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Dedication

To my parents, Dave and Vicki Gordon, who did a good enough job that I can sincerely say all remaining errors are my own.

To Simona, who inspires me to finish things in finite time.

To my wife Julia, to whom everything is dedicated.

ABSTRACT

This dissertation is composed of two essays. The first examines the problem of predatory pricing in the airline industry through the lens of a widely discussed predation case. The second examines the incentives of banks to misreport borrowing costs in their reports to the survey that determines the LIBOR benchmark interest rates. While the applications differ dramatically, there is a unifying theme. Regulation, antitrust, and the design of market institutions in general all face the problem of not being able to observe all of the determinants of the choices made by market participants. Evaluation of the performance of these institutions, by necessity, can only rely on a few observable variables such as prices and number of seats in airline markets or bank quotes in the LIBOR survey. These goal of these essays is to utilize the tools of economic theory and econometrics to infer the the unobserved determinants of these choices and, in turn, use this inference to evaluate the performance of two important market institutions.

In the first essay, I estimate a model of competition in the airline industry to think about predatory pricing in the industry. Two major issues have led courts and antitrust enforcers to take a highly skeptical view when assessing claims of anticompetitive predation. First, predation is an inherently dynamic and strategic phenomenon but the practical tools available to identify predatory behavior are based on a static, competitive view of markets. Second, there is understandable concern about the potential distortionary implications of punishing firms for competing too intensely. This paper analyzes these problems in the context of the U.S. airline industry, where there have been frequent allegations of predatory conduct. I first argue, via an explicit dynamic industry model, that certain features of the industry do make it fertile ground for predatory incentives to arise. Specifically, differences in cost structures between large, hub and spoke carriers and small, low cost carriers give incentives for the large carriers to respond aggressively to low cost carriers. I estimate the model parameters and use it to quantify the welfare and behavioral implications of predation policy for a widely discussed case: U.S. vs. American Airlines (2000). To do this, I solve and simulate the model under a menu of counterfactual antitrust predation policies, similar to those employed in practice. I

find, for the example of the American case, the potential problems of predation policy are not as severe as the problem of predatory behavior itself.

The second essay analyzes data on bank level quotes in the LIBOR survey to investigate the possibility that banks misreport their true costs. The London Interbank Offered Rate (Libor) is an important financial index and is referenced by hundreds of trillions of dollars worth of contracts. Concern has arisen that the Libor, which is intended to measure the interbank borrowing costs of large banks, has been too low during the financial crisis. We document several problems with the hypothesis that banks are truthfully quoting their borrowing costs to the Libor survey. We also show that quotes tend to cluster around discontinuities involved in the Libor's construction, which is predicted by a model where banks take into consideration their portfolios of Libor-indexed contracts when submitting their quotes to determine the overall Libor. We then present suggestive evidence that several banks have large exposures to the Libor through their interest rate derivative portfolios and have recently profited from the rapid descent of the Libor.

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Introduction

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Chapter 2

Predatory Incentives and Predation Policy: The American Airlines Case

2.1 Introduction

In May of 2000 the U.S. Department of Justice (DOJ) sued American Airlines alleging it engaged in anticompetitive, predatory behavior in four markets out of American's primary hub at Dallas-Fort Worth International Airport.[1] In each of these markets, American had responded to the entry of a small "low cost" rival with aggressive capacity additions and fare cuts. The DOJ argued these aggressive responses 1) represented sacrifices of short run profits that 2) were to be recouped through increased monopoly power after the rivals had exited the market; the two necessary elements of proving a predation claim. The court found the DOJ's sacrifice argument unconvincing and dismissed the case.

The ruling in the American case is representative of the prevailing skepticism among courts and antitrust agencies regarding predation claims.[2] This skepticism reflects, first, the high cost of false positives. Firms are accused of predatory conduct after

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[1] United States of America v. AMR Corporation, American Airlines, Inc., and American Eagle Holding Corporation. 140 F. Supp. 2d 1141 (2001).

[2] The ruling was upheld on appeal. United States v. AMR Corp., 335 F. 3d 1109 (10th Cir. 2003)

they are perceived to have offered consumers deals that were *too good* in hopes of driving competitors out of business and increasing markups. The expected welfare loss of uncertain monopolization is mitigated by the current certain welfare gain. More importantly, any attempt to implement a policy preventing this type of behavior risks "chilling the very behavior antitrust laws were designed to encourage".[3]

The high cost of false positives is compounded by the lack of tests, grounded in appropriate economic theory, with which to distinguish predatory behavior from legitimate competition. Predation has long been recognized as a dynamic and strategic phenomenon (Bork 1978) and, while modern strategic theory has discovered plausible mechanisms for rational predatory behavior, it has, for the most part, not delivered the tools that would allow these theories to be implemented in the analysis of real market data (Bolton, Brodley, and Riorden 2003 is an exception).[4] In the absence of these tools, most courts have been forced to rely on static, competitive, cost-based tests to decide cases. The most prominent example of such tests is the "Areeda-Turner" rule, which finds predatory liability when a firm is found to have priced below a measure of marginal cost.

This paper quantifies the behavioral and welfare implications of a menu of typical predation policies for the American Airlines case. I focus on empirically assessing the impact of policy for a single market: Dallas-Fort Worth to Wichita, one of the markets in which the DOJ alleged predation against American. Focusing on a single market allows for more direct comparison with actual practice. Moreover, analyzing a market from an actual case makes the analysis more practically relevant since this is a market chosen by the U.S. government as an example of one that requires intervention. Also, rather than searching for optimal antitrust policy, I instead focus my analysis on evaluating the efficacy of static cost based tests of liability and the chilling effect of proposed remedies.

To assess the implications of predation policy, I proceed in three steps. First, I introduce a dynamic model of price and capacity competition in the airline industry. In the model, cost asymmetries among firms give rise to behavior that is predatory in the sense that it is motivated, in part, by incentives to drive a rival from the market.

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[3] *Matsushita Electric Industrial Co., v. Zenith Radio* (1986) 106 S. Ct. 1348-1367.

[4] There is a large literature exploring predation as an equilibrium phenomenon. Examples include Milgrom and Roberts (1983) , Saloner (1989) , Fudenberg and Tirole (1990) , Bolton and Scharfstein (1990) .

Second I develop an estimation strategy to recover the parameters of the game for the Dallas Wichita market. To do this, I construct a sample of Dallas-Fort Worth markets and firms and assume the data in these markets is generated by equilibrium of the same game, conditional on observable variables, as the one being played in Wichita. I then exploit a revealed preference argument to recover the parameters that rationalize observed behavior as an equilibrium of the game. Third, I use the estimated parameters to solve and simulate equilibrium in the Wichita market under various predation policy regimes.

Predation is an investment of short run profits, through intensified competition, where the expected returns come in the form of future increased pricing power, through elimination of competitors. It is therefore a dynamic decision and any account of equilibrium predation requires two components reflecting this fact. The first is a mechanism through which the firm may cause the exit of rivals and earn a return on the investment. If a potential predator is unable to affect the decisions of its rivals then the marginal value of investment is zero. The second is a mechanism through which the investment can be made. If periods are not linked over time through firm decisions then competing aggressively today can not affect behavior in the future.

In the airline industry, entry of a new firm into a market is often met with aggressive fare cutting and capacity expansion by incumbents. This has led to frequent allegations of predation in the industry. The scenario that has aroused concern among industry regulators and antitrust enforcers has involved the entry of small a small low cost carrier into a route dominated by a hub and spoke incumbent, as in the American case. The approach to predation taken in this paper focuses on how fundamental asymmetries between these two types of carriers affect the dynamics of competition and lead to predatory incentives. Specifically, I focus on differences in marginal and fixed costs between the two types. Low cost carriers have lower variable and marginal costs because they offer fewer service amenities and have lower labor costs and generally leaner operations. Hub carriers have lower avoidable fixed costs due to previous sunk investments in building a large route network and the ability to allocate fixed costs over the large network. I also allow differences in the costs of moving capacity in and out of a route to play a role. These differences may arise due to differences in route and network size and differences in financial position.

The basic theoretical model I introduce is similar to the models of capacity constrained competition of Besanko and Doraszelski (2005) and Besanko, Doraszelski, Lu, and Satterthwaite (2008), which are themselves variants of the Erickson and Pakes (1995) framework. I assume carriers compete by setting prices for differentiated products, reflecting the conventional wisdom that low cost carriers offer inferior flight quality relative to full service hub carriers. Firms face capacity constraints in the form of marginal costs that increase steeply in the carrier's load factor, the ratio of passengers to available seats. The dynamics of the model are then driven by capacity constraints, the costs of adjusting capacity, and the

avoidable fixed cost of operating. Carriers make capacity and entry/exit decisions, fully internalizing the impact of the decisions on its own and its opponents future actions and the implications of these actions for profitability.

Predatory incentives arise as a result of asymmetries in costs between incumbents and entrants. Relative to their small low cost rivals, large hub incumbents have lower avoidable fixed costs and higher marginal costs. Because they have lower marginal costs, competition from low cost carriers have a large impact on the profitability of the incumbents. At the same time, higher avoidable fixed costs means these low cost carriers are less committed to the market and thus more likely to exit. The costs of adjusting capacity then provide the means through which carriers can make predatory investments. Flooding a route with capacity allows a carrier to commit to aggressive pricing in the future. The feature that differentiates the airline industry from other industries with capital investment is that capacity adjustment is costly enough to provide a degree of commitment, but cheap enough that the carrier can reverse course after the exit of the rival.

The incentives of this model are similar to deep pockets/long purse stories of predation (e.g. Fudenberg and Tirole 1985 , Bolton and Scharfstein 1990 **?**).[5] In these theories, some firms have deeper pockets in the sense they are able to tolerate taking larger losses or losses for a longer period than their rivals due to better cash flow or credit sources, etc.. One criticism of these theories is that there is generally not a good story for why we ever actually observe predation. That is, a carrier that knows it will be preyed upon should not enter the market. In this model predation is observed along

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[5] See Ordover and Saloner (1989) for a discussion of these types of theories.

the equilibrium path because whether or not an entrant is preyed upon is uncertain as is the success of the strategy. Firms weigh these probabilities and enter when the expected value of doing so is greater than its expected costs, so the frequency of equilibrium predation and entry are determined jointly in equilibrium. I exploit revealed preference arguments to estimate the parameters of the model. That is, I estimate the model by assuming behavior observed in a sample of markets is optimal, in the sense of Nash equilibrium, and then backing out the parameters that rationalize this assumption. A primary strength of my empirical approach is the measurement of economic costs. In the airline industry, routes are usually connected to other routes so production costs for any one product in any one market depends on production of other products in other markets. This means the variable, fixed, and total cost functions for a particular product are not well defined. In such a situation, any approach that does not make use of observed behavior to infer costs has not only the textbook problem arising from the difference between accounting and economic costs but also necessarily relies on arbitrary "fully allocated" accounting measures. Indeed, in the American case the judge found the DOJ's argument, based on American's complex managerial accounting system, unconvincing largely due to these issues.

Despite the inherently dynamic nature of predation, in practice the problem is almost always examined from a static perspective. The best example of this is the use of static cost based tests of predatory sacrifice. These tests ask whether a measure of the revenue generated by an action is greater than a measure of the cost of the action. If the answer is no, this is evidence of an investment in causing the exit of a rival. In environments with imperfect competition or dynamics these tests will be, at best, proxies for predatory incentives. For example, the classic Areeda Turner test, which compares price to marginal cost, is neither necessary nor sufficient for predation in such environments. Firms with market power are, by definition, setting prices above marginal cost. A price above marginal cost, but below the static profit maximizing price, can then still represent a sacrifice. On the other hand, when dynamics are important, firms may price below static marginal cost in the absence of predatory incentives. Benkard (2003) provides such an example with competition in the presence of learning-by-doing in the aircraft industry.

To analyze the implications of these tests I first compare American's behavior in

the Dallas-Fort Worth-Wichita market against two cost-based tests, similar to those commonly used in antitrust enforcement, an incremental cost test and an avoidable cost test. The incremental cost test compares the extra revenue generated by an addition of capacity with the cost of the addition. The avoidable cost test compares the revenue earned at a particular level of production with the cost savings that could be achieved by taking a different level, i.e. the avoidable costs. Since these tests are only proxies, an important question in any given case is how well these tests capture predatory incentives. To evaluate their performance, I compare the results against a measure of predatory incentives based on a definition of predation proposed by Ordover and Willig (1981) and operationalized by Cabral and Riorden (1997). They define an act as predatory if it is optimal when its impact on a rival's likelihood of exit is taken into account, but suboptimal otherwise. This definition is easily implemented using the model.

Static cost tests also play an important role in the calculation of the damages arising from a predation violation. Calculating these damages requires constructing a counterfactual for the market but for the predatory acts. The counterfactual often considered is the market in the absence of the cost test violation. I therefore also compare the damages implied by the 2 cost tests and compare them with the damages implied by the definition test.

The second important concern in enforcing predation standards is the potential distortionary impact of trying to punish or prevent predation. To analyze these potential distortions, I use the model to simulate the impact of the Department of Transportation's solution to the predation problem, the *Fair Competition Guidelines*. These guidelines, drafted in the late 1990's and ultimately never enacted, proposed restrictions on the responses a dominant incumbent could pursue in response to the entry of a low cost rival. Here, an explicit equilibrium model of predation is useful for exploring the full consequences of policy. In equilibrium, the welfare effects of these policies depend on both the impact of the restrictions as binding constraints on firms behavior, e.g. actual predation, as well as their impact as restrictions on potential behavior, e.g. the threat of predation. The potential problem with these rules is then the fundamental problem of predation policy: Any one-size-fits-all standard that prevents predation is also likely to have unintended consequences possibly including the prevention of or disincentive for legitimate, intense competition.

To preview results, I find the model is able to largely match the behavior from the Dallas-Wichita market using estimated parameters. Using the test of predation based on the Ordover and Willig (1981) definition, I find evidence of predatory incentives in the market and that this test is in agreement with the DOJ's time line for predation. The proposed static cost tests capture these incentives surprisingly well. In particular, the avoidable cost test is in agreement with the definition test, while the incremental cost test gives a false positive and a false negative. Simulations under the *Fair Competition Guideline* type restrictions reveal interesting equilibrium consequences. The restrictions prevent American from attempting to monopolize the market, however, they also dull Vanguard's competitive incentives resulting in reduced probability of intensely competitive market structures. I also find an unintended pro-competitive consequence: the rules reduce the likelihood of monopoly because, without the threat of being preyed upon, Vanguard is more likely to enter the market. Overall, the restrictions I examine are welfare improving on net.

This paper represents the first attempt to analyze predation by connecting a dynamic equilibrium model to real market data. In so doing I contribute to the small number of empirical studies of predation. Genesove and Mullin (1996) and Scott-Morton (1995) develop tests for predation and apply them to the late nineteenth and early twentieth century U.S. sugar and British shipping industries, respectively. This paper also provides a counterpoint to the studies of Bamberger and Carlton (2007) and Ito and Lee (2004), who examine the impact of large carrier responses to low cost entry on the likelihood of low cost exit and find no evidence of predation at an industry level.

This paper also contributes to the large literature on the economics of the airline industry and is the first that explicitly considers the role of capacity choices in competition. In the paper, I consider the implications of the model for predation policy, however, it has broader application to other important industry questions. For example one of the surprises of the post-deregulation airline industry was the lack of responsiveness of incumbent carriers to the threat of entry. The theory of contestable markets (Baumol, Panzer and Willig 1981) predicted that incumbent pricing would be constrained by potential entry because, if it was not, then actual entry would follow. However, potential entry appears to have little effect on airline pricing. Similarly, Goolsbee and Syverson (2008) find no evidence that incumbents attempt to deter entry.

The model presented here suggests the nature of capacity costs, cheap enough to move quickly but expensive enough to provide some commitment, make responding to actual entry more efficient than responding to potential entry. These positive features also have potentially broader normative implications to merger analysis. The model suggests a merger that changes the cost structure of the merged firm will have implications for merged firm responses to entry as well as the entry behavior of potential entrants in the markets affected by the merger.

Finally, I contribute to the growing literature applying structural techniques to dynamic game models. The interest in these applications has been spurred by recently developed techniques for estimating these models (Aguirregabiria and Mira (2007), Bajari, Benkard, and Levin (2007) , Pesendorfer and Schmidt-Dengler (2008)). Early contributions by Benkard (2003, aircraft) and Gowrisankaran and Town (1997, hospitals) required considerable ingenuity and were computationally intensive; estimation required completely solving the game for each candidate parameter vector or devising alternative identification strategies. The new techniques take a two step approach to estimation that allows parameters to be recovered without solving the game. This feature has allowed the estimation of much richer models with many players and/or many state variables. Recent applications include Aguirregabiria and Ho (2008, airlines), Bersteneau and Ellickson (2004, retail stores), Collard-Wexler (2006, concrete), Holmes (2007, discount retailers), Ryan (2006, portland cement), and Sweeting (2007, radio stations).

The rest of the paper proceeds as follows: Section 2 motivates my approach to predation with a brief description of competition at Dallas-Fort Worth and the American case Section 3 describes the model of price and capacity competition among airlines. Section 4 discusses the data, empirical strategy, and estimation. Section 5 introduces price cost tests for predation and simulates equilibrium in the model under the but-for scenarios, the scenarios in which violation of the rules are absolutely prohibited, and compares welfare criteria under each alternative rule. Section 6 concludes.

2.2   Background: American at Dallas-Fort Worth

Dallas-Fort Worth International Airport (DFW) opened in 1974 after the Civil Aeronautics board, the regulator of the pre-deregulation industry decided that the existing airport, Love Field in Dallas, was inadequate for the future travel demands of the Dallas-Fort Worth metroplex market. Soon after opening all carriers, with the exception of Southwest Airlines, moved their operations from Love Field to DFW. As of the beginning of 2008 DFW covered 30 square miles, operating 4 main terminals with 155 gates, serviced by 21 airlines, and providing service to 176 destinations. In 2008, DFW was the sixth largest airport in the world in terms of passenger traffic, serving 167,000 daily, and the third largest in terms of combined passenger and cargo traffic.

Immediately following industry deregulation in 1979, American Airlines moved its headquarters from New York to Dallas and began making DFW its primary hub. Also in 1979, in response to expansion plans by Southwest at Love Field, congressman Jim Wright of Fort Worth sponsored a bill that restricted service from Love Field so that only markets within Texas and the 4 contiguous states to be served from that location. The "Wright Amendment" has been amended several times since 1979, however, Southwest's operations out of Dallas remain severely restricted.[6] [7] This has allowed American to avoid the "Southwest effect", the intense price and quality competition that accompanies entry into a market by Southwest, to a degree at DFW.

By 1993, American's DFW hub operation accounted for 56 percent of all traffic from Dallas's two major airports. Until 2004, when Delta dismantled its DFW hub as part a bankruptcy reorganization plan, DFW was one of only three major airports to be a hub for 2 major airlines. In 1993, Delta served 28 percent of traffic in the Dallas Fort Worth area. Delta now flies to DFW only from its other domestic hubs and through service from regional affiliates.

2.2.1 Entry and Low Fare Competition at DFW:1993-2000

Like other dominant hub carriers, American has enjoyed a substantial "hub premium" on flights originating or terminating at DFW.[8] There is also evidence that economies

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[6] Southwest has declined repeated invitations to move its operations to DFW.

[7] The Wright Amendment is slated for full repeal in 2014

[8] There is a large literature documenting and analyzing the hub premium. See Borenstein (1995) for an example and Borenstein (2007) for a breif literature review.

of network density result in substantially lower operating costs for markets out of a carrier's hub (Caves, Christensen, and Treathway 1986, Berry, Carnall, and Spiller 2006). These factors contribute to DFW being a disproportionately important source of profits for American. From 1993-2000, operations out of DFW have accounted for between 48% and 60% of American's available seat miles but between 61% and 80% of American's profits.

Table 2.1: Hub Carrier Average Fare Per Mile 1995

| Airport (Hub Carrier) | No LCC pres. | | LCC pres. | | |
	Hub Carrier	Other	Hub Carrier	Other	LCC share
Dallas (American)	.330	.262	.242	.197	.055
Atlanta (Delta)	.398	.240	.261	.154	.207
Detroit (Northwest)	.464	.302	.284	.163	.037
Houston-Bush (Continental)	.351	.218	.193	.157	.033
Minneapolis (Northwest)	.400	.257	.217	.155	.036
Newark (Continental)	.461	.291	.220	.175	.087
Salt Lake City (Delta)	.217	.162	.163	.124	.048
Washington-Dulles (United)	.312	.277	.205	.164	.193

Beginning in the early 90's, the competitive advantage of hub carriers was being eroded by the continued growth of Southwest as well as widespread entry of new "low cost" carriers (LCC) . The business model of these carriers, inspired by the success of Southwest, exploited lower operating costs than the majors to provide point to point service with low prices. American Vice President of Marketing and Planning, Michael Gunn, testified that Southwest's costs were 30% lower (in 2000) than American's. For other LCCs that do not offer the same quality standards as Southwest, the difference may be even larger; In 1994 American estimated that LCC Valujet had a cost per available seat mile of about 4.5 cents compared to American's cost of around 8.5 cents. These cost advantages allow LCCs to be profitable at low fares in the markets they enter, forcing incumbents to match prices or risk losing substantial share. Table 2.1 shows the 1995 hub premium, in terms of average fare per mile, for several dominant hub carriers in markets with and without low cost presence. The first two columns show the average fare per mile for the dominant hub carriers and other carriers operating at that airport in markets where there has been no LCC presence. The difference is between these two is the hub premium on routes with no LCC penetration. The second two columns of the table show the same average fares on routes with LCC presence. The table clearly

shows the impact of low cost entry on the profitability of incumbent firms. Both hub carriers and other carriers operating at the concentrated hubs are affected. However, since hub carriers generally serve a disproportionately large share of passengers in these markets, the 30-50 percent price declines represent a much larger decline in profits for the hub carriers.

American took seriously the threat posed by LCC entry to its DFW operations. In 1995 it began investigating the vulnerability of DFW to the LCC threat and potential strategies for combating it. Special attention was paid to Delta's experience with Valujet at its Atlanta hub. A March 1995 internal American report concluded that as a result of Valujet setting up a 22 spoke hub at Atlanta "Delta has lost $232 million in annual revenues" and "Clearly, we don't want this to happen at DFW." American executives concluded that Delta's passive response to the Valujet entry was responsible for this outcome saying, "ceding parts of the market [to Valujet]...was not the proper way to respond"

Internal documents reveal the "DFW Low Cost Carrier Strategy" designed to address the hub's vulnerability, called for aggressive capacity additions and price matching in response to the entry of a startup LCC. American also would monitor the balance sheets ksjdfksjldflksjdflkjsldkjflksjdflkjsldjflksjdfljskdjflskjdflkjsldkjflsjdfl and service capabilities of a low cost rival to determine break even load factors and "tolerances." In a May 1995 document discussing American's strategy against Midway Airlines in the DFW-Chicago Midway market, it was observed that "it is very difficult to say exactly what strategy on American's part translates into a new entrant's inability to achieve [break even] share. That strategy would definitely be very expensive in terms of American's short term profitability." In a February 1996 meeting CEO Robert Crandall commented on the strategy, "there is no point to diminish profit unless you get them out."

There is also evidence that low cost carriers consider how incumbents will respond to their entry. For example, the strategic motto of low cost carrier Access Air was "stay off elephant paths...don't eat the elephant's food...keep the elephants more worried about each other than they are about you" to avoid aggressive responses from the elephants, the major hub carriers. In accordance with this motto Access Air entered only large destinations that were not hubs. A variant strategy, attributed to LCC Morris Air ,

was adopted by many LCCs, including Vanguard after its experience with American. The strategy was to enter only large markets with only a very small presence at first, so as to not provoke a response from dominant hub carriers.

This evidence suggests predation, if it occurs, and entry are determined simultaneously by an equilibrium process. Over the period 1993-2000, DFW experienced entry from 10 low cost carriers into 17 non-stop markets. Figure 2.2.1 gives a snapshot of American's price and capacity responses to these episodes of entry. The figure shows market prices and capacities in the quarter preceding entry on the horizontal axes and the same quantities for 3 quarters after entry (1 year later). The markets in question in the DOJ's suit are highlighted. The figure shows a considerable amount of heterogeneity in American's price and capacity responses to predation, which further suggests the importance of the simultaneous determination of entry and the response to entry. The figure also shows American often responded to low cost entry by lowering fares to compete with the new entrant. Capacity responses, however, were typically more restrained except in a few cases. These were the markets singled out by the Justice Department in its case. These are also the cases that motivate my model.

American responded with large capacity additions only in markets where the value of removing the LCC rival was high and/or the LCC seemed weak. In the Dallas to Atlanta (ATL) market, American faced entry from AirTran, which after merging with Valujet had a strong presence at Atlanta, as discussed above. Furthermore, Delta operated its primary hub at Atlanta and controlled a large share of passengers in the market, making American's exposure relatively small. American responded similarly passively to the entry of Frontier in the Denver (DEN) market. Frontier had and continues to have a strong hubbing operation at Denver, while competing with major carrier United, which also operates a hub at Denver. The figure also shows American responded passively to entry in the Las Vegas (LAS) and Orlando (MCO) markets. Demand in these markets is driven by low margin leisure customers and the routes, particularly Las Vegas, are famously competitive. Removing a rival would thus not have much impact on American's share or margins.

American did respond with large capacity increases to the entry of Western Pacific into the Colorado Springs (COS) market in June of 1995. Following a general strategy,

Figure 2.1: (a) American Price Response to Non-Stop LCC Entry 1993-2000 (b) American Capacity Response to LCC Entry 1993-2000.
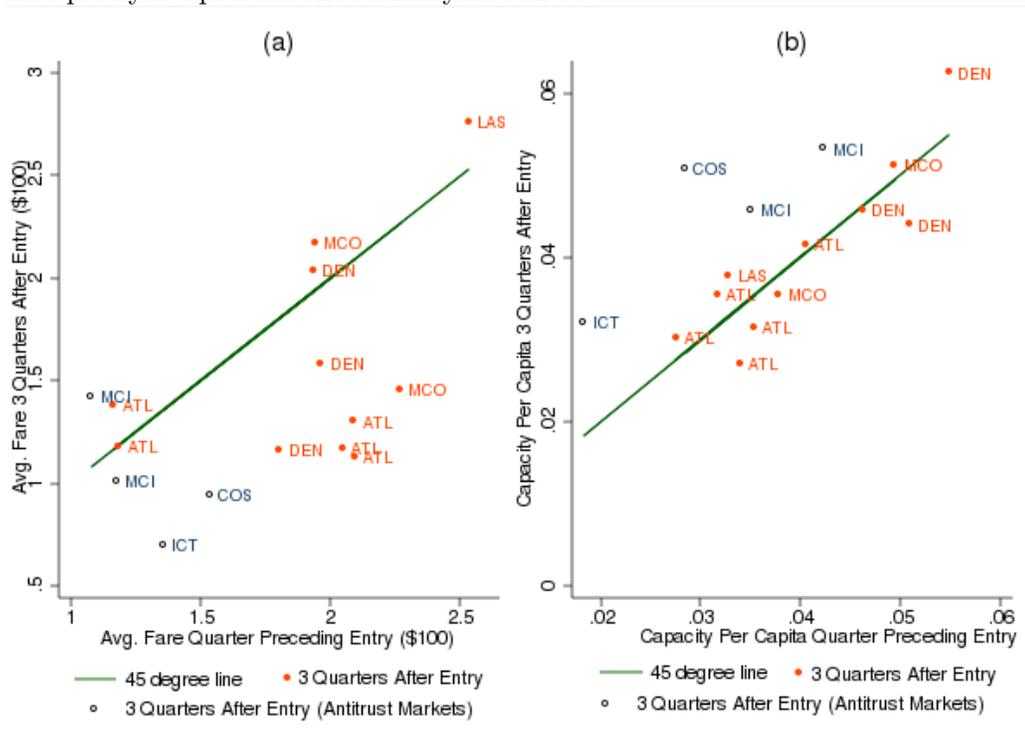
due to limited aircraft availability, Western decreased its capacity in the Dallas to Colorado Springs route and moved it to the Colorado Springs to Atlanta route in November of 1995. In a low cost carrier strategy session American executives decided to increase capacity on the route to try to get Western out before it returned the capacity.

American responded aggressively to the entry of Vanguard on 2 routes, Dallas to Kansas City (MCI) and Dallas to Wichita (ICT). As shown in the figure, Vanguard actually entered Dallas to Kansas City twice. On the first entry attempt, American responded relatively passively, choosing to only match fares on a limited basis and follow its standard capacity planning model. Vanguard entered the route the second time as part of a major DFW expansion plan. American proceeded to respond by forsaking its "revenue strategy" in favor of a "share strategy". I discuss Vanguard's experience in the Wichita market in detail in the next section.

Figure 2.2: Dallas to Wichita Average One Way Fares 1993-2000
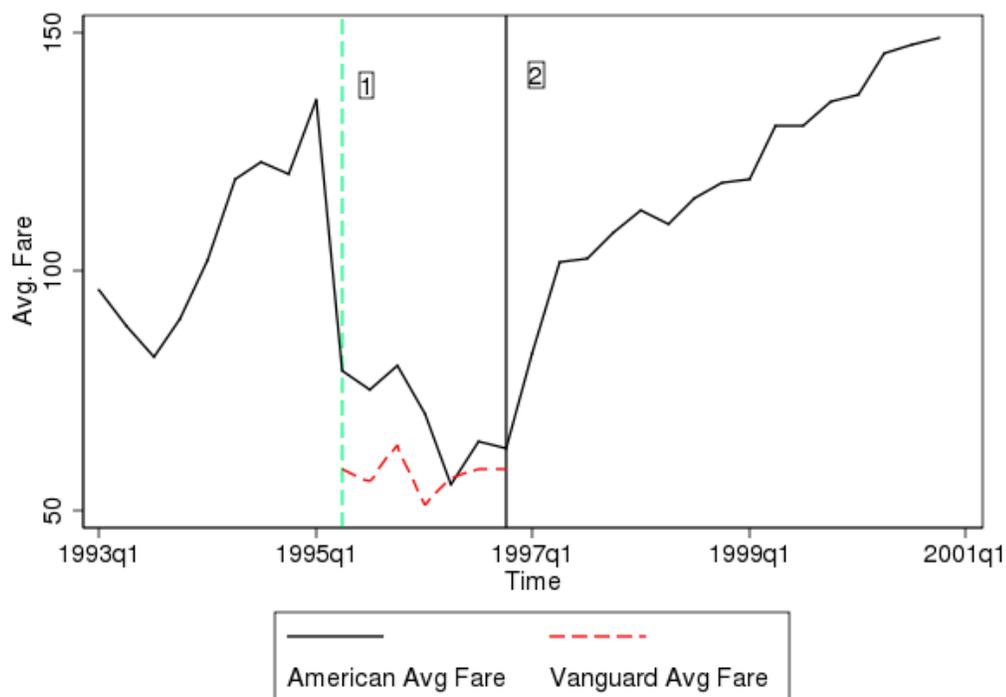
2.2.2 The American Case: DFW-Wichita

The Justice Department's case against American claimed that it engaged in illegal predatory conduct against three low cost rivals on routes from its primary hub at DFW : Vanguard, Sunjet and Western Pacific. In total the case named 25 markets in which American's conduct had anti-competitive consequences, though the behavior was alleged to be illegal in only four of these markets.[9]   In each case the Department of Justice argued the pattern of predation was the same: 1) A small "low fare" airline began non-stop service in a spoke market dominated by American. 2) American dramatically lowered fairs, and crucially 3) American dramatically increased capacity/flight frequency. I focus on American's competition with Vanguard in the DFW to Wichita (ICT) market.

---

[9] Wichita, Kansas City, Colorado Springs, and Long Beach

Vanguard Airlines began operating in December of 1994. In January of 1995 Vanguard made its first foray into Dallas-Fort Worth when it began operating nonstop jet service from DFW to Kansas City. Figures 2.2.2 and 2.2.2 show the time series of average fares and seating capacities for the DFW to Wichita market. Prior to Vanguard's entry, the DFW to Wichita market was served by American and Delta. Before May of 1993, both carriers provided jet service on the route with American offering 5 non-stop flights per day. In May of 1993 both carriers began converting their jet service to turboprop service and by June of 1994 both had removed the last of their jets from the market. In February of 1994 the Wichita Airport Authority asked American to consider reinstating jet service to the airport. American offered to return 3 jets per day to the route on the condition that the Authority would provide a revenue guarantee of $13,500 per round trip. This period is highlighted by the dashed vertical line in figure 2.2.2. The Authority declined the offer and instead approached Vanguard and asked them to introduce jet service to the DFW to ICT market.

Vanguard noticed the opportunity presented by the lack of jet service and, in April of 1995, entered the DFW-ICT market with 2 non-stop jet flights daily, charging $69 for peak unrestricted one way fares and $39 for off-peak. In line with its standard pricing strategy, American responded to Vanguard's entry by with one way fares offered at a $20 premium over Vanguard's one way fares and round trip fares equal to twice Vanguard's one way fare. This period is shown by the dashed line labeled 1 in figure 2.2.2. Vanguard immediately cut deeply into American's share, garnering 44 percent of origin and destination passengers in its first quarter in the market.

Vanguard added a third daily jet flight to the Wichita route in October of 1995. In response to this, American removed its $20 premium on one way fares and began matching Vanguard's prices. The dashed line labeled 2 in figure 2.2.2 highlights this period. Then in July of 1996, Vanguard added a fourth daily jet flight as part of a general restructuring plan that called for expanding its presence at DFW. American immediately decided to return jet service to Wichita, without a revenue guarantee, replacing four of its daily turboprop flights with five jet flights. The aircraft for this addition were "funded by planes sitting idle due to pilot action."

In November, Vanguard's then CEO Robert McAdoo resigned and was replaced by John Tague. Tague proceeded to restructure Vanguard's routes, creating a hub and

spoke network based at Kansas City. He concluded that Vanguard route network was excessively dissipated and needed a stronger geographic focus. The DFW-ICT, along with almost all other non-Kansas City routes, were eliminated. After Vanguard's exit, American gradually raised prices to pre-entry levels and again began to draw down its jet service. As shown in by the black vertical line in the figures, the Justice department alleged that American engaged in illegal, predatory capacity additions in the DFW to ICT market in the 4th quarter of 1996.

Figure 2.3: Dallas to Wichita Seating Capacity 1993-2000
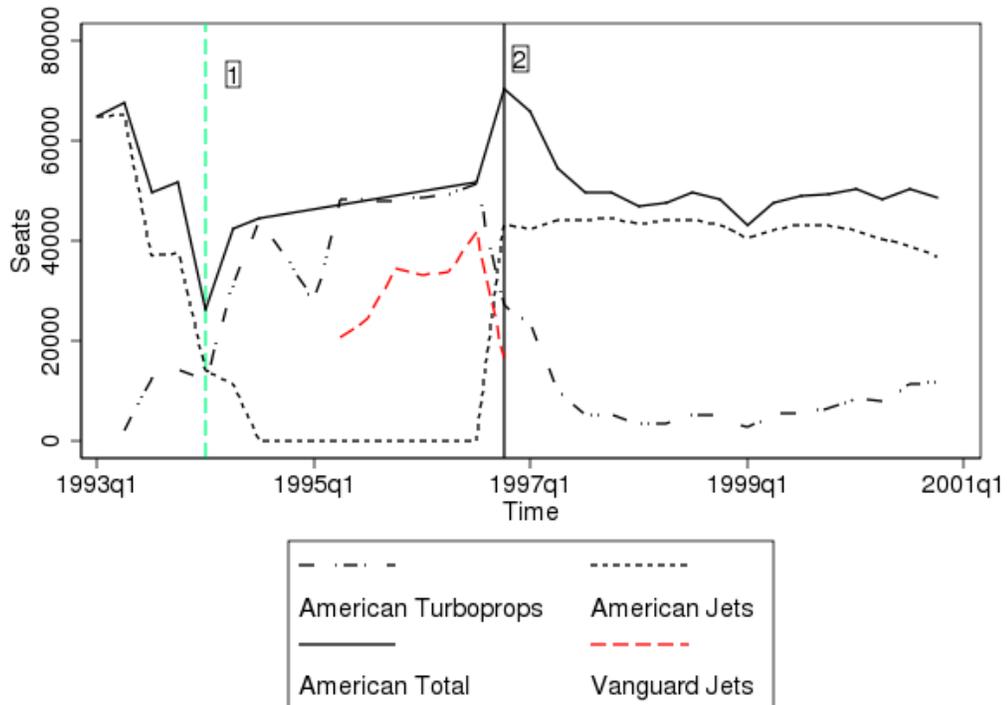
2.3 Model

In this section I introduce a dynamic model of price and capacity competition among airlines competing in a nonstop market. There model has four important components. First, high marginal cost/high quality, hub carriers and low marginal cost/ low quality, low cost carriers compete for non-stop passengers by setting prices for their differentiated

offerings. Second, firms must allocate seating capacity to a route to serve passengers because they face capacity constraints in the form of marginal costs that increase in the ratio of passengers to capacity. Third, moving capacity in and out of markets is costly and these costs potentially differ for hub carriers and low cost carriers. Finally, firms face fixed costs of operating that can be avoided only if the firm exits. These costs may also differ across firms.

Each firm makes choices to maximizes its sum discounted sum of profits. The last two features of the model force rational firms to be forward looking in the sense that they internalize the future consequences of capacity, entry and exit decisions. I describe each component of the model and then discuss equilibrium.

2.3.1 Local Demand

I assume each firm produces a differentiated product. Following Berry, Carnall and Spiller (2007), I assume a nested logit specification with the outside good (no flight) in a nest and available products in a second nest. The utility of consumer i from purchasing product j at time t is:

$$u_{ijt} = \alpha p_{jt} + \beta_3 Opres_{jt} + \beta_4 Dpres_{jt} + \beta_5 Stop_{jt} + \xi_j + \Delta\xi_{jt} + \upsilon(\lambda) + \epsilon_{ijt}$$

Where p_{jt} is the price of product j. The variables $Opres$ and $Dpres$ are a carrier's total traffic at the origin and destination airports less the traffic from the current market. They capture the effect of "airport presence", as in Berry (1990). Travelers prefer to fly airlines, all else equal, that offer more destinations due to, among others, the impact of frequent flier miles and travel agent commission overrides (see Berry 1990, or Borenstein 1990) . ξ_j and $\Delta\xi_{jt}$ are mean carrier unobserved product quality and the deviation from this mean, assumed i.i.d across time and carriers. These variables help account for unobservable factors like flight frequency, ticket restrictions and service quality. Berry (1994) and Berry, Levinsohn and Pakes (1995) discuss the usefulness of these unobservable characteristics for accurately estimating elasticities. ϵ_{ijt} and $\upsilon(\lambda)$ are terms capturing consumer specific heterogeneity. $\upsilon(\lambda)$ is the nesting term, reflecting the fact that there is a fundamental difference between choosing whether or not to fly and choosing which airline to fly. The structure of these two idiosyncratic

terms is assumed to be such that the sum of them is distributed as a type 1 extreme value random variable .

This differentiated product assumption is vital since the goal of the model is to analyze competition between a hub incumbent and a low cost entrant. Berry (1990) and Berry, Carnall and Spiller (2007) show that passengers value the size of a hub carrier's network and this superior quality explains much of the hub premium, the premium a carrier is able to charge on itineraries originating or terminating at its hub. Moreover, many of the cost reductions that low cost carriers have been able to achieve, have come from elimination of unobservable service "frills", presumably at the expense of quality.

Let carrier j's *local demand state*, $\bar{\xi}_{jt}$, be defined as:

$$\bar{\xi}_{jt} = \beta_2 Opres_{jt} + \beta_3 Dpres_{jt} + \beta_4 Stop_{jt} + \xi_j + \Delta\xi_{jt}$$

Then, for a market of size M, the local traffic demand function facing carrier j has the following familiar form:

$$q_j^L(p_j, p_{-j}, \bar{\xi}_j, \bar{\xi}_{-j}) = M \left(\frac{\exp(\frac{\alpha p_j + \bar{\xi}_{jt}}{1-\lambda})}{\sum_{j'} \exp(\frac{\alpha p_{j't} + \bar{\xi}_{j't}}{1-\lambda})} \right) \left(\frac{\left(\sum_{j'} \exp(\frac{\alpha p_{j't} + \bar{\xi}_{j't}}{1-\lambda})\right)^{1-\lambda}}{1 + \left(\sum_{j'} \exp(\frac{\alpha p_{j't} + \bar{\xi}_{j't}}{1-\lambda})\right)^{1-\lambda}} \right) \quad (2.1)$$

Which is the market size times the market share equation from the logit model with the outside good in a nest and all other products in a nest.

2.3.2 Non-Local Demand

A complication arises because any given flight between Dallas and Wichita transports both local traffic, passengers who originate at Dallas and whose final destination is Wichita, as well as non-local traffic, passengers traveling between a different origin and destination connecting over the Dallas-Wichita *route*. Capacity decisions on a route depend on both types of traveler, however, there is no obvious way to allocate the revenues and costs associated with non-local passengers to the local route. I assume the revenue from non-local passengers is allocated to the route by a function that depends

on the total volume of non-local traffic over the route and an exogenously evolving state variable.

I assume the total demand for non-local service from carrier j over a route is given by the inverse demand function $p_j^{NL}(q_{jt}^{NL}, \xi_{jt}^{NL})$, where q_{jt}^{NL} is quantity of non-local traffic and ξ_{jt}^{NL} is carrier j's *non-local demand state*. I specify the demand function as a constant elasticity form

$$p_j^{NL}(q_{jt}^{NL}, \xi_{jt}^{NL}) = \zeta \log q_{jt}^{NL} + \xi_{jt}^{NL}$$

The non-local revenues allocated to the route is then:

$$p_{jt}^{NL} q_{jt}^{NL} = (\zeta \log q_{jt}^{NL} + \xi_{jt}^{NL}) q_{jt}^{NL} \tag{2.2}$$

2.3.3 Variable Costs

Given its capacity level, a non-stop carrier faces a constant marginal cost of carrying passengers plus an increasing "soft" capacity constraint. A nonstop carrier's variable cost function is:

$$
\begin{aligned}
C_j(q_{jt}^L, q_{jt}^{NL}, \bar{q}_{jt}) &= (w_j^L + \omega_{jt}^L) q_{jt}^L \\
&\quad + (w_j^{NL} + \omega_{jt}^{NL}) q_{jt}^{NL} \\
&\quad + \left(\frac{w_{lf}}{1+\upsilon}\right) \left(\frac{q_{jt}}{\bar{q}_{jt}}\right)^\upsilon (q_{jt})
\end{aligned}
\tag{2.3}
$$

ω_{jt}^L and ω_{jt}^{NL} are mean 0 cost shocks identically and independently distributed over time and across carriers, $\bar{q}_{jt}$ is the capacity of carrier j in total seats, and $q_{jt} = q_{jt}^L + q_{jt}^{NL}$. The form of the capacity constraint term $\left(\frac{w_{lf}}{1+\upsilon}\right) \left(\frac{q_{jt}^L + q_{jt}^{NL}}{\bar{q}_{jt}}\right)^\upsilon (q_{jt}^{NL} + q_{jt}^{NL})$ is almost identical to that used in Doraszelski and Besanko (2003) and Doraszelski et. al. (2008). The only difference is these papers set $\omega_{lf} = 1$. The constraint is soft in the sense that a carrier is able to violate the constraint though this cost may be high. A hard constraint would set the cost of violating the constraint to infinity. In this case a rationing rule would be required to calculate equilibrium (if it exists). The parameter υ determines how steeply marginal costs rise in a carrier's load factor, the ratio of a carrier's traffic to its capacity.

2.3.4 Product Market Equilibrium

I restrict the analysis by assuming capacity is the only dynamic variable. Since, conditional on capacity choices, pricing and non-local output decisions do not have any impact on the evolution of state variables, the static pricing game and non-local quantity choice can be solved separately from the capacity choice game. These decisions are determined simultaneously as the solution of 2N first order conditions:

$$q_j^L(p_t, \bar{\xi}_t) + \frac{\partial q_j^L(p_t^L, \bar{\xi}_t)}{\partial p_{jt}} \left(p_{jt}^L - w_j^L - \omega_{jt}^L - w_{lf} \left(\frac{q_{jt}}{\bar{q}_{jt}} \right)^v \right) = 0, j = 1, 2, \ldots, N \quad (2.4)$$

$$\zeta(1 + \log(q_{jt}^{NL})) + \xi_{jt}^{NL} - w_j^{NL} - \omega_{jt}^{NL} - w_{lf} \left(\frac{q_{jt}}{\bar{q}_{jt}} \right)^v = 0, j = 1, 2, \ldots, N$$

Let $p^L(\bar{q}_t, \bar{\xi}_t, \xi_t^Q)$ and $q^{NL}(\bar{q}_t, \bar{\xi}_t, \xi_t^Q)$ be the vector implicitly defined solutions to this system of equations. Period profits are then determined by the vector of capacity and demand states. Define the *reduced form profit function* $\pi_j(\bar{q}_t, \bar{\xi}_t, \xi_t^Q)$, where

$$\pi_j(\bar{q}_t, \bar{\xi}_t, \xi_t^Q) = (\zeta \log q_j^{NL} + \xi_{jt}^{NL}) q_j^{NL} + p_j^L q_j^L(p^L, \xi_t) - C \left(q_j^L(p^L, \bar{\xi}_t), q_j^{NL}, \bar{q}_{jt} \right) \quad (2.5)$$

2.3.5 Capacity Choices

Aircraft are highly mobile capital goods. A carrier can physically redeploy assets from one market to another in the time it takes to fly the plane between the markets. There is also an active leasing and secondary market for used aircraft. These facts suggest the cost of adding or subtracting capacity from a route is cheap. On the other hand, competition in the industry is intense and, historically, there has been no shortage of willing entrants. Those surviving in the industry employ sophisticated operations management techniques to make sure their fleet is as lean as possible. Therefore, changing capacity levels too quickly or too often incurs high opportunity costs. Tight profit margins also suggest a high opportunity cost for the large amount of capital tied up in a plane. Moreover, while the secondary market is relatively active, even the most popular aircraft models often take months to re-market. Pulvino (1998) shows that firms that have to liquidate large parts of their fleets often have to do so at "firesale" prices.

There is good reason to suspect these costs of adjusting capacity varies across carriers. American has a huge route network and a fleet of over 500 planes. Low cost carriers, like Vanguard, have small networks and fleets of size on the order of 10-20 planes. Fledgling low cost carriers also often have weak balance sheets and lack of proven income sources.

At the beginning of each period given a current capacity level, active firms, incumbents and new entrants, choose a capacity adjustment, $\Delta \bar{q}_{jt}$, from a continuous set, $[-\bar{q}_{jt}, \bar{Q} - \bar{q}_{jt}]$. Capacity transitions are deterministic, added in the following period, and can be positive or negative, provided that negative investment does not exceed total existing capacity. Capacity does not depreciate, so the law of motion is simply:

$$\bar{q}_{jt+1} = \bar{q}_{jt} + \Delta \bar{q}_{jt}$$

The costs of adjusting capacity has 2 components. The first is a deterministic component specified as a quadratic function; investing or divesting too quickly incurs increasing marginal adjustment costs. The second is a private information draw that shifts up or down the linear component of costs.

$$C_j^{Cap.}(\Delta \bar{q}_{jt}, \varepsilon_{jt}) = \begin{cases} (\eta_{1j}^{+} + \varepsilon_{jt})\Delta \bar{q}_{jt} + \eta_{2j}^{+}\Delta \bar{q}_{jt}^2) & \text{if } \Delta \bar{q}_{jt} > 0 \\ (\eta_{1j}^{-} + \varepsilon_{jt})\Delta \bar{q}_{jt} + \eta_{2j}^{-}\Delta \bar{q}_{jt}^2) & \text{if } \Delta \bar{q}_{jt} < 0 \end{cases} \tag{2.6}$$

The parameters η_j determine the slope and curvature of the investment cost function. I allow them to differ according to whether capacity is added or subtracted from a route. The parameters η_{j2} determine the penalty exacted on carriers for increasing or decreasing capacity too quickly.

The capacity cost shocks are assumed i.i.d. over time drawn from mean 0 normal distributions with commonly known variances that differ across firms:

$$\varepsilon_{jt} \sim F_j = \mathcal{N}(0, \sigma_j^K)$$

These shocks capture the randomness in the opportunity or real costs of adding or subtracting capacity. For example, planes being made available "due to pilot actions" as they were for American in the Wichita market.

2.3.6 Entry and Fixed Costs

At the beginning of each period, prior to the revelation of capacity costs shocks, Entry costs are drawn from a normal distribution with a mean that is a linear function of the carrier's origin and destination presence and the carrier's type and a common standard deviation.

$$\psi_j \sim \Psi_j = \mathcal{N}(\gamma_{0j}^E + \gamma_1^E Opres_j + \gamma_2^E Dpres_j, \sigma^E)$$

A potential entrant can choose to enter and become an active firm or stay out and disappear.[10]

In the airline industry entry costs are likely to be significant. Entering a route requires the carrier to incur administrative and other expenses to, for example, acquire gate space by entering into leases either directly from the airport or through subleases from other carriers at the airport. It is natural to assume these costs will be smaller for carriers that already have a large presence at the end points of the market, having already established relationships with airport administrators and having already secured the necessary resources to serve other routes. Majority-in-interest agreements at some airports (including DFW) give the major carrier, e.g. American, a say in proposed expansion plans, presumably leading to differences in these costs across carriers beyond even the observable differences in presence. Ciliberto and Williams (2008) give a detailed discussion of the determinants of these costs.

A firm can choose to exit by choosing to sell off all of its capacity. A carrier that chooses to keep a positive level of capacity pays fixed costs in the following period that is the sum of two terms. The first is a fixed cost of continuing operations and the second is proportional to the amount of capacity the firm holds

$$\phi_j + \gamma^{\bar{q}} \bar{q}_{jt} \tag{2.7}$$

---

[10] In the data, I define a potential entrant as any firm that has presence at either Dallas or the destination airport. This means that a potential entrant deciding not to enter today is likely a potential entrant tomorrow. For the same reason a firm that exits today often becomes a potential entrant tomorrow. I assume firms don't consider the option values of waiting to enter/becoming a potential competitor

This specification reflects the fact that at the route level certain expenses are fixed but avoidable, i.e. costs that can not be subsumed into sunk entry costs because they can be avoided by exiting or removing capacity. Also, many system or airport wide expenses, such as executive pay or operations planning, have to be allocated to individual routes for the purpose of measuring the performance of routes and making exit and capacity decisions. In its own decision accounting system, American often allocates such expenses proportionally according to departures or other traffic measures. Though arguably arbitrary, since American bases decisions on these measures, they presumably reflect economic costs fairly well.

2.3.7   Bellman Equations

I restrict attention to Markov perfect equilibria of the above game. There are two reasons for this. First, most of the existing tools for equilibrium computation (e.g. McGuire and Pakes (1995, 2001)) as well as for estimation of structural parameters of the games (e.g. Aguirregabiria and Mira (2007) , Pesendorfer and Jofre-Bonet (2005) , Bajari, Benkard and Levin (2007)) are designed for this class of equilibria. Second, Markov perfection imposes some discipline on the analysis by restricting dynamics to be driven only by fundamental or "payoff relevant" variables. This gives a firmer foundation to the analysis since belief related variables such as reputation are inherently difficult to measure and thus inherently more speculative. This restriction helps answer criticisms of the use of modern strategic theory in the analysis of predation cases (see e.g Bolton, Brodley, and Riorden 2003 and the reply of Elzinga and Mills 2003). The flip side of this strength is that the model does not nest any of the theories that rely on asymmetric information and reputation formation driving forces.[11]

Time is discrete and infinite. Within a period, inactive potential entrants see a random cost of entry and decide whether to pay the cost and become active or disappear. All active firms, including entering firms see a random shock to the cost of capacity adjustment and make capacity adjustment decisions that take effect in the following period. A firm can choose to exit and disappear by choosing to sell off all its capacity.

---

[11] Most theories of equilibrium predation rely on asymmetric information, e.g. Milgrom and Roberts (1983) Saloner (1989) Fudenberg and Tirole (1990) more cites. Cabral and Riorden (1995, 1997) offer a rationale, in the same spirit as the one offered here, that does not rely on asymmetric info.

Firms then compete for passengers and realize profits for the period.

Each market is described by market states that evolve over time and type states which are time invariant. In what follows I omit notation that shows the explicit dependence of values on these type variables. Let $S = (\bar{q}, \bar{\xi}_t, \xi_t^Q)$ Assuming that firms follow Markov strategies, the value of a firm that has decided to remain active in the next period and has viewed its cost draw, ε_j, can be written as the Bellman's equation:

$$V_j^I(S, \varepsilon_j) = \max_{\Delta\bar{q}_j \in [-\bar{q}_j, \bar{Q} - \bar{q}_j]} \pi_j(S) - \phi_j - \gamma^{\bar{q}}\bar{q}_j - C^{\bar{q}}(\Delta\bar{q}, \varepsilon_j) + \beta CV_j(S, \Delta\bar{q}_j) \quad (2.8)$$

$$CV_j(S, \Delta\bar{q}_j) = \int\int V^I(S', \varepsilon_j') \Pr(dS'|S, \Delta\bar{q}_j) F(d\varepsilon_j')$$

Finally, the value of a potential entrant after viewing its sunk cost of entry and prior to seeing its investment cost can similarly be written:

$$V_j^E(S, \psi_j) = \max_{\chi_j \in \{0,1\}} \chi_j \left(-\psi_j + \int V_j^I(S, \varepsilon_j) F(d\varepsilon_j) \right) \quad (2.9)$$

In a Markov perfect equilibrium firms policies are functions only of current payoff relevant state variables. These include the market states for all competitor as well as private information capacity shocks, entry cost draws for potential entrants, and scrap value draws for incumbents. I write these strategies, entry and capacity choice policies for each state as $\Omega_j(S, \varepsilon_j, \psi_j) = (\chi_j(S, \psi_j), \Delta\bar{q}_j(S, \varepsilon_j))$.

Definition 1 *A Markov Perfect Equilibrium is: value functions ,V_j^I, policy functions, Ω_j and transition functions for all $j \in \{1, \ldots N\}$ such that:*

$$V_j^I(S, \varepsilon_j) = \max_{\Delta\bar{q}_j \in [-\bar{q}_j, \bar{Q} - \bar{q}_j]} \pi_j(S) - \phi_j - \gamma^{\bar{q}}\bar{q}_j - C^{\bar{q}}(\Delta\bar{q}, \varepsilon_j) \quad (2.10)$$

$$+ \beta \int\int V^I(S', \varepsilon_j') \Pr(dS'|S, \Delta\bar{q}_j) F(d\varepsilon_j')$$

$$\chi_j(S, \psi_j) = \arg\max_{\chi_j \in \{0,1\}} \chi_j \left(-\psi_j + \beta \int V_j^I(S, \varepsilon_j) F(d\varepsilon_j) \right) \quad (2.11)$$

$$\Delta\bar{q}_j(S, \varepsilon_j) = \arg\max_{\Delta\bar{q}_j \in [-\bar{q}_j, \bar{Q} - \bar{q}_j]} \pi_j(S) - \phi_j - \gamma^{\bar{q}}\bar{q}_j - C^{\bar{q}}(\Delta\bar{q}, \varepsilon_j) \quad (2.12)$$

$$+ \beta \int\int V^I(S', \varepsilon_j') \Pr(dS'|S, \Delta\bar{q}_j) F(d\varepsilon_j')$$

2.3.8 Discussion: Aggressive Pricing and Capacity Behavior

In the model, the intensity of price competition and period profits are determined by the "closeness" of firms in characteristic and capacity space. The more similar firms are in the characteristics, including capacity, of their non-stop product, the greater the marginal impact of price changes on quantity. The capacity constraint induces a similar effect on the cost side. When firms have dissimilar capacity levels, the smaller firms are unable to compete as aggressively on prices because doing so incurs steeply increasing marginal costs. On the demand side the degree to which this closeness matters is measured by the parameter λ. High values of λ correspond to high correlation in utilities among consumers within a market and accordingly highly correlated choices. On the cost side, the degree to which closeness matters depends on the parameter υ. Higher values of υ correspond to harder capacity constraints and more steeply increasing capacity costs.

Profit functions exhibiting these features have been central in the literature of firm and industry dynamics (See Athey and Schmultzer (2001) or Doraszelski and Pakes (2007) for a review of these results in the EP framework). Total industry profits in these environments are greater when 1 firm is dominant causing market equilibrium to tend to asymmetric structures with a dominant firm and occasional periods of intense competition when the laggard tries to become the market leader. In the present model, with the possibility of exit, a dominant firm anticipates these periods of fierce competition and has incentive to preempt them by acting aggressively to cause losses and potential exit by the laggard. The nature of asymmetries between the firms determine the precise nature of these incentives and the corresponding market dynamics.

2.4 Estimation

I will use the above model to simulate equilibrium in the Dallas to Wichita market under various antitrust regimes. In this section I discuss how I estimate the game parameters to do these simulations. The time series of relevant variables from an individual market, e.g DFW-ICT, represents a single observation of a Markov perfect equilibrium. In order to do estimation and inference, I need to observe equilibrium in many such markets.

To this end, I construct a sample of 81 markets out of Dallas-Fort Worth and argue that these markets represent individual observations of the same MPE.

2.4.1 Data and Sample Selection

The primary sources of data are from publicly available databases published by the Bureau of Transportation Statistics. The first is origin and destination DB1B. The DB1B contains a quarterly 10% sample of all domestic origin and destination itineraries including number of connections, carrier and fare paid. I keep those observations originating at Dallas-Fort Worth. I further keep only round-trip fares and drop the lowest and highest 2.5% of fares in terms of fare per mile to avoid frequent flier tickets and possible coding errors. The DB1B lists three types of carrier for each itinerary, ticking, reporting, and operating. I define the carrier as the ticketing carrier and, when there is more than one ticketing carrier, I define the carrier as the listed as the ticketing carrier for the segment out of DFW. I aggregate all remaining fares into passenger weighted, nonstop and connecting fares for each market carrier quarter.

The second source, also from BTS, is the T100 Origin and Destination database. The domestic T100 contains monthly data on traffic for all origins and destinations within the U.S. for carriers with annual revenues greater than $20 million. The variables include: carrier, O&D passengers, seats, departures performed, departures scheduled, and distance for each route a carrier flies. I collect this data for all months from 1993-2000 and aggregate to make it quarterly. As with the DB1B, I only include routes for which DFW is an origin or destination. I define the capacity state as the number of scheduled seats for a quarter. I construct the origin presence variable, $Opres_{jt}$, by summing all passenger traffic originating at DFW for carrier j in period t less the traffic from the non-stop market in question. Similarly the destination presence variable, $Dpres_{jtm}$, is constructed by summing all of carrier j's passenger traffic originating at destination m in period t less the traffic from the non-stop market. Non-local traffic on a route, q_{jt}^{NL}, is the T100 measure of total traffic over the route minus local traffic. To exclude serial entry-reentry, likely driven by network or seasonal factors, I define carrier exit as a carrier's reported DB1B passenger traffic falling below 100 and entry as a carrier's reported passenger total going above 100.[12]

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[12] The DB1B is a 10% sample so this corresponds to 1000 passengers on average.

Since my focus is on capacity, pricing, and entry/exit decisions in non-stop markets further sample selection criteria must be used. Airline pricing and capacity decisions reflect the complicated network nature of the industry, particularly for hubbing carriers. I want to focus on markets and firms within those markets whose decisions are based on the same margins that model decisions are based to make the same equilibrium assumption plausible. When network considerations are first order relative to within market considerations this will not be true.

In order to concentrate on markets in which non-stop traffic is the primary determinant of pricing, I push competitors with with-stop service as well as competitors whose share of route passengers is greater for a with-stop route than a non-stop route, into a competitive fringe and do not analyze their decisions. By similar reasoning, I also only want to consider markets that are not marginal with respect to providing *any* nonstop service. Entry and exit decisions in these, usually small routes are also driven more by network considerations than by fundamentals in the non-stop market. To deal with this I exclude markets in the bottom quartile of traffic density. Also I eliminate any markets that did not have any non-stop service at some point in the sample period. This leaves 81 markets remaining in the sample. Table 2.2 shows some summary statistics for the sample.

2.4.2 Estimation Strategy

I estimate the model in two stages. First, I estimate the parameters of the discrete choice demand system. The demand system is a simple version of those expounded in Berry (1994) and Berry, Levinsohn and Pakes (1995, BLP hereafter) and has been employed in many applications including applications to air travel demand by Berry, Carnall, and Spiller (2006, BCS hereafter), Berry and Jia (2008), and Aguirregabiria and Ho (2008). I then use these demand parameters to exploit the static nature of the pricing game and recover "observed" marginal costs via a traditional markup equation. Using these imputed costs I estimate the marginal cost function and the non-local price equation by using the functional form for variable costs and the first order conditions from the static game to form moment conditions.

The steps up to this point allow me to recover the *realized* variable profits in the data. Estimation of the structural model, however, requires knowledge of variable profits for

Table 2.2: Summary Statistics (Excluding Southwest)

variable	mean	s.d.	min	max
American				
fare	211.56	86.1	52.3	585.3
fare w/LCC	176.27	64.5	54.5	346.8
share	.52	.14	.06	1
Δcapacity≥ 0(per capita)	.0023	.0035	0	.032
Δcapacity≤ 0	-.0025	.0033	-.027	0
Low Cost				
fare	130.02	53.66	50.6	287.3
share	.19	.16	0	.956
Δcapacity≥ 0	.0017	.0020	0	.013
Δcapacity≤ 0	-.0013	.0018	-.017	0
Other				
fare	166.0	89.5	35.3	462.5
Δcapacity≥ 0	.0011	.0014	0	.012
Δcapacity≤ 0	-.0013	.0019	-.02	0
AA Market-periods	2554			
LCC Market-periods	188			
Obs	5231			

all possible points in the state space, whether or not they are observed. Being perfectly consistent with the model would require re-solving the static profit game at each point in the state space (or at least those that are reached with positive probability). This however is computationally demanding. Instead I parametrize the profit function as a function of the state variables and estimate it from the observed profits, appealing to the assumptions of the model to argue consistency.

The final objects I estimate in the first stage are the dynamic policy and transitions functions. Entry and Exit policies are estimated via probits on the market state variables and interaction terms as well as concentration measures that are functions of the state variables. Capacity choice policy functions are estimated via regressions of observed capacity choice on state variables and interactions. The exogenous demand states and the growth rate of market size are assumed to follow simple AR(1) processes

In the second stage I use the forward simulation estimator proposed by Bajari, Benkard and Levin (2007) to estimate the capacity adjustment, fixed, entry, and exit costs. Starting with an initial state in the data, I use the policy functions estimated in the first stage to simulate the evolution of the market under the observed policy and a set of alternative policies. Estimation is based on inequalities implied by the Markov perfect equilibrium assumption, i.e. the assumption that the observed policies have higher (expected) returns than alternative policies. In the demand and variable cost estimates, I am able to exploit the panel nature of the data to saturate the model with fixed effects to deal with unobserved heterogeneity, however the computational burden of the second stage estimator increases dramatically in the number of parameters to be estimated. To deal with this, I allow variable profits, policies, transitions and dynamic cost parameters to vary only according to whether a carrier is one of three types: American, Low Cost, or Other.

2.4.3 First Stage: Demand

Recall consumer's have preferences given by:

$$u_{ijt} = \alpha p_{jt} + \bar{\xi}_{jt} + \upsilon(\lambda) + \epsilon_{ijt}$$

This is the standard "Berry (1994) nested logit". The market share of product j, in

s_{jtm},this formulation is the product of the share of consumers who fly with any carrier, s_{tm}, and the share of consumers who fly with j conditional on flying, $s_{jt|m}$.

$$s_{jtm} = s_{tm}s_{j|tm} = \left(\frac{\exp(\frac{\alpha p_{jt} + \bar{\xi}_{jt}}{(1-\lambda)})}{\sum_{j'} \exp(\frac{\alpha p_{j't} + \xi_{j't}}{(1-\lambda)})} \right) \left(\frac{\left(\sum_{j'} \exp(\frac{\alpha p_{j't} + \bar{\xi}_{j't}}{(1-\lambda)})\right)^{1-\lambda}}{1 + \left(\sum_{j'} \exp(\frac{\alpha p_{j't} + \bar{\xi}_{j't}}{(1-\lambda)})\right)^{1-\lambda}} \right) \quad (2.13)$$

Taking the log of the ratio of the total share of product j and the outside good, rearranging, and substituting equation() for $\bar{\xi}_{jt}$ gives:

$$\log(s_{jtm}) - \log(s_{0tm}) = \alpha p_{jt} + \lambda \log(s_{j|tm}) + \beta_3 Opres_{jt} + \beta_4 Dpres_{jtm} + \beta_5 Stop_{jtm} + \xi_{jm} + \Delta\xi_{jtm}$$
$$(2.14)$$

After the inclusion of carrier market dummies, the unobserved quality shock, $\Delta\xi_{jtm}$, is a deviation from the carrier market mean quality. I assume this deviation is observed by the market participants, when making pricing decisions, but not by the econometrician. Prices and conditional market shares, therefore, are likely to be correlated with the contemporaneous demand shock so instruments are required. Carrier origin and destination presence variables are determined by the number and size of markets served by a carrier at those airports, which are themselves determined by route entry and exit choices. Since these entry and exit choices are based on longer run considerations, I assume the presence variables are predetermined with respect to the demand shock and are valid instruments. By similar reasoning, I ignore the potential selection issue arising from the fact than carriers might condition entry and exit decisions on the demand shocks.

I follow BLP in constructing instruments for prices and conditional shares. They suggest functions of the exogenous characteristics of competitors as instruments. The logic of identification is that these variables change the competitive environment, and shift markups accordingly, but are uncorrelated with the carrier's demand shock for the same reason that the carrier's own exogenous characteristics are uncorrelated with its own shock. I use the means and sums of opponent origin and destination presences as well as the number of total competitors, number of connecting competitors and number of low cost competitors as instruments. For comparison, table 2.3 reports utility parameters for the OLS as well as the IV specification.

Table 2.3: Utility Parameters

	IV	OLS
price($100)	-0.6961	-.0488
	(0.2273)	(.0040)
$s_{j|fly}$	0.7281	.9581
	(0.1466)	(.0025)
stop	-0.3287	-.0919
	(0.1302)	(.00913)
Dest. Pres.(millions)	0.0871	.0275
	(0.021)	(.00375)
Origin Pres.(millions)	0.0727	.0092
	(0.0729)	(.0006)
Obs.	12065	
Implied Elasticities	mean	std. dev
American	-2.04	1.32
Low Cost	-2.01	.72
Other	-2.47	1.82

Equation includes carrier and market dummies. Instruments: Sum of opponent presence and stop variables, dummy for opponent entry

Having estimated the demand coefficients, I can calculate residual demand elasticities for each market, $\hat{\kappa}_{jmt}$. Table ??, at the end of the paper, reports the elasticities implied by the estimates. Mean and median elasticities are slightly higher than those found in previous studies (BCS, Berry and Jia 2008), which find mean elasticities in the range of 1.5 to 2. The difference arises likely because these studies allow for a two type random coefficient distribution and also do not aggregate fares. They find evidence the two types have very different price sensitivities. Since my estimates are, in a sense, averaging over the coefficients of the different types, it is expected they might be biased toward the larger group, i.e. price sensitive passengers. The results for Southwest are most troubling; the average elasticity is below 1 implying negative marginal costs and a significant fraction of markets consistently display elasticities below 1. For this reason, I exclude Southwest in estimating the marginal cost and variable profit function.

2.4.4 First Stage: Variable Costs

Combining the elasticities with the assumption that prices don't influence the evolution of state variables, I can back out marginal cost observations using the standard markup equation.

$$\hat{c}_{jtm} = p_{jtm} \left(1 - \frac{1}{\hat{\kappa}_{jmt}} \right) \qquad (2.15)$$

The variation in the data is insufficient to adequately identify both coefficients in the capacity cost term separately. Instead, I set $v = 5$ to reflect the obvious hard constraint that a carrier can never fly more passengers than it flies seats as well as the observation that carriers fly planes at less than capacity, which suggests increasing marginal costs below the capacity constraint. Also, without price data for non-local traffic, the constant marginal cost of non-local passengers and the non-local demand state are not separately identified. I therefore normalize this cost to 0. The other cost and non-local profit parameters are estimated using the moments:

Z^c and Z^{NL} are vectors of instruments. As with carrier local demand shocks, I assume firms know cost and non-local demand shocks when making output and pricing decisions, making load factors endogenous. It has been documented that load factors correlate positively with the level of competition in a market. My identification strategy here then mirrors identification of the utility parameters. Z^c and Z^{NL} contain carrier market dummies, sums and means of opponent demand characteristics, the number of total competitors, number of low cost competitors, and number of connecting competitors. Within market variation in these variables should be uncorrelated with deviations from own mean marginal costs since entry and network building decisions are based on long run considerations, but will shift local quantities by changing the level of competition. These variables also shift non-local traffic by changing the marginal opportunity cost of non-local traffic but should not be related to the non-local traffic price. The parameters $(\hat{\theta}^C, \hat{\theta}^{NL})$ are estimated by minimize the stacked vector of these two moments. Table 2.4 shows the estimates excluding the carrier market dummies.

The differences in variable costs between American and low cost firms is consistent with the 30-50% difference in operating costs suggested by American's own estimates over the period. The estimates imply American's average variable cost per available

Table 2.4: Variable Cost and Non-Local Price Parameters ($100)

		Coeff.	Standard Error
ω_{lf}		1.34	.250
	Other param.	mean	std.dev.
American	ω_j	.461	.307
	$\omega_{lf}\left(\frac{q_{jt}}{\bar{q}_{jt}}\right)^5$	.194	.153
Low Cost	ω_j	.292	.212
	$\omega_{lf}\left(\frac{q_{jt}}{\bar{q}_{jt}}\right)^5$	.131	.114
Total	ω_j	.561	.523
	$\omega_{lf}\left(\frac{q_{jt}}{\bar{q}_{jt}}\right)^5$	.135	.150

Instruments: Number of carriers, number of lowcost carriers, number connecting products, Sums and means of opponent demand characteristics

seat mile, a common measure of costs, is around 3 cents. This is roughly 35% of the around 8 cent system wide total cost per seat mile gleaned from accounting data, suggesting fixed costs are on the order of 65% of total costs.

It is more difficult to evaluate the plausibility of the non-local price parameters. Non-local revenues must be allocated among the routes of an itinerary so even with price data evaluation of the estimates is not feasible. Overall, however, the estimates seem reasonable. The median non-local price is $37 for American and $33 for low cost carriers. The distribution of these prices is also fairly tight with an interquartile range of $30-$44 for American and $25-$38 for low cost carriers.

2.4.5 First Stage: Variable Profits

With estimates of variable costs, I can now recover period variable profit observations by plugging the imputed costs into the variable profit equation

$$\hat{\pi}_{jtm} = p_{jtm}q_{jtm}^L + (\hat{\zeta}\log q_{jtm}^{NL} + \hat{\xi}_{jtm}^{NL})q_{jtm}^{NL} - \hat{C}_{jtm}$$

The mean and median variable profits for American are $1,393,852 and $2,029,134 . For low cost carriers the corresponding figures are $718,819 and $895,720. Table 2.5 shows statistics from the distribution of these profits broken out into the 3 component parts.

Table 2.5: Variable Profit Breakdown

	American		Low Cost		Other	
	Mean (Mn)	Frac Rev.	Mean	Frac. Rev.	Mean	Frac. Rev.
Total Rev	4.06	1	1.57	1	1.86	1
Local Rev.	2.09	.58	1.10	.74	1.13	.52
Non-Local	1.45	.42	.387	.26	.731	.48
Var. Cost	1.09	.16	.429	.21	.535	.25

Calculations use fitted variable costs and non-local demand. All calculations exclude Southwest

Ideally the static profit function would be recovered by solving the static game for each point in the state space. This is computationally demanding so I opt to estimate the variable profit function by fitting a flexible function of the state variables. Also, the computational burden of the second stage estimator does not allow me to estimate different parameters for each market and carrier. I therefore only allow profit functions to depend on the market state as well as the type of each carrier, one of American, Low Cost, or Other. Specifically, I estimate using the following moments:

$$g_{3N}(\theta^{\pi}) = \frac{1}{T}\frac{1}{M}\sum_{t=1}^{T}\sum_{m=1}^{M}\frac{1}{N_m}\sum_{j=1}^{N_m}f_{type}^{\pi}(S_{tm})(\log(\hat{\pi}_{jtm}) - \log(pop_{tm}) - f_{type}^{\pi}(S_{tm})\theta')$$

(2.16)

Where $f_{type}^{\pi}(S_{jtm})$ is a vector of polynomial (quadratic) basis functions in a carrier's own state and means and sums of opponent's states. The actual estimates are difficult to interpret so I do not include them here.

2.4.6   First Stage: Policy Functions

In a Markov Perfect equilibrium, equilibrium policies are functions of the "payoff relevant" state variable alone. While, this restriction provides useful guidance, equilibrium policies are rarely available in closed form. Without knowing the functional form the optimal way to proceed is estimate the policies non-parametrically. Data limitations, however, preclude this. I choose to estimate linear functions of the state variables and include relevant interaction terms.

Table **??**, in the back of the paper, reports coefficients from entry and exit probits. As found in previous literature, origin and destination presence are very important predictors of entry likelihood and to a lesser extent, exit likelihoods. As found by Berry

(1990), entry by carriers who have no presence at either market endpoint is very rare. In a few markets, there are carriers that appear to repeatedly enter and exit the market. I assume that these are seasonal routes and exclude those market carrier observations for which there are more than two total entries.

I estimate the capacity adjustment policy functions using a flexible polynomial specification. As in the variable profits section, I estimate capacity policies for American, Low Cost, and Other type carriers and treat mean carrier market costs as additional state variables. Formally, I estimate capacity policies via the moments:

$$g_{4N}(\theta^{\Delta\bar{q}}) = \frac{1}{T}\frac{1}{M}\sum_{t=1}^{T}\sum_{m=1}^{M}\frac{1}{N_m}\sum_{j=1}^{N_m}f_{type}^{\Delta\bar{q}}(S_{jtm})(\Delta\bar{q}_{jtm} - f_{type}^{\Delta\bar{q}}(S_{jtm})\theta^{\Delta\bar{q}\prime}) \qquad (2.17)$$

Where $f^{\Delta\bar{q}}(S_{jtm})$ is a vector of selected polynomial terms. As with the variable profit function identification rests on there being sufficient variation in the observed states and the model being correctly specified.

The estimation strategy taken here is inconsistent with the model in two ways. First, in the model, the exit and capacity adjustment decisions are not distinct, a firm exits by choosing to sell off all of its capacity. Here I estimate, and below use for simulation, separately estimated capacity and exit policies. I do this to allow for potential misspecification by allowing factors independent of capacity costs to affect exit decisions. The second inconsistency is the failure to correct the capacity policy estimate for the truncation implied by the assumption that carrier's can not sell off more capacity than they currently hold. The consequences of these choices, however, are minimal. The fitted probability of choosing to move to a negative capacity state is low for states observed in the data and the probability of exit is high for low levels of capacity. In other words, together the exit and capacity policy tell a carrier to move up or get out at low levels of capacity.

2.4.7 Second Stage: Fixed,Entry and Capacity Costs

In this section I estimate the dynamic parameters of the game; the parameters describing capacity, entry and exit costs. I do this by using a forward simulation estimator of the type suggested in Bajari, Benkard, and Levin (2007). The estimator is based on the

inequalities implied by the above Markov Perfect equilibrium assumptions.

Abusing notation, define the value of an incumbent prior to seeing it's capacity cost shock and with all competitors following an arbitrary policy profile Ω by:

$$
\begin{aligned}
V_{type}^I(S|\,\Omega) \;\; = \;\; & E_{\varepsilon^F}[\pi_j(S) - \phi_j - \gamma^{\bar q}\bar q_j - C^{\bar q}(\Delta\bar q_j(\Omega_j),\varepsilon_j) \\
+ \;\; & \int V_{type}^I(S'|\,\Omega_j)\Pr(dS'|\Delta\bar q_j(\Omega_j),S,\Omega_{-j})]
\end{aligned}
$$

Let Ω^* be a Markov perfect equilibrium strategy profile. Then for each carrier j, Ω^* must satisfy:

$$
V_{type}^I(S|\,\Omega_j^*,\Omega_{-j}^*) \geq V_{type}^I(S|\ \Omega_j,\Omega_{-j}^*) \qquad \forall\,\Omega_j,\ \forall S
$$

The second stage estimator exploits these inequalities by plugging in the estimated reduced form policies for the equilibrium strategies

$$
\hat V_{type}^I(S|\,\Omega_j^*(\hat\theta_{FS}),\Omega_{-j}^*(\hat\theta_{FS});\theta_{SS},\hat\theta_{FS}) - \hat V_{type}^I(S|\,\Omega_j,\Omega_{-j}^*(\hat\theta_{FS});\theta_{SS},\hat\theta_{FS}) \geq 0 \quad \forall\,\Omega_j,\ \forall S
$$

where $\hat\theta_{FS}$ is the vector of parameters estimated in the first stage, $\Omega^*(\hat\theta_{FS})$ denotes the reduced form estimate of the equilibrium policy profile, and θ_{SS} is the vector of dynamic cost parameters including the variance parameter describing the distribution of the linear capacity cost shocks.

From the above discussion, for any strategy profile, Ω, the value function is linear function of these parameters and has 3 terms. The first term is the expected discounted value of the flow profits accruing to the firm while it remains an active competitor. The second term is the expected discounted stream of capacity adjustment costs the firm incurs. And the third term is the expected discounted scrap value (entry cost) an incumbent (potential entrant) receives (pays) upon exiting (entering) the market. All expectations are rational in the sense that they are taken with respect to the true underlying transition functions, denoted Ξ and strategies. Formally, the value function for an incumbent can be written:

$$
\begin{aligned}
\hat V_{type,m}^I(S|\,\Omega_j,\Omega_{-j};\theta_{SS},\hat\theta_{FS}) \;\; = \;\; & E_{\Omega,\Xi}\mathbf{\Pi}_j(S;\hat\theta_{FS}) \\
- \;\; & E_{\Omega,\Xi}\mathbf{C}_j^I(S;\theta_{SS},\hat\theta_{FS}) - E_{\Omega,\Xi}\mathbf{\Phi}_j(S;\theta_{SS},\hat\theta_{FS})
\end{aligned}
$$

Where,

$$E_{\Omega,\Xi}\mathbf{\Pi}_j(S;\theta_{FS}) = E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\pi(S_t;\hat{\theta}_{FS})|S_\tau = S\right] \tag{2.18}$$

$$E_{\Omega,\Xi}\mathbf{C}_j^I(S;\theta,\hat{\theta}_{FS}) = \eta_{1,type}^+ E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\max(0,\Delta\bar{q}_j(S_t,\varepsilon_{jt};\hat{\theta}_{FS}))|S_\tau = S\right] \tag{2.19}$$

$$+ \eta_{2,type}^+ E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\max(0,\Delta\bar{q}_j(S_t,\varepsilon_{jt};\hat{\theta}_{FS}))^2|S_\tau = S\right]$$

$$+ \eta_{1,type}^- E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\min(0,\Delta\bar{q}_j(S_t,\varepsilon_{jt};\hat{\theta}_{FS}))|S_\tau = S\right]$$

$$+ \eta_{2,type}^- E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\min(0,\Delta\bar{q}_j(S_t,\varepsilon_{jt};\hat{\theta}_{FS}))^2|S_\tau = S\right]$$

$$+ \sigma_{type}^E E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\Delta\bar{q}_j(S_t,\varepsilon_{jt};\hat{\theta}_{FS})\varepsilon_{jt}|S_\tau = S\right]$$

$$E_{\Omega,\Xi}\mathbf{\Phi}_j(S;\theta,\hat{\theta}_{FS}) = E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\mathcal{I}_{\{\bar{q}_{jt}>0\}}\phi_j|S_\tau = S\right] \tag{2.20}$$

$$+ \gamma^{\bar{q}}E_{\Omega,\Xi}\left[\sum_{t=\tau}^{\infty}\beta^{t-\tau}\mathcal{I}_{\{\bar{q}_{jt}>0\}}\bar{q}_{jt}|S_\tau = S\right] \tag{2.21}$$

The linear form of the value function makes the forming the simulated minimum distance estimator simple. The terms inside the expectations depend only on the simulations using first stage estimates. Bajari et al (2007) show how to form consistent estimates of these terms. The value function can then be expressed as the product of the expected discounted value terms and the vector of second stage parameters:

$$\hat{V}_{type}(S|\ \Omega_j,\Omega_{-j};\theta_{SS},\hat{\theta}_{FS}) = W_{type}(S,\Omega_j,\Omega_{-j};\hat{\theta}_{FS})\cdot\theta_{SS}' \tag{2.22}$$

The Markov Perfect Equilibrium assumption implies there can are no profitable deviations from the observed policy. Here, the profitability of a deviant policy can be expressed as:

$$g(x,\theta_{SS}) = (W_{type}(S,\Omega_j,\Omega_{-j}^*;\hat{\theta}_{FS}) - W_{type}(S,\Omega_j^*,\Omega_{-j}^*;\hat{\theta}_{FS}))\theta_{SS}' \tag{2.23}$$

The estimator chooses policies that minimize the profitability of these deviations. Formally, I randomly draw a set of states and alternative policies from a distribution

H to generate a set of n_k inequalities. The true parameters satisfy:

$$\theta_{SS} = \arg\min \int \mathcal{I}_{\{g(X^{(k)}, \theta_{SS}) > 0\}} g(X^{(k)}, \theta_{SS})^2 dH(X^{(k)}) \tag{2.24}$$

I follow Bajari et al. and form the sample objective function as:

$$Q_n(\theta_{SS}) = \frac{1}{n_k} \sum_{k=1}^{n_k} \mathcal{I}_{\{g(x^{(k)}, \theta_{SS}) > 0\}} g(x^{(k)}, \theta_{SS})^2 \tag{2.25}$$

Using the estimated value of incumbency, I can estimate the distribution of sunk entry costs using the fact that the entry policy satisfies:

$$\Pr(\chi_{jt}^* = 1|S) = \Pr(\psi_{jt} \leq V_j^I(S,)) \tag{2.26}$$

The left hand side of the equation is the firm's entry policy, estimated in the first stage. I therefore estimate the distribution by simulating the value function for K different states and estimating the mean and standard deviation of Ψ_j by:

$$(\hat{\gamma}_{0j}^E, \hat{\gamma}_1^E, \hat{\gamma}_2^E, \hat{\sigma}^E) = \hat{\theta}^E = \arg\min_{\theta^E} K^{-1} \sum_{n=1}^{K} (\hat{\chi}_j^*(S_n) - \Psi(V_j^I(S_n); \theta^E))^2 \tag{2.27}$$

Capacity adjustment costs are identified by comparing the capacity policies to the marginal value of capacity, recovered in the first stage. The estimator asks: Which set of parameters minimize the implied amount of money left on the table, where money on the table is the difference between the marginal value of capacity and the marginal cost of capacity. American adjusts capacity more often and more quickly than its rivals, despite more persistent profitability states. Under the assumption proportional fixed costs are the same across firms, this implies the marginal costs and the curvature of the cost function required to rationalize American's capacity behavior are lower than its rivals. In practical terms identification is achieved through appropriate choices of alternative policies for simulation. I choose alternatives by randomly perturbing the coefficients of the first stage capacity estimates to generate policies that respond more quickly or more sluggishly to changes in the marginal profitability of capacity.

Fixed costs are identified by comparing a firm's exit policy to the overall variable profitability of remaining in the market. Here, the amount of money left on the table is the value of the outside option for a firm that chooses to continue, normalized to zero, or

Table 2.6: Dynamic Cost Parameters

		Coeff.	S.E.
Entry/Exit			
(Thousands of Dollars)			
ψ (Sunk Entry Cost)	AA	–	
	LC	481.87	84.19
	Oth.	338.90	137.94
	$Opres$(millions)	-8.67	5.68
	$Dpres$(millions)	-11.42	1.12
ϕ (Fixed Cost)	AA	132.91	43.17
	LC	236.06	51.23
	Oth.	213.17	88.84
$\gamma^{\bar{q}}$		11.596	2.66
Fixed/Capacity			
η_1^+ (Linear Positive)	AA	19.05	2.28
	LC	26.60	2.96
	Oth.	28.11	6.43
η_1^- (Linear Negative)	AA	18.37	2.47
	LC	24.44	3.63
	Oth.	21.47	5.55
η_2^+ (Quadratic Positive)	AA	2.36e-4	.86e-4
	LC	3.10e-4	1.33e-4
	Oth.	5.16e-4	3.88e-4
η_2^- (Quadratic Negative)	AA	1.51e-4	.77e-4
	LC	2.66e-4	1.09e-4
	Oth.	1.01e-4	2.68e-4

Estimates based on simulations of 1000 alternative paths for each of 100 states. Standard errors based on 100 bootstrap draws.

the value of staying in the market for a firm that chooses to exit. Identification of fixed costs is weak due to a small number of exit observations. For American the problem is worse. Since American never exits, its fixed costs are not identified without the assumed parametric form of the probit model. Entry costs are similarly identified by comparing the value of potential incumbency to the value of staying out of the market. In the case of entry costs, not even the parametric form can identify American's costs. Since American is active in every market in the sample, there are no observations of it as a potential entrant. Table 2.4.7 reports the dynamic cost parameter estimates.

The results imply median net profit margin for American is 18%, while for low cost

firms it is 15%. The corresponding mean values are 26% and 19%. Avoidable fixed costs, represent 13% of median variable profits,$1,393,852 for American and 33% of low cost median variable profits, $718,898. The fixed capacity costs parameter suggests a 150 seat jet costs a carrier that flies it once daily around $200,000 per quarter. In total, fixed capacity costs are around 57% of median variable profits for American and 50% for low cost carriers. Industry sources suggest recent system wide margins, though highly cyclical, range around 8% for large network carriers like American and around 10% for low cost carriers. The estimates are broadly consistent with this after acknowledging DFW is a disproportionately large source of American profits and local markets provide higher margins.

Median Sunk Entry costs for low cost carriers are approximately 67% of median variable profits. This suggests entry costs are high after factoring in the implied sunk capacity costs of entry; Entering firms have to make relatively large capacity additions to cover fixed costs.

2.5 Antitrust Policy

In legal settings, the most commonly accepted definition of predation is the sacrifice of short run profits that leads to the exit of competitors and, in so doing, leads to an increase in long run profits through enhanced market power. The current, *Brooke Group,* standard of predation operationalizes this definition by employing a two part test. The first test requires evidence that an alleged predator has priced below "a relevant measure of cost". The second part requires a plausible scenario of expected "recoupment through monopoly power, generally this is evidence of (re)entry barriers, sufficiently high market concentration etc..

The origins of the cost based tests endorsed by *Brooke Group*[13] is the rule and rationale proposed by Areeda and Turner (1975). They argue a rational firm will never set price below marginal cost in the absence of predatory motives and therefore suggest this cost as the relevant standard. In the absence of acceptable measures of marginal costs, they suggest using average variable costs as a proxy for this ideal standard. The failure of the *Brooke Group* to take a stand on exactly which measure of cost is relevant

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[13] *Brooke Group Ltd. V. Brown & Williamson Tobacco Corp.* (1992) 509 U.S. 209-258.

is indicative of the measurement issues acknowledged by Areeda and Turner as well as the ensuing debate as to which if any justified by a coherent economic theory. Average variable costs, average total costs, average avoidable costs and incremental costs have all been suggested as theoretically appropriate rules.

In this section, I use the estimated model to evaluate American's liability in the Wichita market according to various cost tests that have been suggested and applied since Areeda and Turner (1975). These are average cost based tests, average avoidable cost, average total cost, and average incremental cost, suitably reformulated to the non-price competition of the model I find that American violates all of the proposed cost based tests in the Wichita market. I evaluate the efficacy of these tests by introducing a definition, following Ordover and Willig (1981) of predatory incentives. In their definition, an act is predatory if it is optimal when its effect on rival exit behavior is considered but suboptimal otherwise.

After determining liability, I evaluate how the welfare consequences of predation, as defined, compare to the welfare consequences of various remedies. While the American case was dismissed prior to the consideration of appropriate remedy, I consider two possible remedies.[14] The first remedies I look at the proposed by the Department of Transportation *Fair Competition Guidelines*, drafted at the height of policy concern about airline predation but never enacted. These rules amount to limitations on the amount of capacity incumbent carriers can add in response to a rival entry and I recalculate equilibrium under these restrictions to understand how these change the distribution of market structures over time. Second, I calculate the treble damages implied by each of the cost test violations by using the fitted residual capacity costs, recovered in estimation, to simulate the model under the "but-for" that American was unable to violate the tests.

2.5.1 Benchmark Model

To analyze the implications of predation policy in the Dallas-Wichita market, I first solve the model in the absence of policy interventions. I assume there are 2 potential

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[14] See American's Submission Regarding Remedy. The submission requested that the liability and remedy determination by conducted jointly. The court opted to take the government's position and separate the two.

competitors, American and a low cost competitor. I make this restriction because the data predict a low likelihood of entry from any of the firms with presence at Dallas or Wichita and the market is small.[15]

To solve the model I discretize the state space. I split each firms capacity state into 21 equispaced intervals from 0 to 135,000. Each increment (6500 seats) is approximately equivalent to flying a small jet (150 seats) 3-4 times per week for a quarter. I discretize the local demand state into 5 bins from -4.3 to -3.9, the range over which they vary in the data. I set the non-local demand state to 2.04 for American and 1.80 for the low cost carrier. Constant marginal costs are set to $54 for American and $34 for the low cost carrier.

I calculate the reduced form profit functions for each state by explicitly solving the system of first order conditions (4) conditional on the state vector. Markov Perfect equilibrium, policy and value functions for each player, is then computed using a Gauss-Seidel algorithm similar to that described in Erickson and Pakes (1995). The capacity policy functions give the probability distribution over next period states, where the underlying random variable is the private information capacity cost shock. Similarly the entry policy for a potential entrant is a probability distribution over the binary enter stay out choice. The underlying random variable is the sunk entry cost draw.

To simulate the model, I take draws from the estimated distributions of the private information and plug them into the computed policy functions. Figure 2.5.1 show the model time series for prices and capacities using the observed values of exogenous shocks versus the actual series.

[15] Experiments allowing for 3 competitors show a third firm very rarely enters the market. Moreover, entry of two low cost carriers into this market is unlikely and the estimation results for Other type carriers are implausible.

Figure 2.4: 1993-2000 Benchmark Model Simulation v. Actual Series
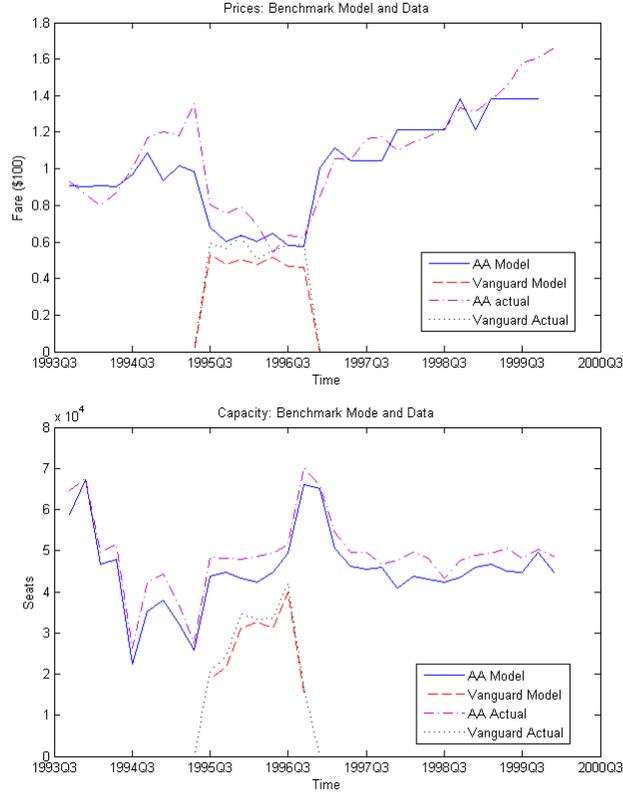
2.5.2 Assessing the Efficacy of Cost Based Liability Tests

The uncertainty in the model induces outcomes that will, ex-post, violate some cost test regardless of the presence of predatory incentives. The appropriate formulations of tests therefore are based on ex-ante beliefs and the information a carrier has when making its decision. The first rule I consider, arguably the most stringent, is the average incremental cost test. From the perspective of a firm with $\bar{q}_j$ units of capacity the adjustment cost of increasing capacity is avoidable, however, in periods subsequent to the increase profits accrue to this decision. I assume the current period cost of adjustment is the cost of adjustment amortized to the infinite horizon. This test asks whether the average revenue earned on a relevant increment (decrement) of output exceeds the average cost of providing that increment (decrement).

$$\beta \mathcal{E}_{\Omega^*(S),\xi'}[\pi_j(\bar{q}_j^*, \bar{q}_{-j}(S), \xi') - \pi_j(\bar{q}_j, \bar{q}_{-j}(S), \xi')|S] \geq \gamma^{\bar{q}}(\bar{q}_j^* - \bar{q}_j) + \frac{1}{r}C^{\bar{q}}(\bar{q}_j^* - \bar{q}_j, \varepsilon_j) \quad \text{(R1)}$$

where q_j^* is the new level of capacity and $r = \frac{(1-\beta)}{\beta}$.

The second rule is a formulation of the average avoidable cost test endorsed in Baumol (1997).   Baumol's notion of avoidable costs only considered the firm's shut down option.   Avoidable costs were those that could be avoided if the firm were to exit.   In this context, however, a carrier can not only choose to shut down but also adjust capacity to avoid some costs.   In fact, shut down is often costly since sunk costs increase quickly in the level of capacity.   I define avoidable costs as the maximum cost savings that could be achieved by choosing a lower level of capacity.

$$\beta \mathcal{E}_{\Omega^*(S),\xi'}[\pi_j(\bar{q}_j^*, \bar{q}_{-j}(S), \xi')] \geq \max_{\bar{q}_j' < \bar{q}_j^*} (\gamma_j^{\bar{q}}(\bar{q}_j^* - \bar{q}_j') + \frac{1}{r}(C^{\bar{q}}(\bar{q}_j^* - \bar{q}_j, \varepsilon_j) - C^{\bar{q}}(\bar{q}_j' - \bar{q}_j, \varepsilon_j))) \quad \text{(R2)}$$

Figure 2.5.2 show plots of American's performance with respect to these tests in the Wichita market. The left hand side profit measure is shown against the right hand side cost measure. Figure 2.5.2 a shows that American violates the incremental cost test in the fourth quarter of 1994 and in the fourth quarter of 1996. Using the avoidable cost test, American is in violation in the fourth quarter of 1996, the period alleged in the DOJ's suit.

To evaluate the efficacy of the cost tests, I use the definition of Ordover and Willig (1981) to measure predatory incentives.   An act is predatory if it is optimal when its impact on its rivals exit probabilities is considered but suboptimal otherwise.   To formalize this, I follow Cabral and Riorden (1997) and ask what behavior would be expected if American did not internalize the marginal impact of capacity additions on Vanguard's exit probability.   To implement this I recalculate American's policy under the assumption that Vanguard's exit probability remains constant across American's capacity states and assumes Vanguard's actual behavior is exactly its observed behavior. Figure 2.5.2 shows the resulting capacity series plotted with the actual (benchmark model) series.   The figure shows that predatory incentives were present throughout Vanguard's tenure in the market.   The incremental cost test draws a false positive in the early period prior to Vanguard's entry, and a false negative in the 3rd quarter of 1996.

Figure 2.5: Incremental and Avoidable Cost Tests
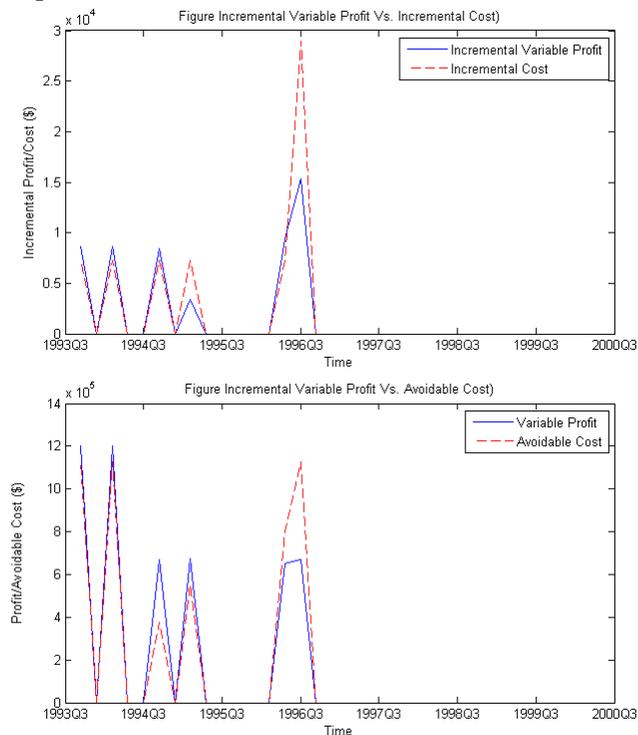
2.5.3 Remedies: Damages

Calculating damages, the lost profits and consumer welfare resulting from illegal preda-
tory acts, requires constructing a counterfactual scenario for the market but for the
predatory acts. I calculate this counterfactual in 2 ways, both of which assume liability
is determined by one of the two cost tests and the relevant counterfactual is the market
but for a violation of the test. In the first approach, I consider equilibrium policies
from the benchmark, unconstrained model and allow American to re-optimize given it
is prohibited from violating a given cost test. In the second approach, I recalculate
equilibrium under the restriction that American is unable to violate the cost test in any
period. Conceptually, the difference between approaches is that in the former the firms
behave as if the restriction is a one off policy, i.e. they behave as if the probability of
detection and punishment is 0, whereas in the latter, firms behave as if violations of the
test are certain to be detected and punished. These can be seen as bounding cases of

Figure 2.6: A Measure of Predatory Incentives
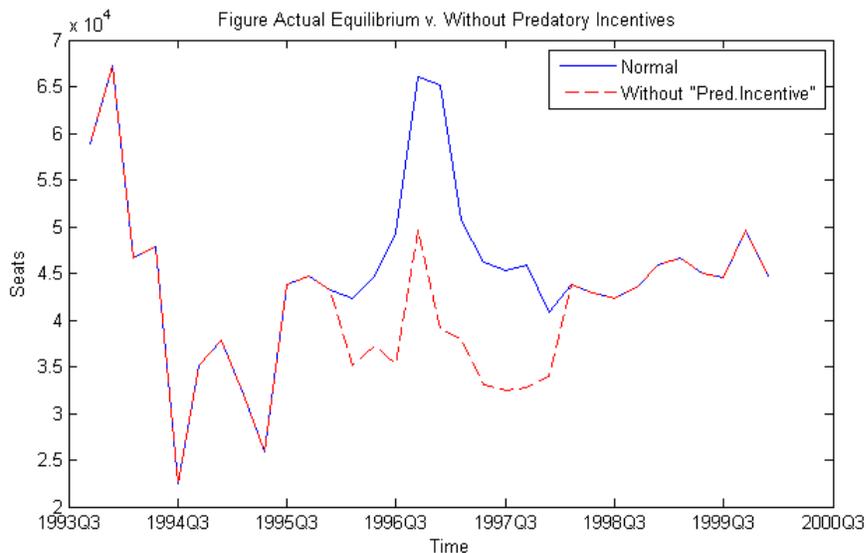
reality in which the probability of detection and punishment is small but not 0.

The particulars of the American case are such that this distinction turns out to be a major one. In the period of Vanguard's exit it was hit with a large negative capacity cost shock, this is seen in the steep decline in capacity in the period preceding its exit and in the *same* period as American's steep increase in capacity, and subsequent violation of the cost tests.[16] The model predicts that Vanguard continues to exit most of the time in the one off scenario. In the recalculated equilibrium, however, Vanguard's behavior is much different exiting far less often.

Table 2.7 shows the results of these simulations. Overall the numbers are modest. In the one off scenario, the incremental cost test gives a large improvement in Vanguard's profits but a *decrease* in consumer welfare. This is because when Vanguard does not exit competition among the firms is quite dull. Vanguard's exit probability is not affected enough to offset the negative welfare impact under the rule in the cases where Vanguard continues to exit. Vanguard's exit policy is materially affected under the complete enforcement scenario. The difference in the damages figures highlights the

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[16] It is likely that this is partially an artifact of the assumption that decisions are made simultaneously at the beginning of a period. However, recall the exit decision was precipitated by a management change and overall restructuring at Vanguard.

Table 2.7: Damages (Thousands of Dollars)

| | "One Off" | | Complete Enforcement | |
	Incremental (R1)	Avoidable(R2)	Incremental	Avoidable
Vanguard Profit Loss	45.67	29.79	123.52	103.80
Consumer Welfare Loss	-94.64	34.10	43.03	85.59
Total Change	-49.03	63.887	166.55	189.39
3xTotal Change	-147.09	191.66	499.65	568.17

Figures are averages of 10000 simulated runs with cost shocks drawn conditional on observed behavior. "One off" means that firms follow benchmark equilibrium except in a period with a cost test violation. "Complete Enforcement" means equilibrium probabilities are recalculated under the restriction that the cost test can not be violated. Welfare change is measured as compensating variation.

subtleties of constructing an appropriate counterfactual.

2.5.4 Remedies: "Fair Competition Guidelines"

During the early 1990s entry and growth of the low cost segment was particularly rapid. By 1995, they had, together, achieved a 20 percent share of the market.[17] In the second half of the 1990s, however, this growth began to slow, leading policy makers and the customers who had benefited from the steeply falling fares to look for reasons why. One popular answer to the question was predatory responses to low cost entry by big incumbents.

From late 1993 to late 1999 there were over 30 complaints of exclusionary, predatory conduct filed by low cost carriers and investigated by the Department of Transportation. The problem was considered severe enough that in April of 1998 the Department of Transportation circulated a draft of proposed "Fair Competition Guidelines" for the industry, stating:

> "We have concluded that unfair exclusionary practices have been a key reason that competition from new low fair carriers has not been able to penetrate concentrated hubs."[18]

The FCG addressed what was perceived to be the typical "predatory" pattern: 1) A low cost carrier enters a non-stop hub route of a dominant incumbent 2) The incumbent responds with steep fare cuts *and* capacity increases. The Guidelines would initiate

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[17] Market share is defined as share of passenger revenue miles from Bureau of Transportation Statistics T1 database.

[18] DOT Fair Competion Guidelines proposal p.7

enforcement proceedings whenever one of 3 rules, stated in terms of the incumbent's passenger and capacity response relative to the entrant's capacity, was violated:

1. The major carrier adds capacity and sells such a large number of seats at very low fares that the ensuing self-diversion of revenue results in lower local revenue than would a reasonable alternative response,

2. The number of local passengers that the major carrier carries at the new entrant's low fares (or at similar fares that are substantially below the major carrier's previous fares) exceeds the new entrant's total seat capacity, resulting, through self-diversion, in lower local revenue than would a reasonable alternative response, or

3. The number of local passengers that the major carrier carries at the new entrant's low fares (or at similar fares that are substantially below the major carrier's previous fares) exceeds the number of low-fare passengers carried by the new entrant, resulting, through self-diversion, in lower local revenue than would a reasonable alternative response

In the context of the model these remedies amount to restrictions on the amount of capacity that can be added to a route by the hub incumbent. Figure 2.6 and 2.7 show the time series plots for model predicted prices and capacities from the the counterfactual equilibrium with American able to add no more than 6500 seats in each period. Table 2.8 shows price, capacity and consumer welfare statistics under various alternative restrictions. The FCG type remedies trade off the increased consumer utility during the predation period with the harm to consumer welfare if the monopolization is successful. As evidenced by Table **??**, the model predicts a net gain in consumer welfare would have been realized had FCG type remedies been in place at the time of Vanguard's entry.

There are several problems with such retrospective analysis, however. First, the rules must be enforced without knowledge of the ex post realizations of uncertainty, the capacity costs in the model. If different realizations lead to different market outcomes than these alternative outcomes have to be weighed. Second, if provisions are intended to protect efficient, small, and financially weak entrants like Vanguard, either selective

Table 2.8: Actual and Expected Profit Changes Under FCG type Remedies(Hundred Thousands of Dollars)

		Actual	Expected
Compensating Variation	Cap = 6500	3.80	.6270
	Cap= 13000	4.03	1.99
	Cap = $\bar{q}_{-j}$	1.08	2.18
Vanguard Profit	Cap = 6500	2.20	2.11
	Cap= 13000	1.35	1.15
	Cap = $\bar{q}_{-j}$	.19	.96
American Profit	Cap = 6500	-4.13	-2.46
	Cap= 13000	-2.44	-1.15
	Cap = $\bar{q}_{-j}$	-.65	-1.04

Figures are means of 10000 simulated runs of the model. Actual change: Simulated cost shocks drawn conditional on behavior actually observed. Expected change: Simulated cost shocks drawn unconditionally. Profits and calculated by the 12 quarter discounted sum of the period values.

enforcement is required or there is a risk that the remedies can be exploited by firms they are not intended to protect.

To address the ex ante uncertainty issue I use equilibrium policy functions to simulate the distribution of market structures over time following the entry of Vanguard in the absence of the remedies. Figure 2.6 displays this distribution for two, eight, and 20 periods following entry for the benchmark equilibrium. While there is a high probability that the incumbent responds aggressively and drives the entrant out of the market, there is also a high probability that the aggressive response is unsuccessful and the firms compete vigorously for customers. Figure 2.6 show the same distributions under the assumption that American is restricted to 6500 seat increases in capacity. Clearly the restriction prevents American from monopolizing the market but it also dulls competition in the intervening periods. The "Expected" columns of table 2.8 show the welfare effects of the FCG remedies from this, ex-ante, perspective. In this market, the chilling effect of predation policy is outweighed by the diminished likelihood of monopolization by driving a rival out, as well as the increased likelihood of rival entry.

2.6   Conclusion

Since the U.S. airline industry was deregulated in 1978, one of the most important changes in the industry has been the rise of the so-called low cost carriers. The growth of these carriers has brought significant benefits to customers, through steeply lower fares, in the markets they have entered. Low cost has been equally damaging to the profitability of incumbent carriers, particularly the large, hub and spoke carriers. These carriers, in the absence of low cost competition, enjoy substantial markups on flights to and from their hubs. Paradoxically, antitrust enforcers and industry regulators have worried that low cost entry has stimulated too much competition in the sense that incumbent responses in the sense that incumbent responses to that entry have been predatory.

This paper has shown that this concern may be well founded. I propose a dynamic model of airline competition, in which predatory behavior arises in the equilibrium of the game. Differences in cost structures between large, hub incumbents and small, low cost entrants cause these predatory incentives to arise. Low cost carriers, with low marginal costs, set low prices and cut into the profitability of the hub carriers. These hub carriers however have lower avoidable fixed costs, due to prior sunk cost investments in their network, and are thus more committed to the market. Hub carriers are then able to prey on their low cost rivals by making costly commitments of capacity to a route.

While ruling out several interesting theories of predation, the structure of the model confers some important advantages. Most important among these is its usefulness in interpreting real market data. An incumbent's principal tool for implementing a predatory strategy, capacity, is easily measured using reliable, publicly available data. The Markov Perfect structure of the model does not allow for predation based on reputation or other belief related phenomenon but provides discipline by forcing predatory incentives to only rely on fundamental features of competition. It also makes to model amenable to techniques for estimating the structural parameters.

Enforcement of predation standards in the airline industry, as in other industries, is difficult. This difficulty stems from the fact that predation is, by definition, a dynamic and strategic phenomenon but there is a dearth of tools to think about it

as such. Caution, therefore, generally has to win out, as authorities fear attempting to prevent an ill-defined behavior risks distorting incentives for vigorous competition. Applying the estimated model to a market from the Department of Justice's 2000 case against American Airlines, I find these problems are less severe than the problem of predatory behavior itself. Commonly used static cost tests, which test for predatory liability by comparing static revenue measures to static cost measures, are shown to capture predatory incentives well when compared against a precise measure of predatory incentives. Also, the results indicate, though predation remedies give rise to competition dulling incentives, they also give rise to pro-competitive distortions, namely increased likelihood of low cost entry. I find, on net, there is substantial scope for welfare improving policy.

This paper has explored only a few of the potential implications of the dynamic model. I have used a single market to demonstrate the model, however, more complete answers to the predation question require deeper analysis. For example predation policy must consider how its impact changes with changing market conditions or across heterogeneous markets. Joskow and Klevorcic (1979) propose a 2 part test for predation in which a court first determines if the structural characteristics of a market make predatory behavior ex-ante plausible and then moves on to apply liability tests. In the airline setting, relevant structural characteristics might include, Business/Leisure traveller mix, market size, market distance, etc. Understanding how changes in these variables affect predatory incentives is important for understanding the potential consequences of antitrust predation policy.

The economics highlighted here also have potential implications for other antitrust and industry problems. For example, there are potential applications to analysis of airline mergers. In the standard analysis, mergers that involve firms that have limited route overlap, "end-to-end" mergers such as the 2004 "barbell" merger of U.S. Airways and America West or the 2008 Delta and Northwest merger, are considered fairly innocuous.[19] The model I have presented casts doubt on this assumption. It implies such mergers may have implications for market entry through changes in the cost structure of the merged firm. I leave these questions for future research.

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[19] The U.S. Airways-America West merger was referred to by the firms as "operation barbell" because it merged U.S. Airways considerable presence on the U.S. east coast with America West's presence in the west.

Table 2.9: Elasticities

Carrier	Type	mean	s.d.	perc.10 .	perc.25	perc.50	perc.75	perc.90
American	Non-Stop	-2.31	1.21	-3.94	-3.11	-2.30	-1.24	-.936
	Connecting	-4.02	2.44	-8.50	-7.36	-6.08	-4.66	-3.49
Low Cost	Non Stop	-2.21	.926	-3.51	-2.82	-2.09	-1.57	-1.21
	Connecting	-3.48	1.13	-4.87	-4.09	-3.39	-2.67	-2.23
Delta	Non-Stop	-2.88	1.48	-4.73	-3.80	-2.76	-1.65	-1.23
	Connecting	-4.81	1.22	-6.47	-5.55	-4.70	-3.95	-3.40
Southwest	Non-Stop	-.669	.223	-1.01	-.793	-.615	-.514	-.415
	Connecting	-2.40	1.73	-4.89	-3.37	-2.00	-1.09	-.594
Other	Non-Stop	-2.45	1.39	-4.27	-3.35	-2.36	-1.30	-.97
	Connecting	-4.14	1.82	-6.24	-4.99	-3.96	-3.05	-2.13

Table 2.10: Non-Stop Entry and Exit Policies

	Entry	Exit
$\bar{q}_j/pop_t$		-161.5
		(15.5)
$\sum \bar{q}_{-j}/pop$	-8.93	10.1
	(1.76)	(2.56)
$\bar{\xi}_j$		-.034
		(.098)
$mean(\bar{\xi}_{-j})$	-.431	.203
	(.073)	(.061)
$Dpres_j(millions)$	.635	-.264
	(1.27)	(.151)
$Opres_j$	.097	-.018
	(.0083)	(.022)
$pop(millions)$	.016	-.149
	(.0069)	(.062)
$distance$	.00034	.00026
	(.00023)	(.00018)
$lowcost$	3.05	1.79
	(.727)	(1.02)
$lowcost * Dpres$	6.72	-.018
	(1.27)	(.695)
$lowcost * mean(\bar{\xi}_{-j})$	.389	.185
	(.101)	(.154)
$Constant$	-5.58	-1.58
	(.556)	(.473)
AA		-.78
		(.334)
Observations	12553	5130

Standard errors in parentheses. Potential entrants
are all firms with presence at either the origin or
destination airports.

Figure 2.7: Dallas-Wichita Predicted Prices Under 6500 Seat Cap
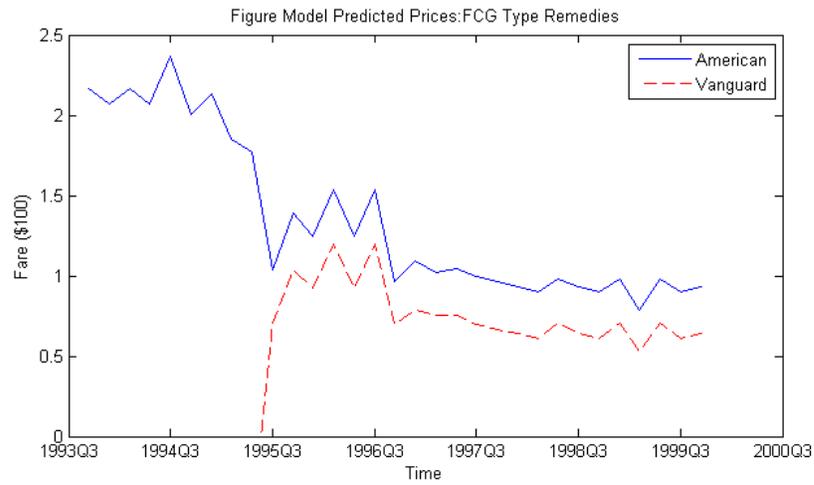

Figure 2.8: Dallas-Wichita Predicted Capacities Under 6500 Seat Cap
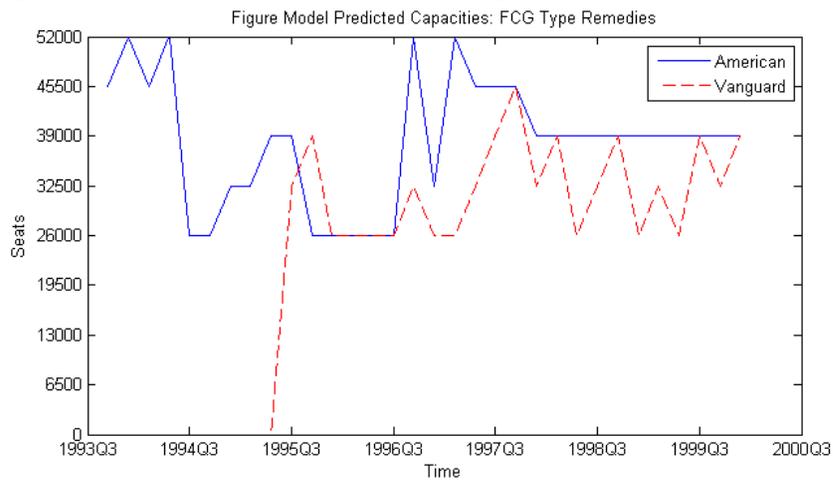
Figure 2.9: Benchmark (Unconstrained) Simulated distribution of market capacity states
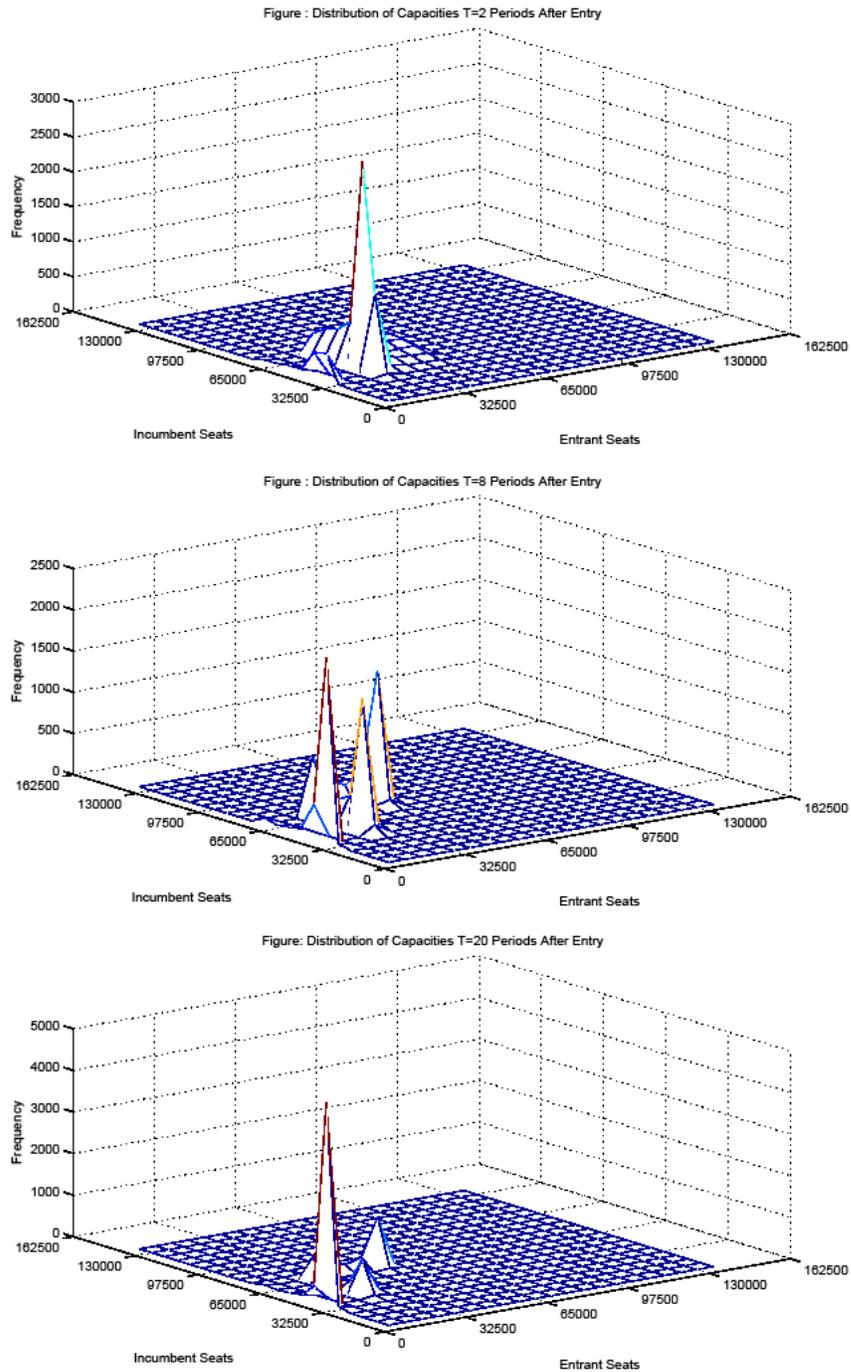
Figure 2.10: Capacity Cap = 6500 Constrained Equilibrium Simulated Market Capacity State Distribution
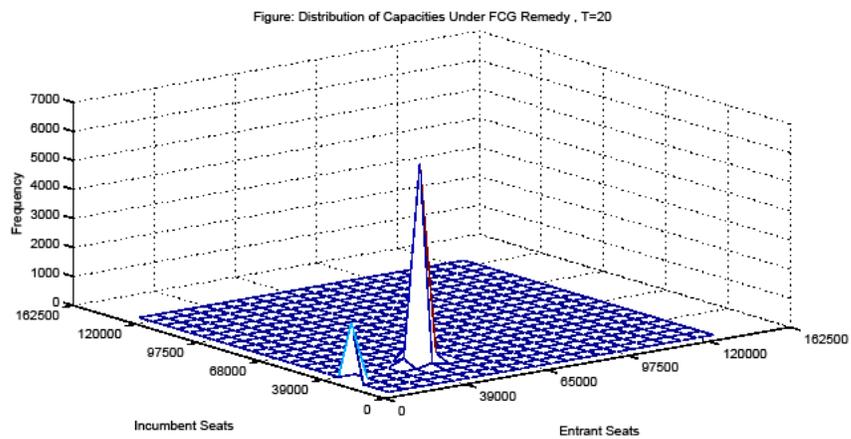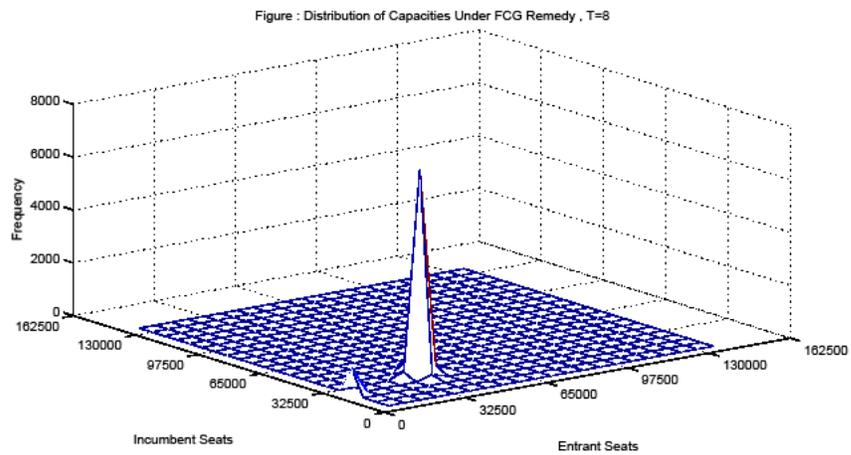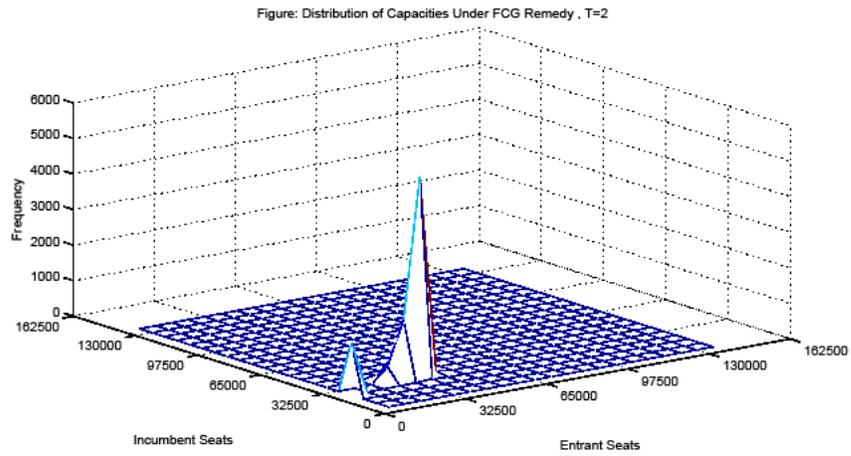
Chapter 3

Does the LIBOR Reflect Bank Borrowing Costs? (with Thomas Youle)

3.1 Introduction

The London Interbank Offered Rate (Libor) is a widely used benchmark interest rate, intended to reflect the average rate at which banks can borrow unsecured funds from other banks. The rate is set each day by averaging the reported borrowing costs of a panel of 16 member banks. Since its introduction in 1986, the Libor has steadily grown in importance and is now among the most widely used benchmark rates in financial contracting. The British Bankers Association (BBA) estimates that $10 trillion of loans and $350 trillion of swaps alone are indexed by the Libor. Since the upheaval in financial markets that started around August of 2007, the Libor has diverged from many of its historical relationships causing market observers to question its proper functioning. An influential article by Mollenkamp and Whitehouse (2008), argued that the Libor was too low and suggested a possible explanation that banks in the panel were intentionally quoting rates that were too low in order to burnish the markets' perception of their riskiness.

In this paper we provide three types of evidence that banks' Libor quotes may not

reflect true borrowing costs. First, we find that bank Libor quotes are very weakly related to other measures of bank borrowing costs, in particular the price of default insurance. This observation is the foundation of the Mollenkamp and Whitehouse analysis and we systematically corroborate their finding in light of some potentially contradictory evidence found in Taylor and Williams (2008). Second, we find it is common for pairs of banks who participate in multiple currency-Libor panels to have different rank orderings in different currencies. This implies that the quoted rates cannot be expressed as the sum of currency specific variables and bank specific variables. Yet most of the variables we would consider important for pricing debt either do not vary across banks, such as the expectations for future inflation, or do not vary across currencies, such as the probability a given bank will default.

The third type of evidence comes from the intraday distribution of Libor quotes. We present a simple model (relegated to the appendix) of bank quote submission in which members may or may not have incentives to misreport. The model predicts, in the presence of misreporting incentives, we should see "bunching "of quotes at particular points. This prediction is due to the form of the rate setting mechanism, which averages the middle eight quotes of the sixteen. If a given bank has incentives to change the Libor (as opposed to simply reporting costs) and it knows the exact location of the pivotal fourth and twelfth quotes, its own quotes will tend to cluster around these pivotal quotes. This is because the marginal impact of that bank's quote on the overall rate, and thus the marginal benefit of changing the rate, goes to zero at these pivotal points. Quotes of banks without these misreporting incentives, should not exhibit this clustering behavior. We find strong evidence of quote bunching behavior consistent with the model. We also show that the intraday distribution of other measures of bank borrowing costs do not exhibit this bunching pattern. Under the reputational theory of misreporting, a bank cares about how the market perceives it's own quote and not the Libor fix itself. It therefore, does not predict that banks will bunch around the pivotal quotes. In this sense, we present evidence in favor of our hypothesis and against the reputation hypothesis and discuss the different policy implications of our results. Moreover, using more recent data, we find evidence of misreporting is stronger in the period *since* markets have calmed somewhat from their recent upheaval.

After establishing our arguments for the existence of misreporting incentives, we

go on to explore the magnitude of quote skewing and the sources of the incentives. To get a sense of the magnitude of skewing we compare the behavior of Libor quotes with the behavior of actual market lending rates in the Eurodollar market. We assume there is a relationship, similar to a bid-ask spread, between the Eurodollar rate and the Libor and that banks are truthfully reporting in a benchmark (pre-financial crisis) period. We then measure the degree of skewing as the divergence in this relationship after the benchmark period. By this measure, we find that the magnitude of skewing is upwards of 40 basis points for some banks, though we emphasize the limitations of the, at best, back of the envelope exercise.[1] Finally, we present suggestive evidence that the misreporting incentives are partially driven by member bank portfolio positions. We find that several banks in the U.S. Libor panel have very large interest rate derivative portfolios, have significant unhedged exposures to U.S. interest rates, and have profited from their interest rate derivative portfolios during the rapid descent of the Libor during 2009. We also argue the direction of bank skewing behavior is consistent with these portfolio incentives. Here, we again emphasize the circumstantial nature of the evidence as the available data is too opaque to make firm claims.

The rest of the paper proceeds as follows: In section 2 we present evidence of the apparent lack of relationship between bank quotes and measures of bank costs as well as evidence of cross currency rank reversals. Section 3 presents our evidence of strategic behavior suggested by the simple model we lay out in the appendix. We also present our Eurodollar bid rate-based counterfactual analysis in this section Section 4 presents our evidence that several panel banks have large Libor positions and have recently profited from a low Libor. Section 5 concludes.

3.2 Libor Quotes and Bank Borrowing Costs

In a competitive interbank lending market, differences in banks' borrowing costs should be significantly related to differences in the banks' credit risk.[2] If the Libor quotes express true, competitively determined borrowing costs, then we should expect the

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[1] There are also many questions about the reliability of the Eurodollar data.

[2] When credit risk is private information, it is possible for credit to be rationed and for risky and safe borrowers to recieve the same interest rates, as in Stiglitz and Weiss (1981). Here we focus on risk measures that are public information, such as market prices for default insurance.

quotes to be related to measures of credit risks, such as the cost of default insurance. Mollenkamp and Whitehouse(2008) were the first to point out the anomalous behavior of bank Libor quotes with respect to bank risk measures, credit default swap (CDS) spreads in particular.[3]

Figure **??** shows the 12 Month U.S. Libor quotes for Citigroup and the Bank of Tokyo-Mitsubishi along with their corresponding 1 Year Senior CDS spreads. The first puzzling fact is that while Citigroup has a substantially higher CDS spread than Mitsubishi, it submits a slightly lower Libor quote. The CDS spreads suggest that the market perceives Citigroup as risker than Mitsubishi, as it is more expensive to insure against the event of Citigroup's default. The Libor quotes, however, tell the opposite story. If Citigroup and Mitsubishi were truthfully reporting their costs, then the quotes suggest that market participants view lending to Citigroup as slightly safer than Mitsubishi. A notable feature the picture is it highlights that bank behavior *after* the crisis had receded, the only time the lower bound rate actually spikes above the actual rate, was more puzzling as other indicators had returned to normal ranges.

A second puzzling pattern is the *level* of Citigroup's CDS spreads relative to its Libor quotes. Given that purchasing credit protection for a loan makes the loan risk free, one would expect difference between the loan rate and the CDS spread to roughly equal the risk free rate. This corresponds to the idea that a loan's interest rate contains a credit premium, here measured by the CDS spread. If loan rates contain other premia, such as a liquidity premia to compensate for the illiquidity of loans, then the loan rate should *exceed* the sum of the CDS spread and the risk free rate. In figure **??**, however, we see that Citigroup's quote is below its CDS spread. This implies that there were interbank lenders willing to lend to Citigroup at rates which, after purchasing credit protection, would earn them a guaranteed 5 percent loss.

The Mollenkamp and Whitehouse analysis and figure **??** paint a picture somewhat at odds with the findings of Taylor and Williams (2008a, 2008b) who find evidence that, at the level of the Libor fix, increasing bank risk *does* explain much the behavior of the

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[3] Credit default swaps are bilateral agreements where one party, the Guaranteer, will pay another, the Beneficiary, if a particular reference entity defaults. The Guaranteer will pay $(1 - R)V$ where R is the recovery rate of the obligations determined in bankruptcy, so that, if the Beneficiary has V amount of obligations owed by the reference entity, the return in the event of default is $RV + (1 - R)V = V$. Purchasing an equal amount of CDS protection makes the debt risk free. In return for this protection the Beneficiary periodically pays rV to the Guaranteer, where r is the 'CDS spread'.

rate. Table 3.1 displays the results of regressions similar to those performed in Taylor and Williams, now including more recent data up to October 2009. The dependent variable in the first specification is the spread between the 3 month U.S. Libor and the 3 month rate on Overnight Index Swaps (OIS).[4] Regressing the overall Libor fix on the Median CDS spread delivers a coefficient of 0.621 which is within the range of coefficients found by Taylor and Williams in their earlier period.

In the next three specifications the dependent variable is the spread of a bank's submitted Libor quote over the OIS rate, and is regressed on the bank's corresponding CDS spread. Now, at the bank level, we find a smaller effect. Controlling for bank-level heterogeneity in the spreads reduces the coefficient further and it becomes negligible once we control for serial correlation in the error terms. The estimated serial correlation is reported as ρ and is very large, as might be expected when working with daily frequency data. Comparing the within and between R^2 of these estimators is suggestive of why the relationship between Libor-OIS and CDS spreads breaks down at the bank-level. CDS spreads seem to do a better job of explaining the quote changes within a single bank than explaining the differences in quotes between banks. This is immediate given the differences in rank ordering as shown in figure **??** where banks with comparatively high CDS spreads submit comparatively low quotes. Furthermore, once we introduce bank-level fixed effects and control for a serial correlation, CDS no longer seem able to explain even the within variation in bank-level Libor-OIS spreads.

The BBA has maintained that, in times of crisis, CDS spreads are not necessarily a better measure of bank borrowing costs than Libor quotes (Mollenkamp and Whitehouse 2008). More evidence can be found by looking at bank behavior in other currency Libor's. Figure 3.2 shows the fix for five such Libor benchmarks.

Many banks participate in multiple Libor mechanisms and presumably there is some relationship between costs between these different markets. It is common for a bank included in multiple currency Libor panels to simultaneously quote a higher rate than another bank in one currency panel and lower rate in another currency. Figure **??** shows the differences in bank quotes in two currencies for four pairs of banks. We see that is is

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[4] Overnight Index Swaps (OIS) are agreements where one party pays a fixed rate in return for a series of floating payments based on an index such the federal funds rate. As the most that can be lost in the event of default is the foregone payments accruing over a short period, they are considered to be considerably safer than bonds and their spread usually considered risk free.

Table 3.1: Bank-level 3 Month LIBOR-OIS Spreads

	LIBOR	Bank-level LIBOR quotes		
		Pooled OLS	Fixed Effects	Fixed Effects, AR(1)
Median CDS	0.621 (0.035)			
CDS		0.474 (0.102)	0.377 (0.098)	0.038 (0.009)
Constant	0.173 (0.020)	0.112 (0.036)	0.334 (0.090)	0.921 (0.001)
N	581	19235	7839	7824
R^2	0.296	0.372		
Within R^2			0.199	0.002
Between R^2			0.001	0.005
ρ				0.995

common for Bank of America to quote a lower rate than the Bank of Tokyo-Mitsubishi in the yen-Libor while submitting a lower quote in the US-Libor. Since the same bank is participating in each currency, the probability of default and thus expected loss is the same for loans in either currency.[5]   is the same for loans issued in either currency. This shows that differences in banks' Libor quotes are not primarily due to differences in credit risk, something we would expect of their true borrowing costs.

The significance of these rank reversals is it that they show that either Libor quotes cannot be expressed as the sum of bank specific variables and currency specific variables, or banks cannot be reporting true costs.[6] Most of the variables that we would expect to be important for pricing debt either do not vary across banks or do not vary across currencies. If banks were truly reporting their costs, then there must be large and

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[5] While bankruptcy laws vary across countries they do not vary across the currency denomination of the obligations.

[6] Formally suppose costs are given by $c_{itm} = \alpha_{it} + \alpha_{mt} + \epsilon_{itm}$, where c denotes borrowing costs, and i, m, and t denote bank, market and time respectively. Differencing differences in bank quotes across markets gives: $(c_{itm} - c_{jtm}) - (c_{itm'} - c_{jtm'} = \epsilon_{itm} - \epsilon jtm$. If the bank-currency specific shocks are such that the ϵs are mean zero and i.i.d, we should see no rank reversals on average.

persistent bank-currency specific risks concerning lenders. While it is possible there could be such effects, such as bank-currency specific liquidity risks, it is less clear that they are important enough to rationalize the magnitude and persistence of the reversals we observe in figure **??**. An alternative explanation would be that in some currencies banks are submitting quotes that are too low. In our earlier discussion, if Citigroup was submitting a quote in the U.S. Libor that was below their true borrowing costs, while a submitting a correct quote in the Yen Libor, this could appear as a rank reversal if Bank of Tokyo quoted true costs in both currencies. We return to this example later.

3.3 Quote Bunching

Our final source of evidence comes from the intraday distribution of bank quotes. First we find that, relative to CDS spreads, Libor quotes are closely clustered together. Prior to August 2007, banks in the U.S. Libor panel submitted similar, often identical quotes. In this pre-crisis period, the CDS spreads for panel banks have also been similar and low. This behavior changed with the onset of the financial crisis in 2007, with the intra-day variation of both Libor quotes and CDS spreads increasing from their historical levels. The intra-day variation of CDS spreads, however, grew considerably larger than that of Libor quotes. Figure 3.4 shows histograms of 12 month Libor quotes, normalized by subtracting the value of the day's fourth highest quote for each bank quote. Libor quotes are much more clustered around the mean than CDS spreads of equal tenor. If banks were truthfully quoting their costs, however, we would expect these distributions to be similar.

There are several possible explanations for the bunching of quotes around the fourth lowest. The one that we pursue here is that some banks have incentive to alter the rate of the overall Libor and the bunching is a result of these incentives interacting with the rate setting mechanism. In the model that we lay out formally in the appendix, a bank's payoff, vis a vis it quote, is the sum of two terms. The first term is proportional to the Libor fix and captures the bank's incentives to change the rate. The second term is the "cost"of misreporting, for example the cost of a BBA investigation, which is triggered by unusual quotes. Bank incentives interact with the truncated averaging mechanism of the Libor. Consider a Libor panel member that knows the quotes of

the 15 other members on a given day.[7]   Figure 3.7 shows graphically that bank's optimal quote problem, which requires equating the marginal benefits of changing the Libor with the marginal cost of misreporting. The marginal benefits function, which assumes the hypothetical bank's payoff is decreasing in the Libor, is a step function with a discontinuity at both pivotal quotes. The optimal quote is the intersection of the marginal cost curves and this step function, which bunches quotes representing a wide interval of true borrowing costs at a (in the picture the lower one) pivotal point.

There may be other explanations for why Libor quotes might be more closely clustered together than other measures of bank borrowing costs. The first is that, in this period, banks faced large reputational risks - bank runs on Northern Rock, Bear Stearns, and others were allegedly fueled by rumors of difficulty of raising funds from other banks. As suggested by Mollenkamp and Whitehouse (2008), an otherwise healthy bank submitting a high quote in the Libor panel might appear to have such problems and, by the same token a bank that actually has these problems might have incentive to submit low quotes to convince the market otherwise. Figure 3.5 shows histograms of bunching behavior for different periods. If anything bunching behavior appears to be stronger since markets have calmed, perhaps due to less volatility and hence more predictability of other bank quotes. That bunching behavior does not appear to go away in the post crisis period, combined with the continued divergence of quote behavior from cost measures in the post crisis period, lends evidence to our proposed incentive channel.

It is important to note different banks may have different net exposures to the Libor. Some banks may profit from a higher overall Libor rate, others may profit from a lower overall rate, and others still might be perfectly hedged. With this in mind, we examine the clustering behavior of individual banks, four of which are shown in figure 3.8. Here we see that Citigroup and Rabobank tend to submit quotes that are identical to the fourth lowest quote of the fifteen other banks, while this is not the case for Norinchukin and WestLB. This is consistent with Rabobank and Citigroup having incentives, potentially stemming from their possession of Libor-indexed contracts, to lower the overall Libor rate, while Norinchukin and WestLB do not have such incentives.

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[7]   Simple forecasting models do an excellent job in predicting the levels of Libor quotes during 2009. This is because Libor is adminstered with a daily frequency and Libor quotes move in a slow and predictable manner. We also note that the basic insight of the model can be extended to the case where there is uncertainty about the exact location of the pivotal quotes.

3.3.1   Constructing the Correct Libor: Eurodollar Bid Rate

The Eurodollar Bid Rate is a market rate for eurodollar deposits. Eurodollars are dollars held by banks outside of the United States, and have historically been an important source of funding for large American banks. We also show that the Eurodollar Bid Rate has had a historically tight relationship with the Libor. Prior to August 2007, indeed for the whole history of the Libor prior to then, the banks submitted quotes between 6 to 12 basis points above the Eurodollar Bid Rate. Banks were treating the Libor, the London Interbank *Offered* Rate, as their perception of the ask rate corresponding to the listed bid rate for Eurodollars. The Eurodollar Bid Rate-Libor spread of 6-12 basis points was then simply something like a bid-ask spread. Since 2007, for the first time the Libor descended below the Eurodollar Bid Rate and at times quite dramatically. Figure 3.10 shows the Eurodollar-Libor spread which is slightly negative prior to August 2007 and then spikes significantly once the Libor dramatically drops below the Eurodollar rate.

In table 3.2 we perform a structural break test to show the collapse of this historic relationship. We can see that, both in levels and in differences, the previous days Eurodollar Bid Rate was more important for determining the following days Libor than the previous Libor rate. This suggests that, prior to the crisis, banks simply observed the preceding days Eurodollar Bid Rate and added a fixed spread. After the crisis, however, the Eurodollar Bid Rate has much less predictive power on the following days Libor. The lagged Libor rate instead becomes much more important as it drops below the Eurodollar rate. The chow test statistic is for a test of the null of no structural break in August of 2007.[8]

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[8]   The statistic follows an $F(4, 2999)$ distribution.

Table 3.2: Structural Break Test

	U.S. Libor	
	Levels	Differences
Eurodollar Bid Rate	0.608	0.696
	(0.033)	(0.031)
U.S. Libor	0.392	-0.123
	(0.033)	(0.032)
Eurodollar Bid Rate	-0.605	-0.589
* **1**(After August 2007)	(0.034)	(0.034)
U.S. Libor	0.600	0.586
* **1**(After August 2007)	(0.034)	(0.034)
N	1911	1392
R^2	1.000	0.423
Chow Test Statistic	175.07	148.5

Dependent variable is the current days Libor. All right hand side variables are lagged.

In their recent study, Abrates-Metz et. al. (2008) investigate the possibility of collusion among Libor panel banks in the post August 2007 period. A commonly used screen for collusion tests for whether cross sectional prices-or quotes in this case-have lower variance during the suspected collusion period relative to a benchmark period. They find that the variance is substantially *lower* in the benchmark pre-August 2007 period. Our results suggest the answer for this is that in the benchmark period, banks are coordinating on the previous days Eurodollar rate. Though, the cross sectional variance in costs presumably also increased dramatically in the period after August 2007.

The above results suggest an obvious counterfactual to construct: What would Libor quotes have been had banks continued to follow their pre August 2007 rule? We first calculate this rule by running the regression in Table 3.2, bank by bank. Figures **??** - **??** show plots of the counterfactual quotes for JP Morgan and Citigroup as well as the

counterfactual Libor fix. To give a sense of the magnitudes of skewing generated by this model, Table 3.3 shows the average and standard deviation of bank quote "skewing", assuming the pre-August 2007 rule gives the correct quotes. Again, it is evident that measures of manipulation are stronger in the period when market turmoil had partially subsided. Manipulation is not the only explanation for the break between the Eurodollar rate and Libor quotes. Cassola, Hortacsu, and Kastl (2009) point out that, because of the lack of actual transactions in the interbank market during the crisis period, Libor quotes were uninformative as the banks themselves had little information. However, it is unclear, from this theory why quotes would be biased downward, or why banks would abandon the Eurodollar Bid Rate as a coordination mechanism. An alternative explanation is that the lack of market data lowered the cost of misreporting as market observers had fewer, accurate benchmarks with which to compare Libor quotes. We also note that the break is broadly consistent with the reputational explanation for misreporting but, again, it is puzzling that quote behavior has not started to revert to past behavior despite the calming of markets.

Table 3.3: Average Magnitude of Quote Skewing: Eurodollar Bid Rate - Libor Quote

| | Pre Aug. 07 | | Aug. 07 - Aug. 08 | | Post Jan. 09 | |
Bank	mean	sd.	mean	sd.	mean	sd.
Barclays	.02	.01	- .081	.10	-.37	.13
Bank of America	.02	.02	-.11	.10	-.393	.14
Bank of Tokyo-Mitsubishi	.029	.01	-.095	.10	-.320	.14
Citigroup	.022	.01	-.118	.10	-.400	.13
CSFB	.022	.01	-.097	.10	-.370	.13
Deutsche Bank	.02	.01	-.106	.10	-.412	.14
HBOS	.023	.01	-.111	.10	-.382	.13
HSBC	.022	.01	-.11	.10	-.51	.13
JP Morgan	.023	.01	-.111	.11	-.434	.13
Lloyd's	.022	.01	-.108	.11	-.381	.13
Norin	.03	.02	-.090	.10	-.31	.14
Rabo Bank	.022	.01	-.111	.10	-.403	.13
RBOS	.019	.01	-.097	-.10	-.301	.12
ry	.015	.01	-.119	-.10	-.345	.10
UBS	.022	.01	-.111	.10	-.361	.11
westlb	.022	.01	-.098	.10	.333	.17

3.4   Sources of Misreporting Incentives

Having established evidence of misreporting, we now turn our attention to the sources of misreporting incentives. We argue bank portfolio exposure to the Libor is a good candidate for generating these incentives. In general, these portfolio positions are opaque and for this reason we focus our analysis on the three American bank holding These banks are required to provide information about their interest rate derivatives and net interest revenue in the quarterly Reports on Conditions and Income (Call Reports) to the FDIC. The level of detail is still not as fine as would be necessary to perform a thorough analysis, so we emphasize the results of this section are purely suggestive and hope they will lead to a more complete analysis.

Interest rate swaps are a very widely used type of interest rate derivative and these three banks hold many of them.[9]   Table 3.4 shows the notional value of the interest rate swaps held by these banks. The Libor is the most commonly used floating rate for swaps, with the 3 month and 6 month U.S. Dollar Libor being the most popular for U.S. Dollar interest rate swaps. Given the large notional values, a small unhedged exposure to the Libor can generate large incentives to alter the overall Libor. If J.P.Morgan, for example, had a swap position with just a 1% net exposure to the Libor in the fourth quarter of 2008, then its costs on its contracts would be proportional to $540 billion. If it was to succeed in modifying the Libor by 25 basis points in a quarter it would make $1/4 * 540 * .025 = 0.337$ or $337 million in that quarter. If it had a 10 percent net exposure it could make $3.37 billion. [10]

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[9]   An interest rate swap is an agreement between two parties, where one pays a fixed interest (the Payer) rate in return for a floating or variable rate from the other party (the Receiver). If f is the fixed rate and L_t is the floating rate at a payment period t for such a contract, then the Payer recieves $(L_t - f)V$ and the Receiver receives $(f - L_t)V$ where V is the *notional value* of the contract. While similar to a principal, the notional value is never exchanged and exists solely for computing payments.

[10]   Note we are focusing solely on swaps, a contract which has a payout that is linear in the Libor. These banks also participate heavily in other more complex derivatives, such as 'swaptions' - options to purchase swaps, whose payoffs may be substantially nonlinear in the Libor.

Table 3.4: Notional value of Interest Rate Swaps (millions)

Quarter	Citigroup	Bank of America	JPMorgan Chase
2007.1	15,712,307	19,305,479	43,357,920
2007.2	16,133,587	19,873,919	49,287,878
2007.3	18,371,402	22,339,658	59,919,028
2007.4	16,955,132	22,472,948	52,097,878
2008.1	19,585,284	25,261,266	55,188,126
2008.2	18,732,046	26,162,587	59,821,075
2008.3	17,360,100	26,230,767	54,907,116
2008.4	15,859,923	26,577,385	54,524,046
2009.1	14,177,696	$49,717,209^a$	49,282,465
2009.2	15,613,216	49,577,518	48,914,118
2009.3	15,230,030	48,676,584	48,893,217

Source: Bank Holding Company FR Y-9C Reports.

a. Bank of America completes merger with Merrill Lynch.

Many interest rate derivatives held by banks are held for the purpose of hedging other items on the balance sheet, so notional portfolio sizes can be misleading. Perhaps the best picture of aggregate exposure is given by aggregate revenue that banks earn from their derivative portfolios. Table 3.5 shows the net interest revenue banks have made over the last 2 years, including the contribution of trading revenue on interest rate derivatives. Notably each of the three banks experience large net revenue increases in the first quarter of 2009, when the Libor fell dramatically.

Table 3.5: Net Interest Revenues ($m)

Quarter	Citigroup	Bank of America	JPMorgan Chase
2007.1	12,129	9,182	6,887
2007.2	13,032	8,683	7,455
2007.3	13,774	7,026	8,961
2007.4	14,046	3,803	6,561
2008.1	12,366	10,394	7,567
2008.2	13,664	11,725	8,760
2008.3	11,527	11,832	6,084
2008.4	7,728	12,888	11,271
2009.1	18,248	14,034	15,214
2009.2	12,355	15,078	14,081
2009.3	13,741	11,042	14,189

Source: Bank Holding Company FR Y-9C Reports. The shown values are the sum of reported

Net Interest Revenue and Trading Revenue on Interest Rate Derivatives.

The bunching on the lower discontinuity shown earlier in figure 3.8 suggests that some banks like Citigroup and Rabobank may have incentive to alter the rate while others may not. Table 3.6 shows Citigroup's reported counterfactual gains from movements in interest rates for several different currencies. In the first quarter of 2009 Citigroup reported it would make $936 million in net interest revenue if interest rates would fall by 25 basis points a quarter over the next year and $1,935 million if they were to fall 1 percent instantaneously. In terms of exposure to Yen interest rates however, Citigroup reports it would make $122 million if Yen interest rates were to rise gradually and $195 million if they rose by 1 percent instantaneously. Citigroup's exposure to the Euro switches signs and is generally low. Figure 3.9 shows Citigroup's quotes relative to the upper and lower discontinuities in all three currencies. Citigroup's U.S. quotes are bunched on the lower discontinuity of the U.S. Libor while its Yen quotes are bunched on the *upper* discontinuity in the Yen Libor, consistent with the direction the model and table 3.6 would suggest. Further, Citigroup's Euro quotes appear to bunch less on

the discontinuities, which is consistent with its apparently smaller incentives to alter Euro rates.

Table 3.6: Citigroup's Counterfactual Net Interest Revenues ($m)

	1% Instantaneous Increase			1% Instantaneous Decrease		
	U.S. Dollar	Euro	Yen	U.S. Dollar	Euro	Yen
2009.3	-1,193	52	228	1,427	-4	NM
2009.2	-1,767	-29	215	1,935	21	NM
2009.1	-1,654	11	195	1,543	-12	NM
2008.4	-801	-56	172	391	57	NM
2008.3	-1,811	-52	142	893	52	NM
2008.2	-1,236	-71	131	1,170	71	NM

Instantaneous means a 'parallel instantanenous 100bp change in rates.'

	1% Gradual Increase			1% Gradual Decrease		
	U.S. Dollar	Euro	Yen	U.S. Dollar	Euro	Yen
2009.3	-563	12	135	526	-12	NM
2009.2	-1,005	-35	122	936	35	NM
2009.1	-888	12	122	660	-12	NM
2008.4	-456	-43	51	81	43	NM
2008.3	-707	-41	72	490	41	NM
2008.2	-756	-51	73	633	51	NM

Gradual means 'a more gradual 100bp (25bp per quarter) parallel change in rates.'

NM - Not Meaningful; a 100bp reduction would result in negative rates.

Source: Citigroup's 10-K and 10-Q reports.

3.5 Conclusion

In this paper we have presented new evidence corroborating concerns that Libor panel banks may be understating their true borrowing costs. Previous analysis of the problem have suggested the cause of this misreporting is the desire of panel banks to appear

strong, especially during the recent banking crisis. In contrast, our theory of misreporting incentives points to a more fundamental source, namely that bank portfolio exposure to the Libor give them incentives to push the rate in a direction favorable to these positions. Our theory, then, suggests that the rate may perform badly even in times of market calm, whereas the reputation theory suggests that we may only have to worry during periods of severe market stress.

The nature of the Libor mechanism, which averages the middle eight quotes out of sixteen, helps us formulate a novel strategy for testing the theory. When the location of the "pivotal"quotes are highly predictable, as they appear to be in our sample, banks with incentive to manipulate the Libor fix bunch around these quotes because the marginal change in the fix drops discontinuously there. Borrowing costs, on the other hand, presumably have no relationship with these pivotal points and so neither should quotes from banks with no incentives to manipulate the fix.

Understanding the sources of misreporting incentives has important policy implications. Concerns about the Libor's accuracy has led a large money market broker ICAP to recently launch the 'New York Funding Rate' which is intended to replace the Libor. The primary innovation of the New York Funding Rate is that submitted quotes are anonymous. This reflects the view that the primary motive for banks to submit downward or misleading quotes is to signal their strength or soundness. If, in addition, a major incentive for banks to misreport their true borrowing costs is to influence the overall rate of the Libor, as we suggest, anonymity may actually make it easier for banks to misreport. Though there may be many other reasons for it, it is interesting to note that the New York Funding Rate has often been lower than the Libor throughout 2009.

As in the reputation enhancement story of misreporting, the primary problem our theory points to is that in the Libor, and similar indexes derived from surveys, participants face little in the way of costs for submitting false or misleading quotes. Creating a system that properly incentivizes truthful reporting would require major changes and possible unintended consequences would have to be carefully weighed. On the other hand, our theory suggests a simple approach based on diminishing the incentives for misreporting by adding more banks to the panel. Just as adding firms to a market (usually) makes a market more competitive by reducing the impact any one firm has on price, adding banks to the panel would lower the marginal impact any one bank would

have on the rate.

3.6 Supplementary Model

We now introduce a simple model of how member banks submit their quotes. Let $i = 1, \ldots, 16$ be the banks in the Libor panel for a given currency and tenor. Let $t = 1, \ldots, T$ denote the days where the Libor was administered. We let $q_{it} \in [0, \bar{q}]$ denote the quote of bank i at date t. The Libor fix, $L_t = L(q_{it}, q_{-it})$, is then the average of the middle 8 quotes. The true borrowing costs of each bank is denoted $c_{it} \in \mathbf{R}_+$ and the profile of costs c_t is distributed according to the joint distribution F_t. We write the net "profit" accruing to bank i in period t as:

$$\Pi_{it}(q_{it}, q_{-it}, c_{it}) = v_{it} L(q_{it}, q_{-it}) + \pi_{it}(q_{it}, q_{-it}, c_{it})$$

where v_{it} is the bank's portfolio exposure to the Libor and π_{it} captures the reputational motives of the bank. We allow the reputational concerns reflected in π_{it} to depend on the quotes of other panel banks and its true borrowing cost, c_{it}. This is consistent with our favored interpretation that bank portfolio positions give them an incentive to manipulate the Libor, but they face reputational or other costs for being too far away from other banks and, potentially, for setting quotes too far from their actual costs of borrowing. Note that they are subscripted by bank and time, so we allow for incentives to vary due to, for example, changing bank portfolios.

We choose to model a bank's payoffs as linear in the Libor as the majority of contracts have linear payouts. Adjustable rate mortgages, futures, forwards, swaps and corporate loans all have linear payouts in their underlying reference index, often the Libor. A portfolio composed entirely of these contracts would itself have a payout linear in the Libor, and although these banks likely do possess a small amount of nonlinear contracts, we consider linearity to be a good approximation. We also assume that π_{it} is continuously differentiable, strictly concave in q_{it} and $\frac{\partial^2 \pi_{it}}{\partial c_{it} \partial q_{it}} > 0$. These latter assumptions reflect our view that banks suffer reputational penalties for submitting increasingly 'extreme' quotes and for quotes that are far away from their true costs. We also assume that F_t is absolutely continuous and has full support on $\mathbf{R}_+^{16}$.

Let $\ell(q_{-it})$ denote the fourth lowest quote of q_{-it} and $r(q_{-it})$ is the fourth highest. From i's perspective, these are the points where the marginal response of the Libor

changes discontinuously. We now state a proposition that forms the basis of our prediction we should see bunching around the pivotal quotes $\ell(q_{-it})$ and $r(q_{-it})$.

Proposition 1 *Let q_{-it} be such that $\ell(q_{-it}) < r(q_{-it})$. Then if $v_{it} < 0 \ (> 0)$ there is an interval of costs where i's best response is to quote $q_{it} = \ell(q_{-it}) \ (= r(q_{-it}))$. Moreover, the width of this interval is increasing in $|v_{it}|$.*

Proof: Suppose that $v_{it} < 0$. Whenever costs are such that

$$-\frac{v_{it}}{8} > \frac{\partial \pi_{it}(q_{it}, q_{-it}, c_{it})}{\partial q_{it}}\Big|_{q_{it}=\ell(q_{-it})} \tag{3.1}$$

$$0 < \frac{\partial \pi_{it}(q_{it}, q_{-it}, c_{it})}{\partial q_{it}}\Big|_{q_{it}=\ell(q_{-it})} \tag{3.2}$$

then $\ell(q_{-it})$ is a local optimum. If, further

$$0 > \frac{\partial \pi_{it}(q_{it}, q_{-it}, c_{it})}{\partial q_{it}}\Big|_{q_{it}=r(q_{-it})} \tag{3.3}$$

then $\ell(q_{-it})$ is a global optimum. This follows from the concavity of π_{it} in q_{it} which ensures $\partial \pi_{it}/\partial q_{it}$ is decreasing in q_{it}. The other discontinuity, r, is not a local equilibrium. Our assumption on the cross derivatives ensures that $\partial \pi_{it}/\partial q_{it}$ is strictly increasing in c_{it} and is thereby invertible in c_{it}. Inverting equations (2) - (4) conditional on q_{it} and q_{-it} defines an open interval of costs which is weakly increasing in $-v_{it}$. A symmetric argument follows for the case when $v_{it} > 0$. $\square$

This proposition, combined with the absolute continuity and full support of F_t, will deliver a point mass at $r(q_{-it})$ or $\ell(q_{-it})$ in the distribution of q_{it} conditional on q_{-it}. This logic extends to a perfect information game as well.

Proposition 2 *Let $v_{it} < 0$ for some bank i and let $c_t = (c_{1t}, ..., c_{16t})$ be a given profile of borrowing costs. If there is a Nash equilibrium q_t^* where $q_{it}^* = \ell(q_{-it}^*) < r(q_{-it}^*)$ then there is an interval (c^l, c^u) of costs for i such that for any $\tilde{c}_{it} \in (c^l, c^u)$, q_t^* remains a Nash equilibrium for the new cost profile $\tilde{c}_t = (c_{1t}, .., \tilde{c}_{it}, ..., c_{16t})$.*

Proof: If $q_{it}^* = \ell(q_{-it})$ is optimal, it is necessarily a local equilibrium, so equations (5) and (6) must hold for q_{it}^*. The only possible other optimal solution is $\tilde{q}_{it} > r(q_{it})$

that satisfies the first order condition $\partial \pi_{it}/\partial q_{it} = 0$. As q_{it}^* is optimal, it must be $\Pi(q_{it}^*, q_{-it}, c_{it}) \geq \Pi(\tilde{q}_{it}, q_{-it}, c_{it})$ or equivalently,

$$-v_{it}[r(q_{-it}) - \ell(q_{-it})] \geq \int_{\ell(q_{-it})}^{\tilde{q}_{it}} \frac{\partial \pi_{it}}{\partial q_{it}} \, dq_{it} \tag{3.4}$$

As $\partial \pi_{it}/\partial q_{it}$ is increasing in c_{it} for each q_{it}, the right hand side of (8) is increasing in c_{it}. So for any $\tilde{c}_{it} < c_{it}$, (8) is satisfied, and if $\tilde{c}_{it}$ satisfies (5) and (6) as well then it remains optimal for i to quote q_{it}^* for costs in this interval. As i quotes the same, and no other cost has changed, it remains a best response for every other bank to quote q_{-it} and q_t^* remains an equilibrium for the new cost profile containing $\tilde{c}_{it}$.

Figure 3.1: One Year LIBOR Quotes and CDS Spreads
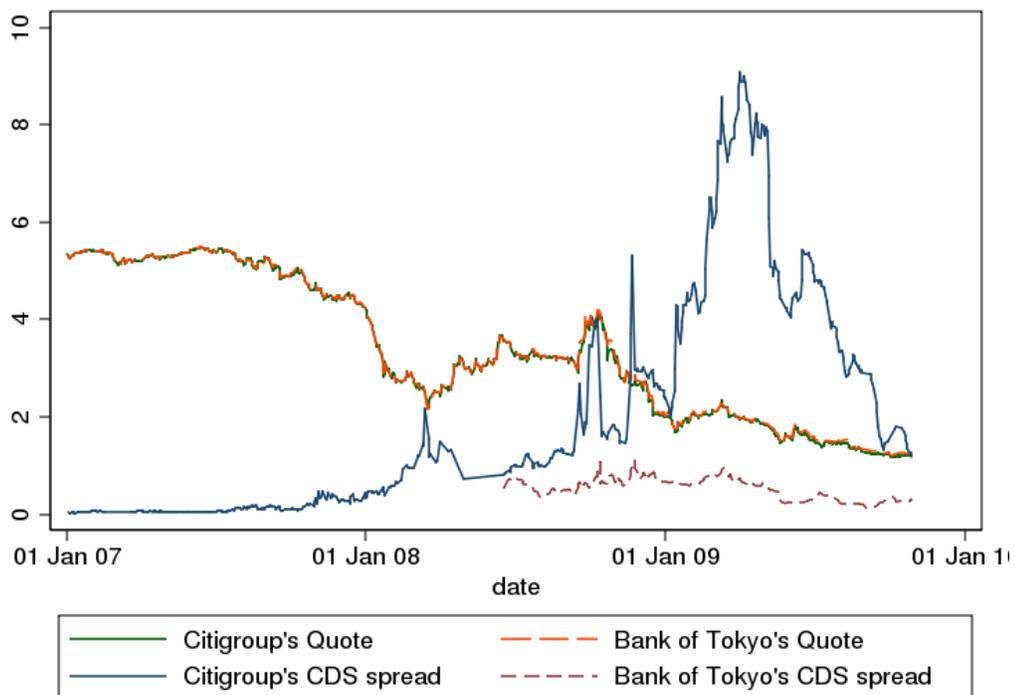
Figure 3.2: Libor Rates in Different Currencies

6 Month LIBOR

— DOLLAR — YEN — EURO — GBP — SWISS FRANC

9/13/2006   9/13/2007   9/13/2008
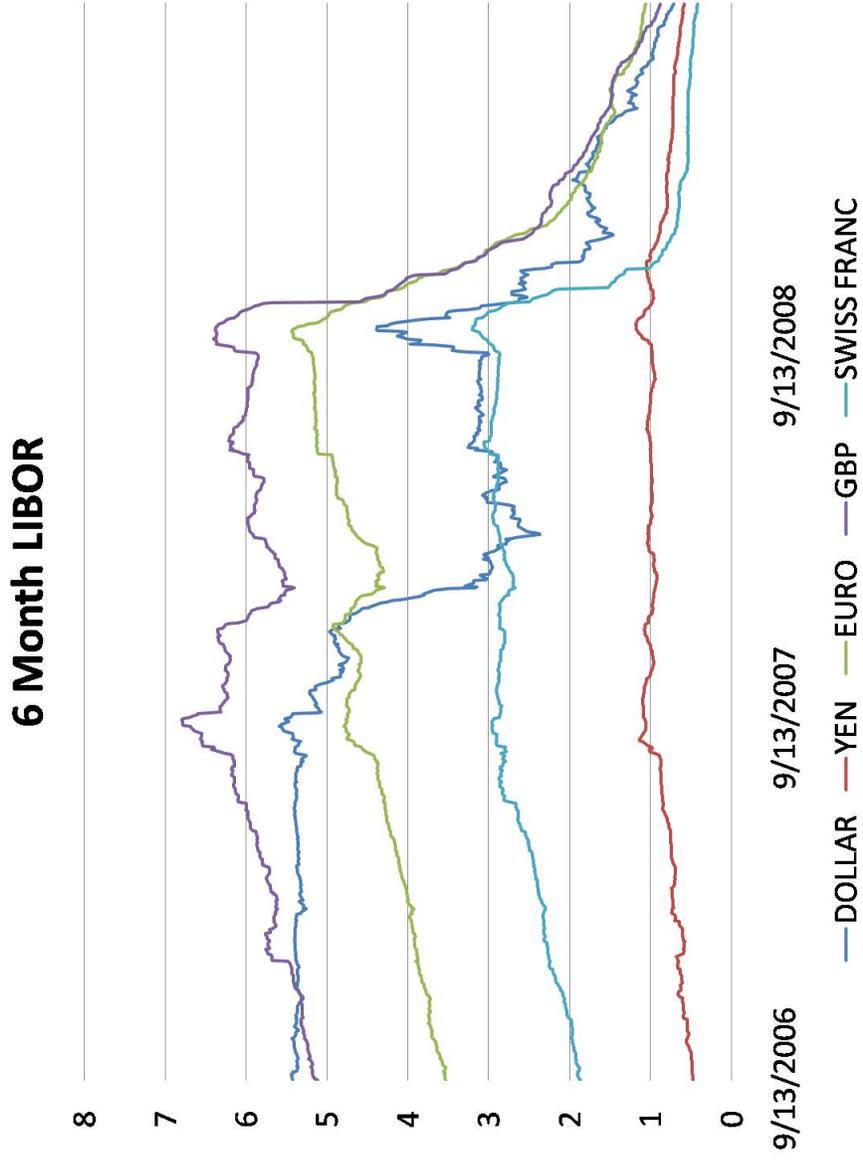
Figure 3.3: Cross Currency Rank Reversals
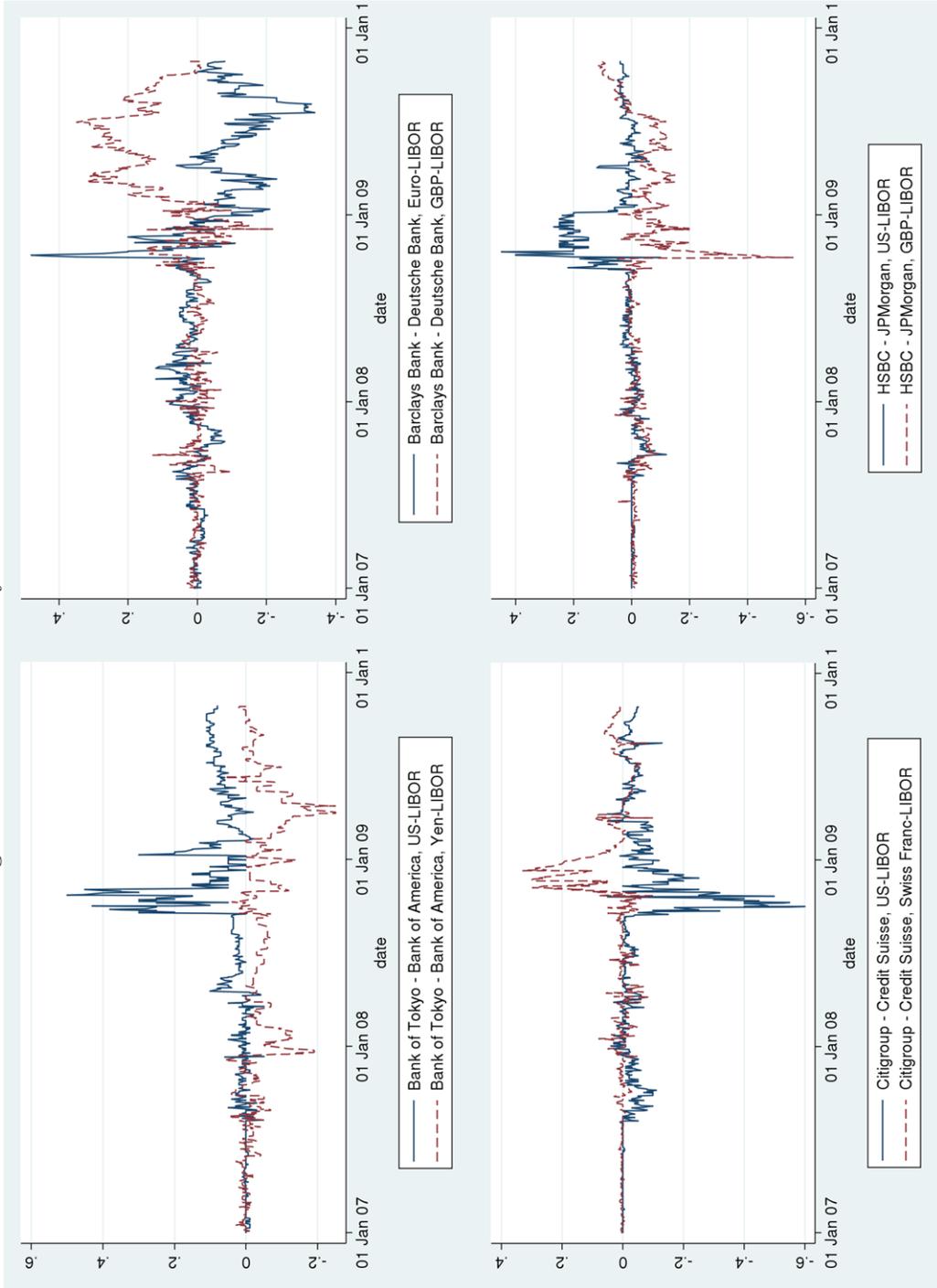
Figure 3.4: Distribution of Libor Quotes and CDS Spreads
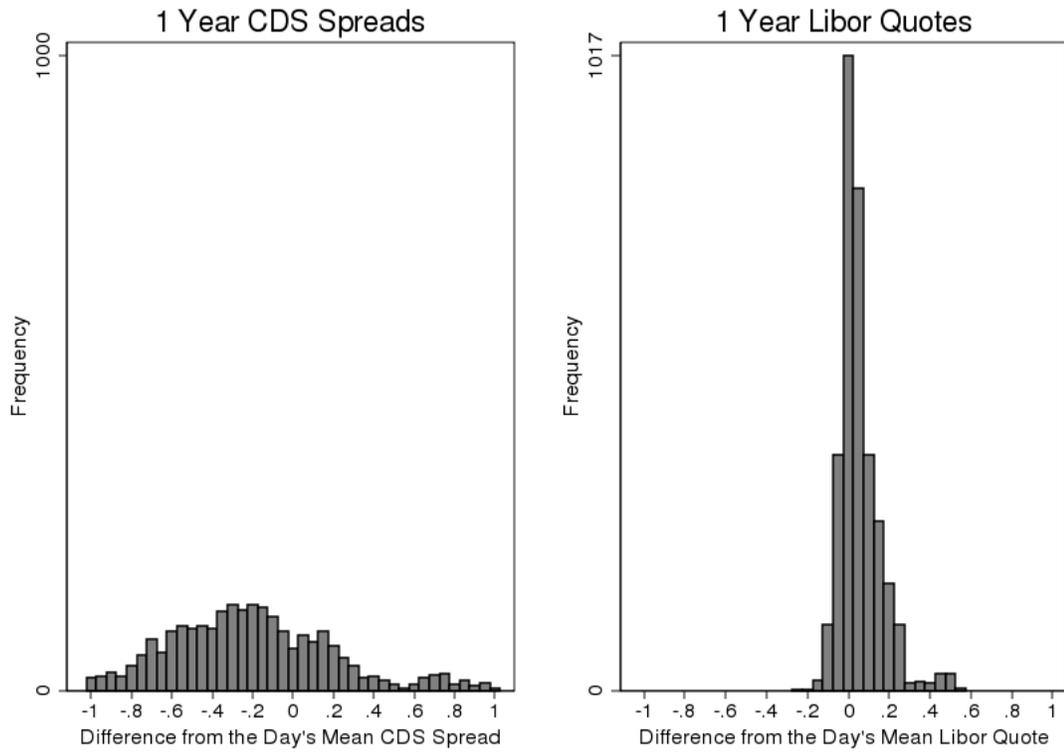
12-Month U.S. Libor quotes and 1-Year Senior CDS spreads.

Figure 3.5: 3 Month Quote Distributions for Different Time Periods
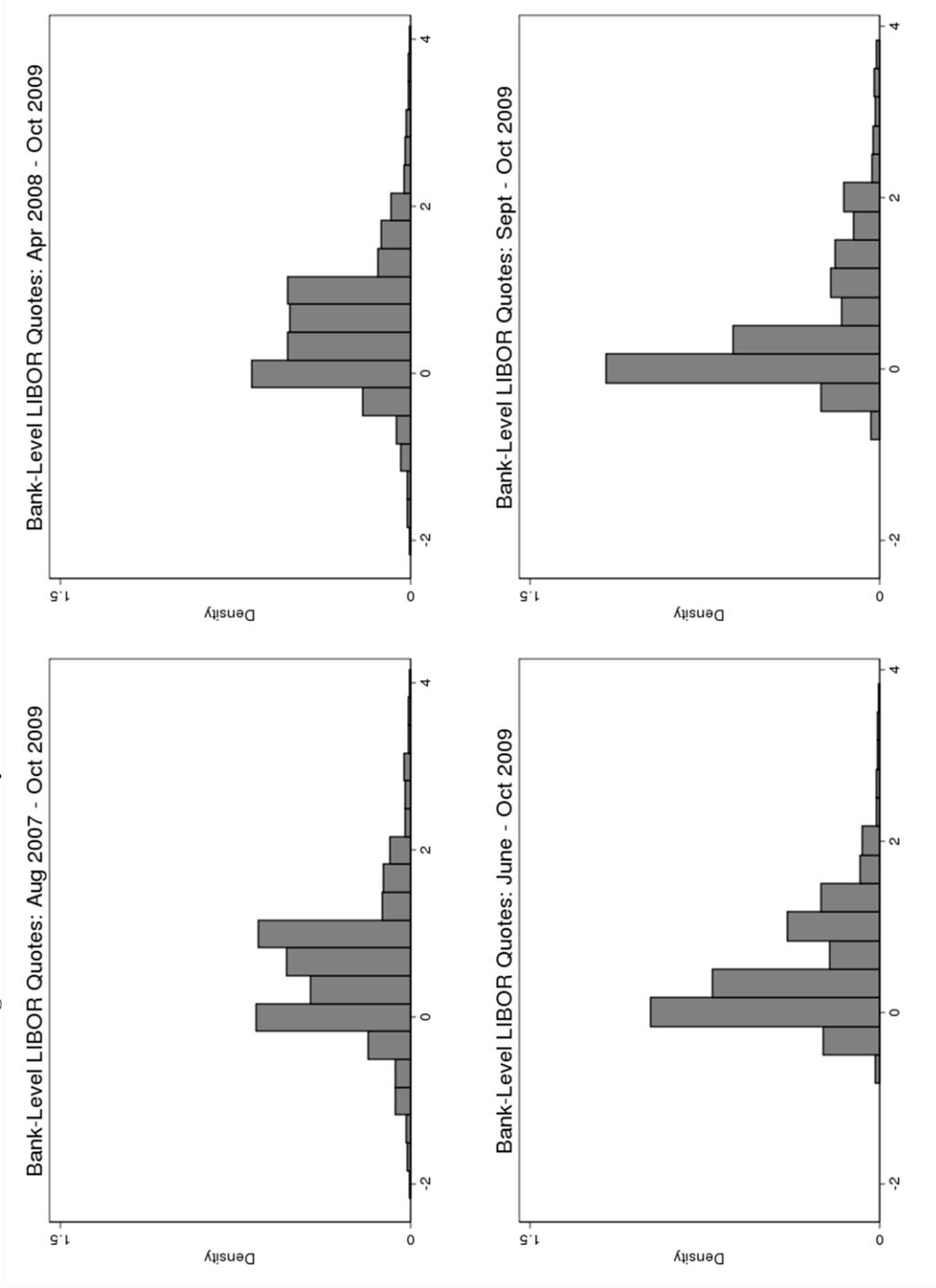
Figure 3.6: Responses in the Libor to a Bank's Quote
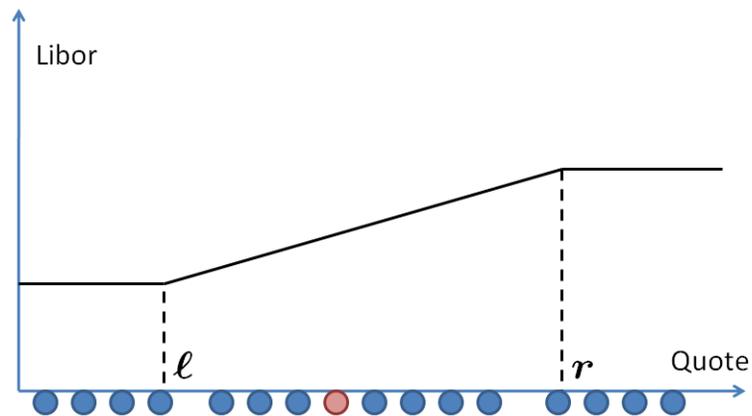
The circles represent the quotes of the 16 banks. The four highest and four lowest quotes are dropped and the average of the remaining eight quotes determines the Libor rate. Shown is the counterfactual Libor rate if one of the middle eight banks were to change their quote.

Figure 3.7: Discontinuities in the Marginal Response of the Libor
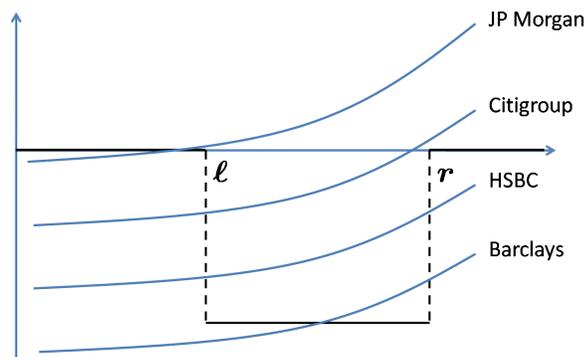
Shown is the marginal benefit and cost curves for banks whose portfolios are such that they profit from a lower overall rate of the Libor.

Figure 3.8: Clustering of Libor Quotes around Discontinuities in the 3 Month U.S. Libor
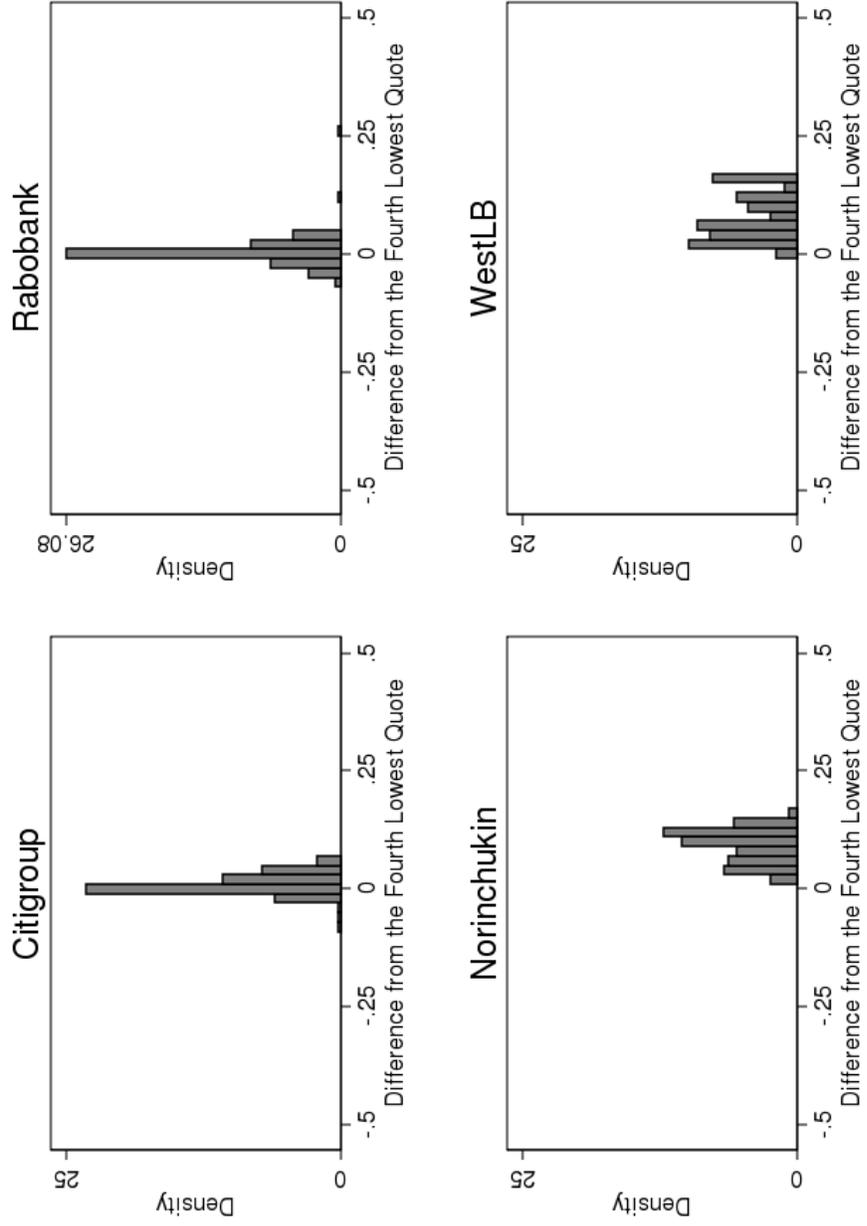
Figure 3.9: Citigroup's Quotes Across Currencies
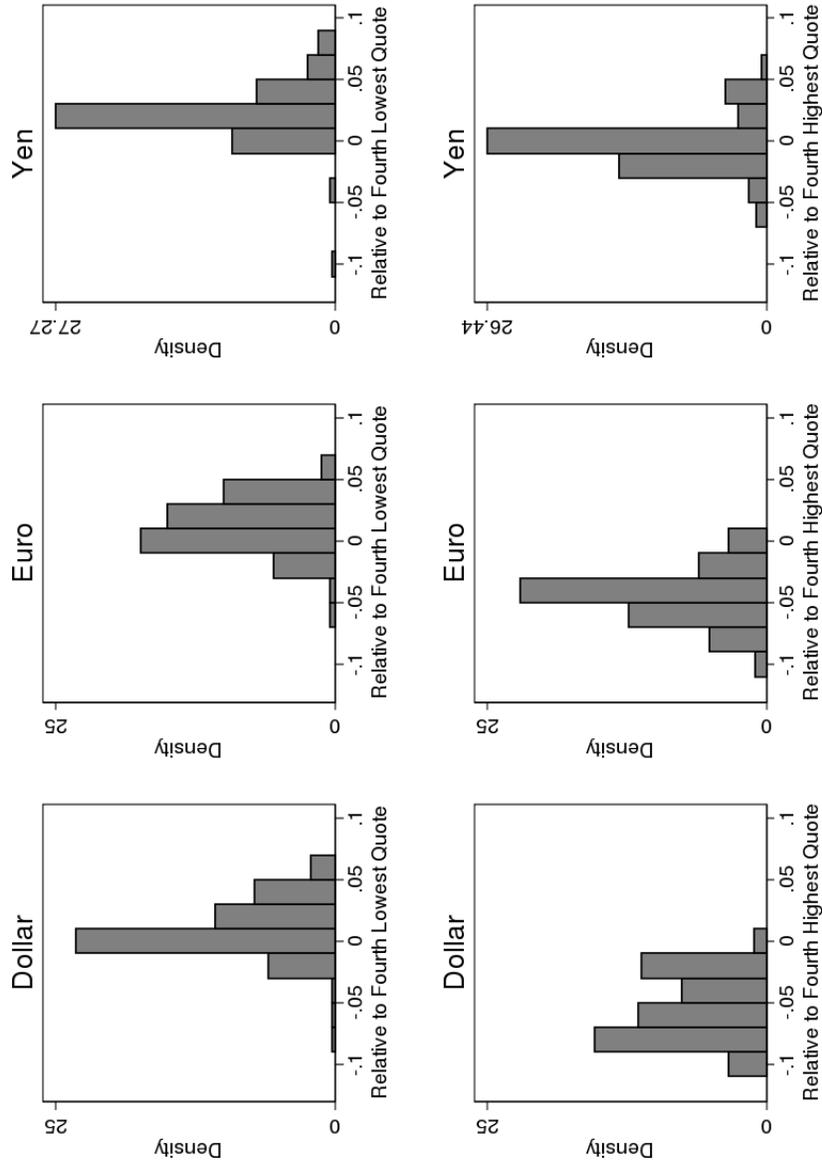
Citigroup's quotes are clustered on the lower discontinuity in the U.S. dollar Libor while clustered on the upper discontinuity in the Yen Libor. As shown in table 3.6, Citigroup profits from lower U.S. interest rates and a higher Yen interest rates.

Figure 3.10: 3 Month Eurodollar - U.S. Libor Spread
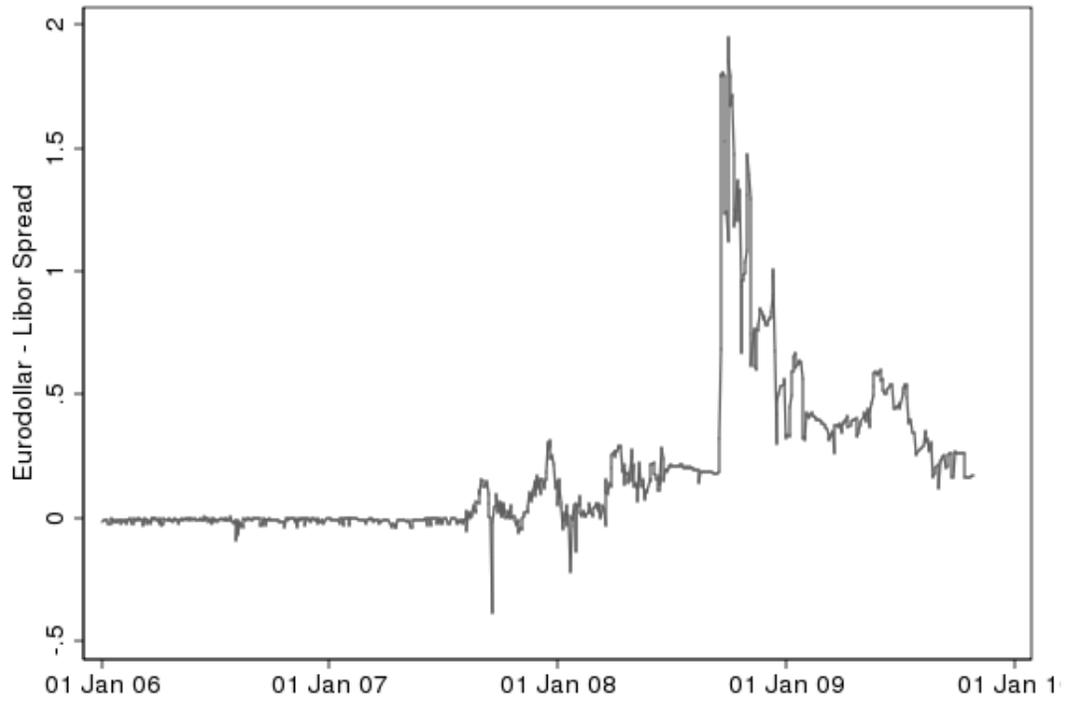
Figure 3.11: Bank of America - Actual and Counterfactual Quotes
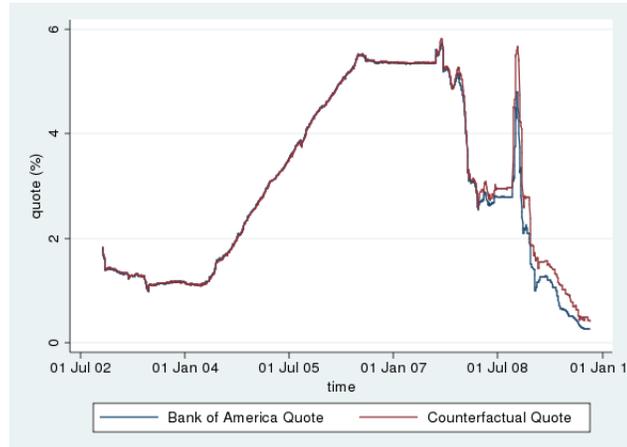
Figure 3.12: Citigroup - Actual and Counterfactual Quotes
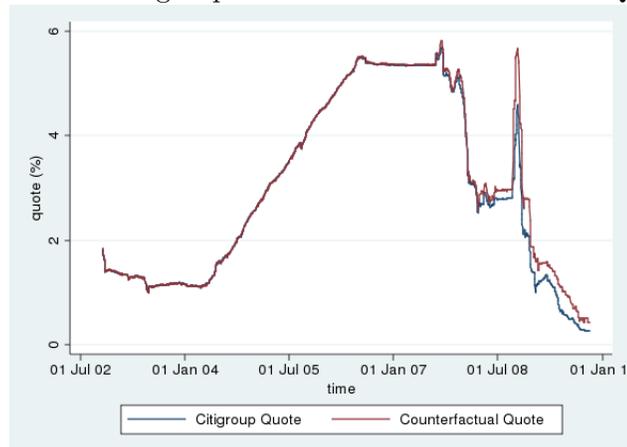
Figure 3.13: JP Morgan - Actual and Counterfactual Quotes
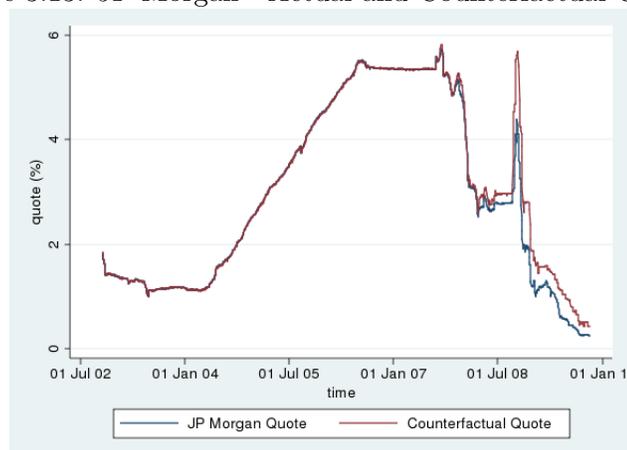
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