Multiple Equilibria and Deterrence in Airline Markets

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Abstract

We use data from the US airline industry to estimate a model of entry deterrence. We model the interaction among airlines as a repeated static game, where we allow for a very general form of heterogeneity. We consider a menu of three alternative games that describe the strategic interaction among airlines: simultaneous and sequential move games, and a sequential move game with deterrence investments. Following Bernheim [1984], deterrence investments include all investment that raises barriers to entry, and for which the incumbent must incur some investment costs. We show that the profits that incumbents can make in the sequential game, both with and without deterrence investments, are larger than those that they can make if the game is played simultaneously. Thus, we find that on average it is profitable for all firms to deter new entrants, with the exception of United Airlines. Remarkably, United Airlines was under bankruptcy protection during the period of analysis, suggesting that its deterrence investments were not credible. Overall, we find that the data is explained better by a model where firms make deterrence investments. Thus, we cannot reject the hypothesis that incumbents deter entrants in the airline industry.

Keywords: Multiple Equilibria, Entry Games, Heterogeneity, Deterrence, Airline Industry, Sequential Move Game, Simultaneous Move Game.

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1 Introduction

In 1999 the Transportation Research Board (TRB [1999]) prepared a list of informal complaints of anticompetitive behavior submitted by airlines to the Department of Transportation. The list of complaints was striking for several important reasons. First, all of the complaints were made by low cost carriers against legacy carriers. Second, the complaints concerned competition in markets connecting the hub of the legacy airline and medium-sized cities, such as Mobile, Des Moines, or Jacksonville. Finally, and most importantly for this paper, all complaints centered on the claim that legacy carriers had used exclusionary tactics to maintain their monopoly in the markets cited in the complaint. In essence, this list of complaints provides stylized and anecdotal evidence that legacy carriers act to deter the entrance or force the exit of low cost carriers in order to maintain a monopoly in certain markets. In this paper, we propose a practical and transparent methodology to determine whether firms make investments to raise barriers to deter new entrants. Determining whether firms successfully deter new entrants is an important topic of research because, where entry is not artificially impeded, competition ensures that prices are in the long run reflective of the full cost of efficiently providing airline services.

We start from the observation that in any theory of entry deterrence, the incumbent can prevent the entry of competitors but only at a cost or investment that the incumbent could avoid if entry were instead accommodated. We call these costs the "deterrence investments" (Bernheim [1984]). Then, we exploit the theory developed in Bernheim [1984], where the definition of deterrence investment is intentionally ambiguous so as to abstract from the complex issues that arise with particular theories of entry deterrence and to focus on the fundamental trade-off that the incumbent faces. Firms can make deterrence investments to block the entry of profit-lowering competitors, and deterrence investments include all investment that raise barriers to entry, but these investments are costly. Our objective is to estimate the costs of deterrence investments and compare them with the profits made by the firm when they do not deter their competitors; we then predict whether or not firms make these investments when they face the threat of new entry.

We model the interaction among airlines as a repeated *static* entry game, where we allow for very general forms of heterogeneity, which lead to multiple equilibria. In the same spirit as Kadiyali [1996], we estimate a *menu of different games* to choose the one that fits the data best. The first game is a repeated static simultaneous move entry game with complete information. This is akin to the game studied by Ciliberto and Tamer [2009], except that airlines interact repeatedly over time. The second game is a repeated static game, where firms can face two scenarios, depending on the *exogenous* history of the game. If one of the firms was the only incumbent in the prior period, then the firms play a sequential move game where the incumbent moves first. Otherwise, the firms play a one-shot simultaneous move game as in Ciliberto and Tamer [2009] and move to the next period. Finally, we consider a game where the firms can make deterrence investments in a sequential move game. Thus, the model that allows only for simultaneous move games is nested into the one that allows for sequential move games depending on the game history, which is nested into the one that allows for firms playing a sequential move game to also make deterrence investments.

To identify deterrence investments, we use changes in firms' entry decisions over time. The idea is to compare entry decisions across similar markets whose market structures change differently over time. In particular, if there are two markets that have identical observable and unobservable characteristics, and in one there is only one incumbent over time, while in the other there are periods with two firms, then it must be the case that the incumbent in the first market does deter new entrants. Using this simple idea, we estimate the costs that incumbents must face to make "deterrence investments" and determine if there are some airlines that systematically prevent new entry.

Data are from the Origin and Destination Survey (DB1B), which is a 10 percent sample of airline tickets from reporting carriers. These are quarterly data from 2004, and they are organized by market, year, and quarter. The panel data provide the variation needed to identify both the competitive effect of the firms' entry (δ) and the cost of the deterrence investments (c). First, we observe entry in markets where there are no incumbents (or there is more than one incumbent), and there we will assume that firms play a simultaneous move game. We also observe entry in markets where there is only one incumbent, and there we will assume that firms play a sequential-move game. Therefore, we identify c separately from δ. Second, the set of competitors vary by market, so it is possible to allow firms to have heterogeneous competitive effects and deterrence costs.

The estimation is largely based on Tamer [2003] and Ciliberto and Tamer [2009], who propose a methodology to estimate a game among airlines in a one-shot static simultaneous-move game. The fundamental idea behind their methodology, which we will briefly review in the paper, is that even in the presence of multiple equilibria, one can estimate sets of parameters of the profit functions that correspond to models with different equilibrium selection rules. Tamer [2003] and Ciliberto and Tamer [2009] show that one can construct upper and lower bounds for the probabilities that the various equilibrium outcomes can take and then choose the parameters that minimize an appropriately defined distance between these lower and upper bounds and the empirical probabilities. Methodologically, the difference here is that when firms can play a sequential move or deterrence game, there will be almost always a unique equilibrium. However, because in some markets firms play a simultaneous move game, we still will only be able to estimate sets of parameter values, and so we will not be able to achieve point identification.

We find that the model where firms make deterrence investments fits the data much better than a model where firms play a simultaneous or sequential move game. Thus, we cannot reject the hypothesis that incumbents deter entrants in the airline industry. In addition, we show that the profits incumbents can make if they move first are larger than those that they can make if the game is played simultaneously. This result is stronger, as one would expect, when incumbents can deter new entrants. Finally, we find that all firms deter new entrants, with the exception of United Airlines. Remarkably, United Airlines was under bankruptcy protection during the period of analysis, suggesting that its deterrence investments were not credible. This last result underscores the importance of modeling firms as heterogenous competitors.

Our paper contributes to two important literatures. First we contribute to the literature on the estimation of entry games with complete information (Bresnahan and Reiss [1990], Berry [1992], Mazzeo [2002], and Ciliberto and Tamer [2009]) by allowing firms to play a simultanous or sequential-move game and to deter new entrants. Bresnahan and Reiss [1990] and Berry [1992] considered a sequential and a simultaneous-move game as alternatives to describe the interaction between car dealers and airlines. However, Bresnahan and Reiss [1990] and Berry [1992] maintained that firms were playing the same game, whether simultaneous or sequential-move, in all markets. Here, the selection of the type of game played is a function of the past history of the game, and thus firms play sequential and simultaneous move game across different markets and time.

Second, we contribute to the literature on deterrence. Our paper is closest to Kadiyali [1996], which examines deterrence and entry in the photographic film industry. Kadiyali [1996] estimates the post-entry demand and cost functions of two firms by estimating a menu of different games and choosing the game that fits the data best. With these demand and cost estimates, she concludes that the incumbent was forced to accommodate the entrant because the profit the incumbent would have made under a deterrence strategy was lower than the profit it made under accommodation. Kadiyali's strategy relies on identifying one particular postentry game that is being played in all markets. In our paper, we allow for firms to play multiple types of games across markets and time. We also allow for firm heterogeneity, which leads to multiple equilibria in the number and identity of firms; this allows for a more general framework for examining deterrence. Other papers in the deterrence literature include Ellison and Ellison [2011] and Goolsbee and Syverson [2008]. Ellison and Ellison [2011] test a theoretical prediction of the relationship between investment and market size - a relationship that differs depending on whether or not firms deter potential entrants. Goolsbee and Syversion [2008] identify deterrence by looking at changes in incumbent behavior that result from exogenous changes in potential entry behavior. Differently from these two papers, our paper explicitly allows for multiple equilibria and for firms to decide between deterrence and accommodation. There are also dynamic structural models of deterrence, including Sweeting [2013], Williams [2011], Chicu [2012], and Snider [2009]. These dynamic models allow forward-looking behavior by firms; however, none of these papers allow for multiple equilibria.

The theoretical literature on deterrence is vast. Both Spence [1977] and Dixit [1980] provide theoretical arguments for deterrence. Spence [1977] shows that entry can be deterred by the mere existence of capacity; Dixit [1980] extends the argument and shows that since investment in capacity can alter the outcomes in the post-entry game, there can be incentives to invest in capacity in order to deter potential entrants. There are many variations on this basic theoretical model. Fudenberg and Tirole [1984] add advertising and show that an incumbent's low advertising pre-entry is a credible threat of deterrence, because it allows the incumbent firm to cut prices if a competitor were to enter. Judd [1985] allows for multiproduct incumbent firms, and he allows these firms to exit after entrants enter the market; he shows that intensive post-entry competition may facilitate entry, because the multiproduct incumbent firms are more likely to exit the market. Bulow et al. [1985] show that the incentives for a firm to engage in deterrence differ depending on whether potential competitors' goods are substitutes or complements. In particular, when goods are strategic complements, firms may underinvest in capital in order to reduce future competition. Bernheim [1984] extends the basic model to allow firms to enter over multiple periods. In this case, he shows the counterintuitive result that policies that are intended to increase competition, such as subsidizing entry, can have the opposite effect. Finally, Anderson and Engers (1994) do not focus on deterrence, but they develop a theoretical model that solves the problem in the standard Stackelberg model that the order of moves is exogenously specified. In their model firms compete over entry time. In our analysis, the order of moves is exogenous, but it changes across markets and time.

The paper is organized as follows. Section 2 describes anecdotal evidence of deterrence in the airline industry. Section 3 describes the model and econometric methodology. Section 4 provides information on the data, and Section 5 details the idenfitication strategy. Section 6 presents the estimation results, and Section 7 compares counterfactual profits under each type of game. Section 8 concludes.

2 Anedoctal Evidence of Strategic Deterrence

In 1999, the Transportation Research Board, a unit of the National Research Council, prepared a report on entry and competition in the US Airline Industry. As part of this extensive and informative report, the Transportation Research Board provided a list of informal complaints received by the Department of Transportation from new entrant airlines about unfair exclusionary practices between March 1993 and May 1999.

Table 1 summarizes the list of informal complaints received by the Department of Transportation by the Complaining Party, always a Low Cost Carrier; by the party against whom the complaint was filed, always a national carrier; the quarter when the complaint was filed; and the markets which were involved in the complaint.

Table 1: Informal Complaints Received by the Department of Transportation

Complaining Party	Complained Against	Period	Markets Involved in the Complaint
AccessAir	Northwest (NW)	3/1999	Markets between New York, Los Angeles and Des Moines and Moline/Quad Cities/Peoria
AccessAir	Delta, NW, TWA	5/1999	Markets between New York, Los Angeles and Des Moines and Moline/Quad Cities/Peoria
AirTran	Delta	8/1998	General
Kiwi	Continental	2/1998	Niagara-Newark
Valuejet	Northwest	3/1997	Atlanta-Memphis
Valuejet	Delta	2/1997	General (e.g. Atlanta-Mobile)
Frontier	United	1/1997	General (e.g. Denver-Los Angeles)
Spirit	Northwest	11/1996	Detroit-Philadelphia, Detroit-Boston
Vanguard	American	10/1996	DFW and Kansas City, Phoenix, Cincinnati, Wichita
Air South	Continental	3/1996	Newark and Charleston, Columbia, Myrtle Beach
Vanguard	Northwest	8/1995	Minneapolist and Chicago Midway, Kansas City
Valuejet	USAir	3/1995	Washington Dulles and Florida, Hartford, Boston.
Valuejet	Delta	12/1993	Markets out of Atlanta, in particular to Jacksonville, Memphis
Reno Air	Northwest	3/1993	Reno-Minneapolis

From the Special Report 255: "Entry and Competition in the US Airline Industry Issues and Opportunities," Transportation Research Board, National Research Council, July 1999.

Table 1 provides three fundamental insights on the nature of competition between low cost carriers and national carriers.

First, some national airlines show much more aggressive behavior against new entrants than others. In particular, Delta, Northwest, American, and Continental have used aggressive competitive behavior in several markets and over time. One telling case involved Northwest's behavior toward Reno Air. In 1993, Reno Air announced that it would enter the Reno-Minneapolis/St Paul market, which, at that time, was not served on a nonstop basis by Northwest. After Reno's entry, Northwest announced that it would not only start nonstop service between Reno and Minneapolis/St Paul, but it would also enter three of Reno Air's existing nonstop markets: Reno-Seattle, Reno-Los Angeles, and Reno-San Diego. Northwest would also match Reno Air's fares in all markets.

Second, the markets where national carriers have reacted aggressively against low cost carriers were always markets out of the hub of the national carrier. In light of Spence [1977] and Dixit [1980], this is not surprising, since national carriers make large sunk investment costs at their hubs. Spence and Dixit show that incumbents might strategically invest in capacity to deter new entrants, and this is exactly what national carriers might be doing at their hubs. Airlines make sunk investment costs in their hubs through the signing of long-term leases for the use of gates and check-in positions, and participation in the costs of airports' expansions and modernizations.

Finally, the markets that are mentioned in **Table 1** are mainly markets between a hub and a medium-sized MSA, such as Mobile, Des Moines, or Jacksonville. The markets where national carriers show aggressive behavior toward low cost airlines are not markets between the largest MSAs in the United States.

3 The Entry Game Played by the Airlines: Estimation

We assume here that the game played by the airlines is played repeatedly over time. In each period, airlines know each other strategies and payoffs; thus, this is a complete information game. A strategy profile in this game tells each firm under what conditions to enter into a market, and it will depend on the nature of the game that the firms play (i.e. whether the game is simultaneous- or sequential-move).

Formally, there are I airlines, indexed by $i = 1, ..., I$, that must decide whether to enter into the market $m = 1, ..., M$ at time $t = 1, ..., \infty$. Let $y_{imt} = 1$ if firm i enters in market m at time t and $y_{imt} = 0$ otherwise. The entry decisions $\mathbf{y}_{mt}$ are observed but the profits made by the firms, $\boldsymbol{\pi}_{mt}$, are unobservable.

The data consist of a random sample of market-firm-time specific observations

$(\mathbf{y}_{mt}, \mathbf{X}_{mt})$. Let $\boldsymbol{\epsilon}_{mt} = (\epsilon_{1mt}, \ldots, \epsilon_{\mathrm{Im}\,t})$ be a mean zero random variable, independent, both across time and across markets, of $\mathbf{X}_{mt}$, and it has a known (up to a finite dimensional parameter Ω) distribution F_{Ω}. $\boldsymbol{\epsilon}_{mt} = (\epsilon_{imt}, ..., \epsilon_{\mathrm{Im}\,t})$ is known to the players but unobserved to the econometrician, which is why we have a game of complete information.

The unobservable error ϵ_{imt} is modeled as follows:.

$$\epsilon_{imt} = \nu_m + \xi_{mt} + \eta_{im} + \zeta_{imt}.$$

ν_m represents market unobservables that are market specific and constant over time; it captures, for example, the fact that in market m there is a large share of business passengers. ξ_{mt} is a market shock that changes over time, and which affects firms in market m in the same way; for example, changes in the demand for travel over time. η_{im} is a time-invariant market-specific airline shock to allow different firms to face different unobservables in the same market; for example, some airlines might see a larger share of business passengers in the same market than other airlines do. Finally, ζ_{imt} are time-variant, firm-specific shocks.

$\mathbf{X}_{mt}$ is a $k \times I$ matrix of k exogenous determinants of entry decisions, both market- and carrier-specific. It includes both a vector of market characteristics that are common among the firms in market m and a vector of firm characteristics that enter into the profits of all the firms in that market.

3.1 Simultaneous Move Game

The instantaneous profit function is written as follows:

$$\pi_{imt} = X'_{imt}\alpha + \sum_{j \neq i} \delta_j y_{jmt} + \epsilon_{imt}.$$

The observed part of the profit is known up to a finite dimensional parameter vector $\boldsymbol{\theta} \equiv (\alpha, \boldsymbol{\delta})$.

An important feature of the profit function in this paper is the presence of δ_j, which summarizes the effect that airline j has on i's profits. In particular, notice that this function depends directly on the identity of the firms (y_j's, $j \neq i$). If we assume that firms play a simultaneous-move game in all markets and in all periods, then this is simply the model in Ciliberto and Tamer [2009] applied to panel data rather than to cross section data. We refer to that paper for the detailed description of the estimation methodology. Here we provide a brief summary.

The statistical model associated with the simultaneous move game is as follows:

$$\begin{cases} \pi_{1mt} = X'_{1mt}\alpha + \sum_{j\neq 1} \delta_j y_{jmt} + \epsilon_{1mt}, \\ \pi_{2mt} = X'_{2mt}\alpha + \sum_{j\neq 2} \delta_j y_{jmt} + \epsilon_{2mt}, \\ \qquad \qquad .... \\ \pi_{Imt} = X'_{Imt}\alpha + \sum_{j\neq I} \delta_j y_{jmt} + \epsilon_{\mathrm{Im}\,t}, \end{cases} \tag{1}$$

with $j = 1, ..., I$. Thus, this is simultanous system of discrete choice equations. The problem with the estimation of such model is that in general it has multiple equilibria. Tamer [2003] proposed a methodology to identify sets of parameters of the model for the case of two firms choosing between two decisions (e.g. whether or not to enter into a market) and Ciliberto and Tamer [2009] provided a practical methodology to estimate sets in the case of many firms making multiple decisions. In particular, Ciliberto and Tamer [2009] show that Model (1) provides the following inequality restrictions on regressions:

$$\mathbf{H}_1(x, \theta) \leq \Pr(\mathbf{y}|x) \leq \mathbf{H}_2(x, \theta), \tag{2}$$

where $\Pr(\mathbf{y}|x)$ is a 2^I vector of choice probabilities that we consistently estimate using the data, and we interpret the inequalities element by element. The $\mathbf{H}$'s are functions of θ and the distribution function F_Ω, where Ω is part of the vector θ. As

Ciliberto and Tamer [2009] explain, the identified set, Θ_I, is then the set of parameter values that obeys the inequality restrictions for all x almost everywhere and represents the set of economic models that is consistent with the empirical evidence. For a given parameter value, the estimator is based on minimizing the distance between this vector of choice probabilities and the set of predicted probabilities.

We estimate Model (1) using a sharp two-step minimum distance estimator. First, we estimate the conditional choice probabilities non-parametrically, using a simple frequency estimator. Then, we estimate the identified set Θ_I using the simulation procedure provided in Ciliberto and Tamer [2009]. In practice we simulate random draws of ν_m, ξ_{mt}, η_{im}, and ζ_{imt} from four independent normal distributions with mean zero and variance equal to 1.

3.2 Sequential Move Game

We now consider the case when firms might play different games depending on the exogenous history of their previous interactions. More specifically, we will maintain that at each time t and in each market m, airlines can play one of two types of games: a simultaneous-move game or a sequential-move game. The game that firms play at time $t+1$ is determined by the observed market structure at time t. If in the data we observe that at time t in market m firm 2 was the only incumbent, then at time $t+1$ the two firms play a sequential move game, where firm 2 is the leader and firm 1 is the follower. (If there were no incumbents or multiple incumbents in the previous period, then the firms play a simultaneous-move game). In a sequential-move game, one firm makes her entry decision before the other firms choose theirs, and all other firms can observe the first mover's choice. Thus, in a sequential-move game the followers' actions are conditional on the first mover's actions. If the firms play a sequential-move game, then they use the subgame-perfect Nash equilibrium solution concept to solve the game they play. A subgame-perfect Nash equilibrium is a combination of firm's strategies $\mathbf{y}_{mt}^{*}$ such that no firm can unilaterally benefit from choosing a different strategy at any stage of the game.

To illustrate the type of game that firms play at each period, consider **Table 2**, which presents several possible scenarios with two airlines (American and Delta) in one particular market. In the first quarter of 1998 neither of the two airlines was serving this particular market. Therefore, in the second quarter of 1998, there was no incumbent, and thus the two airlines played a simultaneous-move game. Among the possible realizations, the airlines ended up in the one where American entered into the market, while Delta did not enter. In the third quarter of 1998, American is now the incumbent and moves first, and Delta follows. The interpretation of the game in the other quarters is analogous.

Table 2: The Game Played by Airlines in One Particular Market

	Time (quarter/year)					
Airline	1/1998	2/1998	3/1998	4/1998	1/1999	2/1999
AA	0	1	1	1	0	0
DL	0	0	1	1	1	1
Type of Game	...	Simult.	Sequential AA Moves First	Simult.	Simult.	Sequential DL Moves First

Note: Observable and unobservable market conditions change over time.

Consider now the game played in the third quarter of 1998 by the two firms. American was the incumbent in the second quarter, and thus American must decide whether or not to enter before Delta makes its decision. To determine the one-shot equilibrium of the game, the game is solved through backward induction. First, we determine the Nash pure strategy equilibria in the second stage of the game, the one where only Delta must decide whether to enter, given the decision made by American. Then, we determine whether in the second stage equilibrium "chosen" by

Delta, American makes nonnegative profits. If there is such an equilibrium (or more) in the second stage, American can pick it by moving first.

Consider, for example, the situation where there are two equilibria in the simultaneous-move game, which is the game that the two firms would be playing if American did not have a first-mover advantage. Let the categorical variable $y_{AA} = 1$ if American is in the market, otherwise $y_{AA} = 0$. Similarly, $y_{DL} = 1$ if Delta is in the market. Let the first equilibrium be $(y_{AA}, y_{DL}) = (0, 1)$: American does not enter, while Delta enters into the market. Let the second equilibrium of the last stage game be $(y_{AA}, y_{DL}) = (1, 0)$: American enters, Delta does not enter. In the sequential game where American moves first, there will be a unique equilibrium, $(y_{AA}, y_{DL}) = (1, 0)$.

The sequential and simultaneous move games have the same payoffs but they possibly have different equilibria. The set of equilibria of the sequential move game is a subset of the one in the simultaneous move game. This observation leads to the discussion concerning the estimation.

If the firms play a sequential move game in a market at some point in time, and there is a unique equilibrium, then the inequalities (2) hold with equality. The way we derive the equalities and inequalities is conceptually analogous to the way that Ciliberto and Tamer [2009] derive the inequalities for the simultaneous move game.

First, we estimate non-parametrically the empirical probability of each market structure as in the first step for the estimation of the parameters in the simultaneous move game, except that now we need to include the information on whether or not there is an incumbent, and its identity.

Then, we determine the game that the firms play, whether simultaneous- or sequential move. In particular, we determine for each market m in each period t the equilibria of the simultaneous-move game. Then, we determine whether there is at least one equilibrium where the incumbent (e.g. American) is in the market among these simultaneous-move equilibria. As in the example above, if there is such an equilibrium, then the incumbent will move first and will able to select this equilibrium. Clearly this process is only applied if there is an incumbent in the market; otherwise, we solve the game as if it were a simultaneous move game.

3.3 A Game of Strategic Deterrence

Generally, the fact that one airline, say American, has the first mover advantage does not imply that there exists a subgame perfect equilibrium where American is in the market. This only occurs if there is one subgame perfect equilibrium where American is in the market. This is where the role of strategic deterrence comes into play. Following Bernheim [1984], we will assume that an incumbent can opt to deter new entrants when the game is sequential. An incumbent firm i can make deterrence investments by paying a deterrence cost c_i at time t and ensure that it will be a monopolist at time $t+1$.

To understand the role of the deterrence investments, consider again the example of the strategic interaction between American and Delta illustrated in **Table 2**. In the third quarter of 1998, American must decide first whether to deter new entrants. If American pays a deterrence cost c_{AA}, then American can deter new entrants and make the expected value of the stream of future profits when the firm is a monopolist today, π^M_{AA}. American's value to entry would then be given by $\pi^M_{AA} - c_{AA}$. If American does not pay the deterrence cost, then the airlines play the sequential game just described.

American will deter new entrants if: i) the cost of deterrence is lower than the monopoly value to entry; ii) the profit that American makes under deterrence, $\pi^M_{AA} - c_{AA}$, is not smaller than the lowest value to entry that American would make in any of the subgame perfect equilibria of the sequential game played by airlines should American not deter new entrants. Thus, American might not deter new entrants even when it could do so.

In the sequential-move game where firms can make deterrence investments we proceed as follows. As in the sequential-move game, we first estimate the empirical probability of each market structure conditional on whether one of the firms was a single incumbent in the previous period. So the first stage nonparametric estimates are the same in the case when we allow firms to play a sequential move game and when we allow them to make deterrence investments.

Then, we solve the game as if the firms were playing a sequential-move game; that is, as if they did *not* have the possibility to make deterrence investments. We then compute the profits of the incumbent in each of the subgame perfect equilibria of the sequential game. Among all these profits we choose the one where the incumbent makes the *lowest* profit. Next, we compute the "deterrence profit", given by the profit that the incumbent would make as a monopolist, and we subtract the deterrence cost c. We compare the "deterrence profit" of the incumbent to the lowest profit that the incumbent would make in the equilibria of the sequential game. If the "deterrence profit" is lower, then the incumbent plays a sequential game; if the profits minus the deterrence costs are non-negative, the incumbent incurs the deterrence cost and deter new entrants; otherwise the firms play a simultaneous-move game.

4 Data and Variables[1]

4.1 Data

The main data are from the Airline Origin and Destination Survey (DB1B) from the year 2004; this data include details on each domestic itinerary, including operating carrier, origin carrier, origin and destination airports, number of passengers, distance, and the fare. We merge this dataset by operating carrier with the T-100 Domestic Segment Dataset, which contains domestic market data by air carriers, origin and destination airports for passengers enplaned. Unlike the DB1B dataset, the T-100 is not a sample; it reports all domestic flights in a given month of the year. From the merged dataset we drop tickets with flights that have a frequency that is less than weekly, and we also drop tickets with flights for which there is no record in the T-100 Segment. We then clean the dataset as described in Ciliberto and Tamer [2009].[2] The unit of observation in the cleaned dataset is by market-carrier-year-quarter. Since we are only interested in knowing whether or not a carrier served a market, we construct an indicator variable that equals 1 if the carrier serves the market and 0 otherwise. Therefore, the unit of observation is by market-year-quarter in the final dataset. Time is denoted by t, and a unit of observation is individually denoted by the triple jmt.

We define a market as a trip between two airports, regardless of intermediate transfer points and direction of flight. Table 1, which lists informal complaints about

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[1] Ciliberto and Tamer [2009] use the same dataset but on a different set of markets and as a cross-section.

[2] In particular, we drop: 1) Tickets with more than 6 coupons; 2) Tickets involving US-nonreporting carrier flying within North America (small airlines serving big airlines) and foreign carrier flying between two US points; 3) Tickets that are part of international travel; 4) Tickets involving non-contiguous domestic travel (Hawaii, Alaska, and Territories); 5) Tickets whose fare credibility is questioned by the DOT; 6) Tickets that are neither one-way nor round-trip travel; 7) Tickets including travel on more than one airline on a directional trip (known as interline tickets); 8) Tickets with fares less than 20 dollars; 9) Tickets in the top and bottom five percentiles of the year-quarter fare distribution. We define a firm as serving a market if it transported at least 20 passengers in one quarter.

unfair exclusionary practices, provides insights on the nature of competition between low cost carriers and national carriers, and we use these insights to determine the relevant markets. We merge our data with demographic information from the U.S. Census Bureau for all Metropolitan Statistical Areas (MSA) of the United States. We then rank airports by the MSA's market size. To maintain exogeneity of selection of markets to the observed patterns of entry, we include all markets out of the top 150 MSAs as ranked by their population.[3] We then drop all markets where the two endpoints are both in the top 30 MSAs.[4]

We also include markets that are *temporarily* not served by any carrier, where the number of observed entrants is equal to zero. To distinguish markets that are almost never served by any carrier from markets that are only temporarily not served by any carrier, we proceed as in Ciliberto and Tamer [2009]. Using the full 1996-2007 dataset of market-carrier-year-quarter observations, we compute the number of quarters that a market has been served by at least one carrier, for each market, m.[5] Then, we drop all markets that were not served in at least 50 percent of the quarters in the full dataset.

We consider all the national carriers (American, Continental, Delta, Northwest, United, USAir, Southwest). Small, low-cost carriers are present in only a few markets.[6] Rather than dropping these carriers from the market analysis because we cannot identify their impact on the entry decisions of competitors, we group them in

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[3] Following Borenstein (1989), we assume that flights to different airports in the same metropolitan area are in separate markets.

[4] The list of the MSAs is available from the authors.

[5] We exclude the Muskegon County Airport, the Saint Petersburg-Clearwater International Airport, and the Atlantic City International Airport because there are too few markets between these airports and the remaining airports.

[6] One important issue is how to treat regional airlines that operate through code-sharing with national airlines. As long as the regional airline is independently owned and issues tickets, we treat it separately from the national airline.

a meaningful way in order to capture the impact of their presence. To this end, we construct an indicator variable, `Low Cost Carrier Small`, LCC, which is equal to 1 if one or more low cost carriers are present in the market, and 0 otherwise. Carriers are denoted by i. We exclude all markets in which one of the carriers has a hub at either endpoint.

As in Ciliberto and Tamer [2009], the entry decision in each market for each airline is interpreted as a "marginal" decision, and the airline's network structure is taken as given. This marginal approach to the study of airline markets is also used in the literature that studies the relationship between market concentration and pricing. For example, Borenstein [1989] does not include prices in other markets out of Atlanta (e.g. ATL-ORD) to explain fares in the market ATL-AUS.

4.2 Variables

Using Berry's [1992] insight, we use the carrier's *Airport Presence* at the market's endpoints to construct measures of carrier heterogeneity. To compute airport presence at one airport, we compute a carrier's ratio of markets served by the carrier out of an airport over the total number of markets served out of an airport by at least one carrier. We then average the carrier's airport presence at the two endpoints to define the carrier's Airport Presence.[7]

A firm- and market-specific measure of cost is not available. To proxy for the cost that a carrier incurs in order to serve a particular market, we construct a measure of the opportunity fixed cost of serving a market. To do this, we first compute the sum of the geographical distances between a market's endpoints and the carrier's closest

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[7] In the case of the Medium Airlines (MA), we first compute the airport presence for USAir, Continental, and America West, and then we take the maximum of the three. In the case of the Low Cost Carriers (LCC), we first compute the airport presence of each of the low cost carriers, and then again we take their maximum.

hub.[8] Then, we compute the difference between this distance and the nonstop distance between the two airports, and we divide this difference by the nonstop distance. This ratio can be interpreted as the percentage of the nonstop distance that must be traveled if the airline were to use a connecting flight instead of a nonstop flight to serve the market. This is a good measure of the opportunity fixed cost of serving a market, because it measures the cost of the best alternative to non-stop service, which is a connecting flight through the closest hub. This measure is associated with the fixed cost of providing airline service because it is a function of the total capacity of a plane but does not depend on the number of passengers transported in a particular flight. We denote this variable as *Cost*.

We include six control variables. Three are demographic variables.[9] We calculate *Market Size* as the geometric mean of the city populations at the market endpoints in order to measure the size of the potential market. We use average per capita incomes (*Per Capita Income*) and the average rates of income growth (*Income Growth Rate*) of the cities at the market endpoints to measure the strength of the economies at the endpoints. The other three control variables are geographical variables. *Market Distance* is the non-stop distance between the endpoints. The distance from each airport to the closest alternative airport (*Close Airport*) controls for the strength of

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[8] Data on the distances between airports, which are also used to construct the variable *Close Airport* are from the dataset *Aviation Support Tables : Master Coordinate*, available from the National Transportation Library. To construct the measure of *Cost* we consider the following hub airports: Dallas Fort Worth and Chicago O'Hare for American; Cleveland, Houston International, and Newark for Continental; Atlanta, Cincinnati and Dallas Fort Worth for Delta; Phoenix and Las Vegas for America West; Minneapolis and Detroit for Northwest; Denver and Chicago O'Hare for United; Charlotte, Pittsburgh, and Philadelphia for USAir. To derive the measure of *Cost* for the Medium Airlines (MA) we take the minimum among the distances that we compute for Continental, USAir, America West, and Northwest. Southwest does not really have major hubs; it uses several airports, among which we consider Chicago Midway, Baltimore, Las Vegas, Houston Hobby, Phoenix, Orlando. With the exception of ATA, Low Cost Carriers do not have hubs in the same sense that we mean for the largest carriers. To construct a measure of the cost, we computed the (minimum) distance from airports where LCCs had a meaningful presence.

[9] Data are from the Regional Economic Accounts of the Bureau of Economic Analysis, download in February, 2005.

passengers' alternative option, which is to fly from a different airport to the same destination.[10] Finally, we also include the sum of the distances from the market endpoints to the geographical center of the United States (*US Center Distance*). This variable controls for the fact that, just for purely geographical reasons, cities in the middle of the United States have a larger set of close cities than cities on the coasts or cities at the borders with Mexico and Canada.[11]

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[10] For example, Chicago Midway is the closest alternative airport to Chicago O'Hare. Notice that for each market we have two of these distances, since we have two endpoints. Our variable is equal to the *minimum* of these two distances. In previous versions of the paper we addressed the concern that many large cities have more than one airport. For example, it is possible to fly from San Francisco to Washington on nine different routes. In a previous version of the paper,we allowed the firms' unobservables to be spatially correlated across markets between the same two cities. In the estimation, whenever a market was included in the subsample that we drew to construct the parameter bounds, we also included any other market between the same two cities. This is similar to adjusting the moment conditions to allow for spatial correlation. In our context, it was easy to adjust for it since we knew which of the observations were correlated, i.e., ones that had airports in close proximity.

[11] The location of the mean center of population is from the Geography Division at the U.S. Bureau of the Census. Based on the 1990 census results, that was located in Crawford County, Missouri.

Table 3: Summary Statistics, by Airline

	AA	CO	DL	LCC	MA	NW	UA
Variables							
Airline	0.298 (0.457)	0.259 (0.438)	0.466 (0.499)	0.141 (0.348)	0.230 (0.421)	0.255 (0.436)	0.227 (0.419)
Airline Incumbent	0.044 (0.205)	0.072 (0.258)	0.173 (0.378)	0.002 (0.046)	0.010 (0.098)	0.065 (0.247)	0.022 (0.145)
Airline Entry	0.034 (0.182)	0.020 (0.140)	0.046 (0.209)	0.014 (0.120)	0.038 (0.190)	0.036 (0.188)	0.035 (0.184)
Airport Presence	0.344 (0.157)	0.227 (0.187)	0.530 (0.207)	0.127 (0.083)	0.219 (0.123)	0.283 (0.180)	0.275 (0.138)
Cost	0.576 (1.154)	0.536 (1.017)	0.645 (1.297)	0.510 (1.220)	0.266 (0.475)	0.868 (1.606)	0.803 (1.469)
Market Distance				0.815 (0.477)			
US Center Distance				1.220 (0.427)			
Closest Airport				0.347 (0.212)			
Market Size (population)				1.998 (0.995)			
Change Income Market				4.089 (0.313)			
Number Airports				1.611 (0.550)			
Number of Markets				844			
Number of Quarters				4			
Number of Observations				3376			

Table 3 presents summary statistics for the exogenous variables that determine entry[12]. All the variables are means within a market.

In order to run the estimation and compute the confidence intervals using Chernozhukov, Hong, and Tamer [2007], we discretize the continuous variables. Variables could be discretized in quartiles or deciles; here, we discretize the variables using extremely fine discretizations so that the discrete variables have the same means and standard deviations as the continuous variables.

5 Identification

5.1 Identification of Strategic Deterrence

There are at least three reasons why one firm might be a monopolist for a long period of time in a market that are completely unrelated to strategic deterrence.

First, a firm might have a particularly high market-carrier shock, allowing it to operate as a monopolist over a long period of time. To address this possibility, we use the basic idea that one bad shock to a firm cannot explain why a firm never enters in a market where American is the incumbent. If the other firm is profitable on average, then that firm should enter unless American deters its entry. To identify deterrence from a high market-carrier shock, we include η_{im}.

Second, there might only be space for one firm in the market, in the sense that two firms would not be able to both make nonnegative profits. However, if this is the case, then we should see no pattern in the identity of the monopolist over time. Third, there might be multiple equilibria with different number of firms in a market, and we might simply observe the equilibrium with one firm rather than one with two

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[12] Several variables, such as prices or market shares are excluded because they are endogenous. For example, markets with a larger number of firms are more likely to see lower prices. We only include variables that are predetermined or clearly exogeneous to the entry decision.

or more firms. The first two columns of **Table 4** illustrate how we plan to identify strategic deterrence from these other two possibilities.

There are two firms that compete against each other in one market, and for simplicity of exposition, we again consider American and Delta as the two competing firms. At time 0 neither firm is present in the market, because neither firm makes nonnegative profits. Then at time 1 there is a positive shock to the profits of both firms and *either one but not both* of the firms can enter into the market. American enters. At time 2 there is another positive shock to the profits of both firms, and now *both* American and Delta can profitably enter into the market. However, we observe only American in the market. At time 3 there is a negative shock to the profits of both firms and American must exit the market. At time 4 there is a positive shock to both profits and *either one but not both* of the firms can enter into the market. This time Delta enters. At time 5 there is another positive shock to both profits and both American and Delta enter into the market.

The first two columns of **Table 4** summarize this example. American was able to prevent the entry of Delta when American was the incumbent, while Delta was not able to prevent the entry of American when Delta was the incumbent.

Table 4: Occurrence of Strategic Deterrence

Time	Possible Firms in Equilibrium	Number of Firms Observed in the Data	Profits of the Firms
0	0	0	$(0,0)$
1	AA or DL	AA	$\left(\pi_{AA}^{M},0\right)$
2	AA and DL	AA	$\left(\pi_{AA}^{M}-c_{AA},0\right)$
3	0	0	$(0,0)$
4	AA or DL	DL	$\left(0,\pi_{DL}^{M}-\delta_{AA}\right)$
5	AA and DL	AA and DL	$\left(\pi_{AA}^{M}-\delta_{DL},\pi_{DL}^{M}-\delta_{AA}\right)$
...	...	...	...

Possible Firms in Equilibrium indicates the identity of the firms that could be making nonnegative profit in equilibrium. Actual Firms in Equilibrium indicates the identity of firms that are observed in the data.

Table 4 implies that American must face lower deterrence costs than Delta and that American did deter Delta from entry at time $t = 2$. The last column of **Table 4** shows how the identification strategy discussed in the first two columns of **Table 4** can be used to identify the cost that airlines must incur to deter new entrants. Since American deterred Delta from entry at time $t = 2$, then it must be that $\pi_{AA}^{M} - c_{AA} > \pi_{AA}^{M} - \delta_{DL}$, that is the value to entry of American in this market when it deters Delta is higher than the value to entry of American as a duopolist. On the contrary, $\pi_{DL}^{M} - c_{DL} > \pi_{DL}^{M} - \delta_{AA}$, Delta's value to entry as a monopolist in this market is not large enough to justify the deterrence costs. The variation across and within markets identifies π_{AA}^{M}, π_{AA}^{D}, π_{DL}^{M}, π_{DL}^{D}, c_{AA}, and c_{DL}.

The critical feature of this stylized model is that the incumbent faces a trade-off. The incumbent can deter new entrants, but only at a cost c_i. Whether the incumbent will actually deter new entrants depends on the characteristics (and unobservables) of the market and of the new entrant.

The critical variation that is needed for the econometric analysis concerns new entry and exit. In order to identify the role of strategic deterrence, it is crucial to see firms entering in markets that were not previously served by any airline and firms entering in markets that are already served by other airlines. This variation in the market structure within markets over time separately identifies the effect of strategic deterrence from the role that sunk costs, operating costs, and demand changes have on market structure. **Table 5** illustrates this type of variation in the data.

Table 5: Variation in Entry and Exit

	One Incumbent							No	More Than	Total
New Entry	AA	CO	DL	LCC	MA	NW	UA	Incumbent	One Incumbent	
AA	...	6	6	0	0	8	4	19	73	116
CO	3	...	11	0	2	1	1	7	43	68
DL	14	16	...	0	3	3	3	58	57	154
LCC	0	1	4	...	0	2	0	5	37	49
MA	9	4	16	0	...	5	3	17	73	127
NW	5	5	11	0	1	...	4	26	72	124
UA	7	1	9	0	2	9	...	16	74	118
Total	38	33	57	0	8	28	15	148	429	756

There are 756 new entries over the time period considered. Some patterns are clear from the table. First, most of these new entries occur where there is more than one incumbent in the market or where there are no incumbents. Only 20 percent of the new entries were in markets where there was only one incumbent. Second, low cost carriers enter disproportionately in markets where there are other incumbents,. Finally, there that there is less entry by the national airlines where a Low Cost Carrier is the only incumbent in the market.

5.2 Exclusion Restrictions

We assume that the unobservables are not correlated with our exogenous variables. We consider a reduced form profit function, where all of the control variables (e.g. population, distance) are maintained to be exogenous.

The main difficulty of estimating Model (1) is given by the presence of the competitors' entry decisions, since it is a simultaneous move entry game. Theorem 2 in Ciliberto and Tamer [2009] shows that we can identify the parameters with an exclusion restriction consisting of a variable that enters firm i's profit but not firm j's. If this variable has wide support (i.e. a large degree of variation), then this reduces the size of the identified set. We have two variables that work as exclusion restrictions: *Airport Presence* and *Cost.*

6 Results

We present the results for the empirical specifications in the same order as the statistical models in Section 3. We present the results for the (repeated static) simultaneous, sequential, and deterrence games. Then we compare the results across the various specifications.

In our results, we report superset confidence regions that cover the truth, θ_I, with a prespecified probability. This parameter might be partially identified. Since, in general, these models are not point identified, and since the true parameter, along with all parameters in the identified set minimize a nonlinear objective function, it is not possible to provide estimates of the bounds on the true parameter. Instead, we report confidence regions that cover the true parameter value and that can be used as consistent estimators for the bounds of the partially identified parameter θ_I. In each table we report the cube that contains the confidence region that is defined as the set that contains the parameters that cannot be rejected as the truth with at least 95% probability.[13]

Column 1 of **Table 6** presents the results of the estimation of a static simultaneous move game. Here, the effect of American's entry is different from the effect of Delta's entry on other airlines. However, American's entry affects all its competitors in the same way. For example, $\delta_{AA} \neq \delta_{DL}$. The effect of American on all of its competitors is included in $[-11.589, -9.597]$, while the effect of Continental is included in $[-13.816, -11.926]$. This implies that the entry of a second competitor is less likely if Continental enters the market than if American does. The negative effect of the entry of an LCC on the probability of entry of another competitor is even stronger,

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[13] Not every parameter in the cube belongs to the confidence region. This region can contain holes but here we report the smallest "cube" that contains the confidence region.

as it is included in $[-18.954, -16.335]$. Overall, LCCS have the strongest negative effect on competitors, as was also found in Ciliberto and Tamer [2009]. American has the weakest effect, while the other airlines are comparable ($[-12.436, -10.834]$ for Delta, $[-12.681, -11.103]$ for the MA type, $[-12.910, -11.190]$ for Northwest, and $[-12.801, -10.324]$ for United). In general, the results in **Column 1** of **Table 6** do not provide any support for the hypothesis that larger airlines are more aggressive than low cost airlines. Instead, low cost airlines are the most aggressive in the market, since it is much less likely that other firms enter when they are present.

Next, market presence, the measure of heterogeneity, has a strong positive sign and is included in $[11.422, 13.233]$. The higher the percentage of markets that one airline serves out of an airport, the more likely it is that a firm enters into a market. This is consistent with previous work (Berry [1992] and Ciliberto and Tamer [2009]). The distance from the hub of an airline (our measure of fixed costs) is negatively associated with entry ($[-2.408, -0.868]$), which we expected. Both of these results are robust across the three Columns in **Table 6**.

The remaining rows of **Column 1** in **Table 6** present the results for the control variables. The effect of market distance is included in $[0.772, 1.362]$, which implies that entry is more likely when the distance between cities is larger. The effect of market size is included in $[1.711, 2.407]$, which implies that larger markets are more likely to be served. Markets whose endpoint cities are seeing their incomes increasing are more likely to be served ($[0.646, 1.469]$). Markets between cities that have multiple airports are less likely to be served, ceteris paribus. This does not imply, of course, that cities with multiple airports are less likely to be served; it just says that airlines are not likely to serve two markets out of the same city. These four results are robust across the three specifications. Then, there are two results concerning the distance from the geographical center of the US and the distance among airports of a city. Neither of these results is robust to changes in the specifications, and it is thus difficult to draw a clear interpretation.

We calculate the goodness of fit by taking the percentage of realized observations that were correctly predicted by the model. For example, in the simultaneous game, if the realized observation is *one* of the multiple equilibria predicted by the model, that particular observation is counted as correctly predicted. We correctly predict 37% of the outcomes in the simultaneous game.

Table 6: Regression Results

	Simult. Move Game	Seq. Move Game	Deterrence Game
	Coefficient Bounds	Coefficient Bounds	Coefficient Bounds
American, δ_{AA}	[-11.589 -9.597]	[-10.880 -7.231]	[-13.722 -11.155]
Continental, δ_{CO}	[-13.816 -11.926]	[-12.831 -9.111]	[-15.870 -13.052]
Delta, δ_{DL}	[-12.436 -10.834]	[-11.956 -8.692]	[-16.778 -13.984]
LCC, δ_{LCC}	[-18.954 -16.335]	[-16.202 -12.464]	[-15.590 -12.490]
MA, δ_{MA}	[-12.681 -11.103]	[-10.837 -7.610]	[-14.263 -11.254]
Northwest, δ_{NW}	[-12.910 -11.190]	[-12.687 -9.206]	[-12.989 -10.561]
United, δ_{UA}	[-12.801 -10.324]	[-11.157 -7.232]	[-13.011 -10.618]
Deterrence cost AA, c_{AA}			[-7.458 -3.441]
Deterrence cost CO, c_{CO}			[-10.430 -8.526]
Deterrence cost DL, c_{DL}			[-3.990 -0.258]
Deterrence cost LCC, c_{LCC}			[-7.791 -2.679]
Deterrence cost MA, c_{MA}			[-9.684 -5.554]
Deterrence cost NW, c_{NW}			[-2.576 0.392]
Deterrence cost UA, c_{UA}			[-13.535 -9.692]
Market Presence	[11.422 13.233]	[8.680 9.988]	[7.678 10.637]
Min Cost Hub	[-2.408 -0.868]	[-2.029 -1.344]	[-1.102 -0.636]
Market Distance	[0.772 1.362]	[0.718 1.372]	[8.030 9.285]
From Center	[-1.304 -0.502]	[-0.517 0.055]	[1.601 2.873]
Min Distance	[-1.513 0.159]	[0.608 2.449]	[2.636 3.619]
Market Size	[1.711 2.407]	[1.198 1.683]	[2.402 3.320]
Change Income	[0.646 1.469]	[0.513 1.713]	[1.927 3.696]
Number Airports	[-1.726 -0.799]	[-0.661 0.049]	[-5.481 -4.134]
Constant	[-1.613 1.544]	[-3.318 0.254]	[-1.408 3.915]
Function Value	1735.521	1881.632	1724.826
Goodness of Fit	0.37	0.34	0.49
Number Obs	3376	3376	3376

Column 2 of **Table 6** presents the results of the estimation of the game where firms can play sequentially. Recall that this is the framework where the type of game that firms play depends on the exogenous history of the game. If there is a single incumbent, then the firms play a sequential move game. Otherwise, the firms play a simultaneous move game. The estimation results in **Column 2** are quite similar to those presented in **Column 1** of **Table 6**. The only relevant difference is in the magnitude of the strategic effects for the larger firms, but the differences are not statistically significant as the intervals overlap. Similarly to the simultaneous game, we calculate the goodness of fit by calculating the percentage of realized observations that are correctly predicted by the sequential game model. Using the estimated parameters, we predict when incumbents would move first, thereby restricting the equilibria to those in which the incumbent serves the market. When the realized equilibrium is one of our predicted equilibrium, we consider that observation as being correctly predicted. In the sequential move game, we do slightly worse in our predictions, though the difference is not significant.

Column 3 of **Table 6** presents the results when firms can make deterrence investments. This is the first set of the central results of the paper. The results are very rich and we go over them in two steps. First, we discuss how the "competitive effects," δ, differ in **Column 3** from **Columns 1** and **2**. Then, we discuss the estimation results for the cost of the deterrence investments, c.

First, we observe that the competitive effects are, in some cases, larger in magnitude in **Column 3** than they were in **Columns 1** and **2**. For example, we find that the effect of American on its competitors is now in $[-13.722, -11.155]$ while before it was in $[-11.589, -9.597]$. Thus, it is larger (in absolute value) and statistically different. We find similar results for Continental and Delta. Remarkably, we find the opposite for the low cost carriers, as now their effect on competitors is in $[-15.590, -12.490]$ while in Column 1 it was in $[-18.954, -16.335]$. The results for MA, Northwest, and United are similar across the three columns. These are interesting results and indicate that allowing for deterrence investments can lead to different estimates of the competitive effects than when we do not allow for firms to deter.

Now, consider the estimates of the costs of deterrence. These costs are crucial for our analysis, because the higher they are, the less likely it is that a firm deters new entrants. We find that American can deter the entry of new firms in its markets by paying deterrence costs included in $[-7.458, -3.441]$. These costs are lower than the competitive effects of any of American's rivals (the lowest is Northwest, which is included in $[-12.989, -10.561]$). This implies that American would definitively pay the deterrence cost if it had the option to do so. The analysis is the same for all the other firms except for United, whose costs of deterrence overlap the competitive effects of American, Continental (though by little), LCCs, MA, and Northwest. This implies that United would only make deterrence investments if facing the potential competition of Delta. We will return to this finding below.

Overall, these results are striking and indicate that all firms have an incentive to make deterrence investments, though they face different costs of doing so.

To determine the fit of the model to the data, we estimate the model under the deterrence parameters and predict when firms would deter entrants. When firms deter, we predict only one equilibrium (the incumbent remains in the market as a monopolist). When the incumbent does not deter, the firm still has a first-mover advantage and the firms play a sequential game. Under these assumptions, we correctly predict almost half of the observed outcomes. Since the deterrence game restricts many market predictions to a single equilibrium (incumbents deter the majority of the time) instead of allowing for multiple equilibria as in the simultaneous and sequential games, the increased goodness of fit provides strong evidence that firms are, in fact, using deterrence investments.

7 Comparing Profits Across Types of Games

The results in this section compare the profits made in the simultaneous game, the sequential game and the deterrence game for the incumbent firm only. Because we can only identify the profits up to a scale, we use the ratios of profits in the different games to gauge the economic importance of being a first mover in the context of sequential-move and deterrence games. There are two ways we could compute the profits for comparison purposes. For example, suppose we would like to compare the deterrence profits to the sequential game profits. One way to do this is to calculate the deterrence profits under the parameters estimated in the deterrence scenario (**Column 3** of **Table 6**) and compare these profits to the sequential game profits calculated *using those same deterrence parameters*. The second way to compare these two profits is to compare the deterrence profits under the deterrence scenario to the sequential profits *using the parameters in the sequential-move game* (**Column 2** of **Table 6**). In the first case, which would be what is done in typical counterfactual analysis, we would be assuming that the firms actually do play a deterrence game. Instead, we use the second approach because we are comparing across a menu of games that firms can be playing. Thus, we compare the profits that we would predict under the estimates in **Columns 1-3** in **Table 6**. In the remaning analysis we use the parameter values where the distance function is minimized and simulate 1000 errors and compute the profits. The ratios of these profits are reported in **Tables 8, 9** and **10**.

We begin with the simultaneous-move game and we use the parameters in **Col-**

Table 7: Entry in Simultaneous Game

	% Times in Market in Best Simult Game	% Times in Market in Worst Simult Game	% Times in Market in Rand. Simult Game
AA	0.890	0.038	0.338
CO	0.978	0.055	0.345
DL	0.984	0.106	0.461
LCC	1.000	0.009	0.231
MA	0.849	0.000	0.181
NW	0.936	0.023	0.300
UA	0.805	0.022	0.258

umn 1 of **Table 6.** We first check if there is a unique equilibrium because in that case we have one profit for each firm in the equilibrium. If there are multiple equilibria, then for each incumbent firm we consider three possibilities: i) the *highest profit* that the firm makes among all the possible equilibria; ii) the *lowest profit*, which can be zero if the firm is not in the unique equilibrium or if the firms is not in at least one of the multiple equilibria; iii) and the case where the equilibrium is selected *randomly*, with equal probabilities across equilibria.

Table 7 shows the percentage of the time each firm enters the market in the simultaneous game under these three possibilites. Consider **Column 1** of **Table 7**. For example, the number 0.890 in the first column and first row means that American is present *at most* 89 percent of the times in either the unique or one of the multiple equilibria of a game that corresponds to one simulation. The number 0.038 in the second column and first row means that American is predicted to be present *at least* 3.8 percent of the time. Finally, the number 0.338 in the third column and first row means that American is present 33.8 percent of the times when we choose among the multiple equilibria in a random fashion, and includes the cases where American is present in the unique equilibrium of the game.

For sequential-move equilibria without deterrence investments, equilibrium profits

Table 8: Ratio of Sequential to Simultaneous Profits

	Best Case Simultaneous Profits	Worst Case Simultaneous Profits	Randomized Simultaneous Profits
AA	[0.123 0.941]	[1.957 14.955]	[0.326 2.494]
CO	[0.161 0.907]	[0.906 5.123]	[0.417 2.354]
DL	[0.242 0.872]	[1.812 6.518]	[0.493 1.774]
LCC	[0.042 1.128]	[7.733 209.447]	[0.167 4.529]
MA	[0.006 0.547]	–	[0.029 2.606]
NW	[0.123 0.992]	[1.105 8.883]	[0.365 2.932]
UA	[0.074 0.738]	[0.792 7.911]	[0.233 2.325]

Table 9: Ratio of Deterrence to Sequential Profits

	Compared to Max Profit in Sequential game	% Times Firm Deters	Compared to Min Profit in Sequential game	% Times Firm Deters
AA	1.947	0.920	15.290	0.920
CO	1.344	0.971	7.743	0.971
DL	2.114	0.971	7.618	0.971
LCC	2.059	1.000	55.773	1.000
MA	4.660	1.000	415.605	1.000
NW	2.376	1.000	19.106	1.000
UA	2.202	0.226	17.840	0.700

are calculated using the parameters estimated in **Column 2** of **Table 6**. As discussed above the incumbent moves first but we do not allow for the incumbent to choose the specific resulting equilibrium. For example, suppose American is the incumbent. If there are multiple duopoly equilibria, American can choose to be one of the firms in the market, but it cannot choose its competitor. Therefore, we report bounds on the sequential profit, where the lower bound is the minimum profit the incumbent could make in the sequential game and the upper bound is the maximum profit the incumbent could make in the sequential game. The reported sequential profit is the average profit for the incumbent firm.

For equilibria in the game with deterrence investments we use the parameter estimates in **Column 3** of **Table 6**. As before we simulate the games 1000 times and take the average profit that each firm makes when it chooses to deter.

Table 10: Ratio of Deterrence to Simultaneous Profits

	Best Case of Simult Profits	Randomized of Simult Profits	Lower Bound of Simult Profits
AA	1.882	4.990	29.927
CO	1.243	3.225	7.018
DL	1.847	3.756	13.801
LCC	2.322	9.327	431.317
MA	2.547	12.144	–
NW	2.357	6.968	21.111
UA	1.318	4.154	14.136

Tables 8 reports the ratio of sequential profits to simultaneous profits. The simultaneous equilibrium profit is calculated using three different methods, as explained above. The sequential profit is calculated using both the minimum and maximum sequential profit, which provides bounds on the ratio of the sequential to simultaneous profits. The first column in **Table 8** reports the ratio of sequential profits to simultaneous profits, where the simultaneous equilibrium is chosen as the best possible equilibrium for the incumbent firm. In **Column 1** we show the ratio of profits in the sequential game to the highest (best case) profits in the simultaneous game. The values have a range that falls below 1 for most firms, which implies that firms, on average, do better when they are able to choose the best possible equilibrium in the simultaneous game (the "best case") compared to when they are playing a sequential game and have a first-mover advantage but cannot choose a *particular* equilibrium.

The second columns in **Tables 7** and **8** reflect the "worst case" simultaneous profits, where each simultaneous equilibrium is chosen as the lowest profit for the firm. MA is never able to enter the market in the worst case scenario, so the lower bound of simultaneous profits is zero for this firm. For the low cost firm, the ratio of sequential to lower-bound simultaneous profits is very high; this is due to the fact that the low cost firm can enter the market only very rarely in the worst-case scenario.

The third column in **Table 8** reports the ratio of sequential profits to simultaneous profits when the simultaneous equilibrium is chosen at random from all possible equilibria; the corresponding column in **Table 7** reports the percentage of times the incumbent enters in the market in equilibrium. The range of the ratio of profits and the percentage of entry both fall between the best case and worst case scenarios. This is because the simultaneous equilibrium is chosen at random. This means that relative to the best case, each firm will enter less, on average, and make lower profits in the simultaneous game; relative to the worst case, each firm will enter more, on average, and make more profits in the simultaneous game.

The three ratios of profits provide bounds on the ratio of profits made in the sequential game to those made in the simultaneous game. The randomized simultaneous profits provide perhaps the most informative ratio in the sense that the randomized profits reflect the average profits a firm would make in the simultaneous game, if the simultaneous game were played many times. For example, American makes, on average, somewhere between 0.441 and 2.896 times as much profit when it plays a sequential game versus a simultaneous game where the simultaneous equilibrium is truly chosen randomly.

Table 9 reports the ratio of deterrence profits to simultaneous profits, where the deterrence profit is calculated in two different ways. A firm either compares the profit when it deters to its maximum possible profit in the sequential game (columns 1 and 2), or it compares the deterrence profit to its minimum possible profit in the sequential game (**Columns 3** and **4**). In the first column, we compare the deterrence profit to the maximum sequential profit. In the third column, we compare the deterrence profit to the minimum sequential profit.

When American decides to deter based on its maximum possible profit in the sequential game, it makes 1.677 times as much profit in the deterrence game compared to its best profit in the sequential game and deters 92.0 percent of the time when it is an incumbent. The remainder of the time, the firm plays the sequential game. When comparing its deterrence profit to the minimum possible sequential profit, American makes, on average, 11.001 times more profit when it chooses to deter. It still enters the market 92.0 percent of the time. For all firms except United, the decision to deter does not change when comparing the minimum to maximum sequential profits. This implies that the profits in the sequential game are generally much lower than when firms choose to deter. The exception is United. United deters much more when comparing the deterrence profit to the minimum sequential profit versus the maximum sequential profit. This could be due to the fact that United faces the highest cost of deterrence, and so would be more sensitive to the relative benefit of deterrence. It could also be the case that the range of profits United makes in the simultaneous game is greater than for the other airlines.

Table 10 reports the ratio of deterrence profits to simultaneous profits, where the simultaneous profits are calculated using the three methods described above. Even when using the *best* possible scenario in the simultaneous game, column 1 shows that firms are, on average, better off when playing the deterrence game. This benefit grows when the simultaneous equilibrium is chosen randomly and grows even more when the simultaneous profit is calculated using the worst possible equilibrium for the firm. In the simultaneous game, MA face a lower bound of zero profits and are never in the market.

Overall, the profits that incumbents can make in the sequential game, both with and without deterrence investments, are larger than those that they can make in the simultaneous move game. Further, on average it is profitable for all firms to deter new entrants, with the exception of United Airlines.

8 Conclusions

We use a practical approach of estimation to determine whether firms make investments to raise barriers to deter new entrants. The objective of the estimation is to quantify the cost of "deterrence investments" (Bernheim [1984]) and relate them to the monopoly profits that firms make when they successfully deter new entrants and the profits that they would make as accommodating oligopolists. We model firms as playing different types of games depending on the exogenous history of the game in each market. We find that the data are consistent with a model where firms make deterrence investments. Also, we find that the profits incumbents can make if they move first are larger than those that they can make if the game is played simultaneously. This result is stronger, as one would expect, when incumbents can deter new entrants. Finally, we find that all firms deter new entrants, with the exception of United Airlines.

There are several limitations to our work which we leave for future research. First, and most obviously, we find that firms make deterrence investments, but we do not characterize the nature of those investments. This avenue of research is clearly important for policy interventions. Second, we consider a repeated static game where the history of the game in each period is exogenous. However, firms are likely forward-looking when they make their investment decisions. This avenue of research is important to exactly quantify the cost of deterrence. However, the benefit of deterrence should be even higher if we allow for its benefit to extend over time, because firms would be able to maintain their position as incumbents longer. Therefore, we can still think of our estimates as providing a measure for what would be the best case scenario for airlines that wanted to make the case that they do not deter new entrants. Since we do find evidence of strategic deterrence even in a repeated static game, we would expect our findings to be even stronger in a dynamic game.

9 References

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