the acquisition price $P(a_k^{(l)}|\mathcal{J}^t,\theta)$ is equal to the value function of the acquiree conditional on rejecting every equilibrium merger offer. Thus, obtaining an acquisition price is the same as simulating a value function for the fringe firm. Such a value function contains three of the above terms, namely, $V_k^{(\pi)}$, $V_k^{(F)}$, and $V_k^{(R)}$, which are simulated using the aforementioned sufficient statistics in the nested loop.