Exchanges of Cost Information in the Airline Industry.

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Abstract

We empirically analyze exchanges of cost information in a multi-market oligopoly model for the airline industry with entry and incomplete information on marginal costs. We develop an algorithm to solve the Nash Equilibrium numerically. We estimate the structural model of supply decisions using data on the American Airlines and United Airlines duopoly at Chicago O'Hare airport. Our results provide probabilities of entry, expected quantities, prices, and profits on each market. Given the estimated parameters, we simulate competition under a hypothetical agreement to exchange cost information. We find that such exchanges would benefit airlines without hurting consumers.

Keywords: Structural Estimation, Incomplete Information, Airline Industry, Exchanges of Cost Information, Entry, Network.
JEL Classifications : L11, D82, C15, C51, L93, R41

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1. Introduction

In the past ten years, the airline industry has witnessed a proliferation of marketing alliances. Within alliances, airlines are able to market and sell tickets on their partner's flights and share revenues on joint flights. These practices, known as code sharing, require exchanges of information on production processes, particularly on costs of production. Given recent proposed alliances between major U.S. carriers, such as Continental Airlines and Northwest Airlines, and American Airlines and US Airways, the implications of these cost information exchanges have become highly relevant. Armantier and Richard (2000) find that, while exchanges of cost information raise expected profits in multi-market settings like the airline industry, expected consumer surplus may increase or decrease depending upon the model's parameters. Since policy makers and courts in antitrust cases traditionally consider consumer surplus the deciding factor, this issue is significant. In this paper, we estimate the structural parameters of a multi-market model of airline competition, and, to analyze how cost exchanges affect consumer surplus, we run some simulations.

In the airline literature, the existing empirical models by Reiss and Spiller (1989), Berry (1992), Berry, Carnall, and Spiller (1996), Richard (2000) analyze decisions on single-markets under complete information. We expand on the findings of the earlier literature as we recognize that firms rarely observe their rivals' costs accurately and entry into a market typically affects the state of other markets. Namely, to analyze exchanges of cost information, we propose a static oligopoly model with incomplete information on costs and simultaneous entry decisions across multiple markets with demand complementarities. There are no fixed costs and marginal costs are assumed to be random private signals, known to the firm but not its rivals. These are drawn from a joint distribution, which is common knowledge among firms. Our model is analytically intractable, and we propose an algorithm, based upon Monte-Carlo simulations, to determine the Bayesian Nash Equilibrium numerically.

We apply this model to American Airlines (AA) and United Airlines' (UA) duopoly competition at Chicago O'Hare airport. The sample data, from the third quarter of 1993, includes 83 markets with flights from at least one of AA or UA, and 17 major markets with no flights. First, we estimate the demand functions, which we assume to be exogenous to the structural model. We then estimate the distribution of marginal costs with the structural inference method recently proposed by Florens, Protopopescu, and Richard (1999) for games of incomplete information. We find an average cost per passenger/mile of $0.165. This figure is consistent with trade publications. Our method also provides probabilities of entry, expected quantities of passengers, prices, and profits. The results closely match observed values.

Finally, we assume that AA and UA agree to exchange cost information truthfully. In this scenario, the two airlines compete under complete information. Using the estimated distribution of marginal costs, we simulate and compare the airlines' equilibrium decisions under both incomplete and complete information. As expected, the average profits increase on every market when AA and UA exchange cost information. Interestingly, these exchanges leave the expected consumer surplus essentially unchanged, and consumers typically benefit on a majority of markets (57%). Hence, a marketing alliance between AA and UA to exchange cost information would be advantageous to airlines without hurting consumers.

The paper is structured as follows. We introduce the theoretic model in Section 2. We propose an algorithm to solve the Bayesian Nash Equilibrium in Section 3. Section 4 discusses the application to the airline industry. In Section 5, we discuss the structural estimation method and present our findings. Section 6 then analyzes exchanges of cost information. Section 7 concludes.

2. A Model of Firms' Decisions

To analyze exchanges of cost information, we develop the following theoretic model.

There are N symmetric firms ($i = 1, .., N$) and M markets ($m = 1, ..., M$). Firms decide simultaneously whether to enter and how much to produce on each of the M markets.

There are no fixed costs, and marginal costs of production are constant. We assume incomplete information on marginal costs. Each firm i is endowed with a vector of private types $c_i = (c_{i,1}, ..., c_{i,m}, ..., c_{i,M})$ where $c_{i,m}$ is firm i's constant marginal cost of production on market m. Firms know their own marginal costs, but they do not observe their rivals' $c_{-i} = (c_1, .., c_{i-1}, c_{i+1,}, .., c_N)$ when deciding upon an optimal strategy. Cost values $c_{i,m}$ are independently and identically distributed (hereafter i.i.d.) across firms and independently distributed across markets. Let $f_m(.|\theta)$ denote the probability density function (p.d.f.) of $c_{i,m}$ indexed by the vector $\theta \in \Re^k$. The p.d.f. $f_m(.)$ and the parameter θ are common knowledge among firms.

The demand function on a market is common knowledge and exogenously determined. It is linear and symmetric across firms. If production is limited to one market, then goods on that market are perceived to be perfect substitutes across firms. Goods across markets are complements and expressed in a common unit. The price for a representative customer of firm i on market m, $P_{i,m}$, is a non-negative function of quantity choices across all M markets:

$$P_{i,m} = \alpha_m + \beta_m \sum_{m' \neq m}^{M} q_{i,m'} + \lambda_m \sum_{m' \neq m}^{M} \sum_{j \neq i}^{N} q_{j,m'} - \gamma_m \sum_{j=1}^{N} q_{j,m} \tag{2.1}$$

where $q_{i,m}$ is firm i's quantity on market m and $\alpha_m, \beta_m, \lambda_m, \gamma_m$ are parameters verifying $\alpha_m > 0$, $\gamma_m > \beta_m \geq \lambda_m > 0$. This specification allows for the level of complementarity to differ across firms (i.e., $\beta_m \geq \lambda_m$). Namely, a consumer who purchases a good may be more willing to buy another good from the same firm than from another firm. Brand loyalty or compatibility problems across brands may explain this behavior.[1] Hence, consumers' willingness to pay for goods which would be considered perfect substitutes if there were no complementarities may vary. We also assume that firm $i's$ price on a market m is equally affected by an increase in quantity on any market $m' \neq m$, even when m' is a new market.[2] We can interpret β_m and λ_m as the marginal increase in a consumer's willingness to pay for good m due to one more unit supplied on a market $m' \neq m$.

Given their marginal costs, firms simultaneously decide whether to enter and how much to produce on each of the M markets. In other words, given c_i, firm i maximizes its expected profits across all M markets by selecting non-negative quantities $q_i^* = \left(q_{i,1}^*, .., q_{i,m}^*\right)$ such that

$$\begin{aligned} q_i^* &= \varphi_i\left(c_i, \theta\right) = \underset{\left\{q_{i,m}\right\}_{m=1,..,M}}{Arg \max} \sum_{m=1}^{M} E\left[\left(P_{i,m} - c_{i,m}\right) q_{i,m} \middle| \theta, c_i\right] \\ & \qquad \text{subject to} \qquad q_{i,m} \geq 0 \qquad \forall m = 1, ..., M \end{aligned} \tag{2.2}$$

where $\varphi_i\left(c_i, \theta\right)$ is firm $i's$ equilibrium strategy function. We do not impose that profits nor expected profits are positive on a given market. In the subsequent simulations, firms have positive expected profits on every market even if they sometimes incur losses. Note as well that the non-negativity constraints on prices are non-binding in the simulations.

Substituting (2.1) into (2.2), we have that

$$\begin{aligned} q_i^* &= \underset{\left\{q_{i,m}\right\}_{m=1,...M}}{Arg \max} \sum_{m=1}^{M} (\alpha_m + \beta_m \sum_{m' \neq m}^{M} q_{i,m'} + \lambda_m \sum_{m' \neq m}^{M} \sum_{j \neq i}^{N} E\left[q_{j,m'} | \theta, c_i\right] \\ & \qquad - \gamma_m \sum_{j \neq i}^{N} E\left[q_{j,m} | \theta, c_i\right] - \gamma_m q_{i,m} - c_{i,m}) \, q_{i,m} \\ & \text{subject to} \qquad q_{i,m} \geq 0 \qquad \forall m = 1, ..., M \end{aligned} \tag{2.3}$$

Subsequent to their quantity choices, firms observe the realizations of prices and profits on each of the M markets.

3. Computing the Bayesian Nash Equilibrium Solution

To analyze exchanges of cost information, we need to derive the Bayesian Nash equilibrium. We find that there is no analytical solution to the problem, and we propose an algorithm, based upon Monte-Carlo simulations of the game, to find the equilibrium solution numerically. This numerical technique is central to our analysis. We use it both to estimate the structural model and to quantify the effects of cost information exchanges on consumer surplus.

3.1. The Kuhn-Tucker conditions

The Kuhn-Tucker conditions for the constrained optimization problem in (2.3) are as follows:

$$
\begin{aligned}
V_{i,m} = \alpha_m + \sum_{m' \neq m}^{M} (\beta_m + \beta_{m'})\, q_{i,m'} + \lambda_m \sum_{m' \neq m}^{M} \sum_{j \neq i}^{N} E\left[q_{j,m'} | \theta, c_i\right] \\
-\gamma_m \sum_{j \neq i}^{N} E\left[q_{j,m} | \theta, c_i\right] - 2\gamma_m q_{i,m} - c_{i,m} \leq 0 \\
q_{i,m} V_{i,m} = 0 \qquad and \qquad q_{i,m} \geq 0 \qquad \forall m = 1, ..., M \qquad \forall i = 1, ..., N
\end{aligned} \tag{3.1}
$$

where $V_{i,m}$ is the partial derivative of (2.3) with respect to $q_{i,m}$.[3]

Since firms are ex-ante symmetric and private signals are i.i.d. across firms, we find that at the equilibrium $E\left[q_{j,m} | \theta, c_i\right] = E\left[q_{j',m} | \theta, c_{i'}\right] = E\left[q_m | \theta\right] \quad \forall j \neq i \quad \forall i \neq i' \; or \; \forall j \neq$

j'. We then write

$$V_{i,m} = \alpha_m + \sum_{m' \neq m}^{M} (\beta_m + \beta_{m'})\, q_{i,m'} + \lambda'_m \sum_{m' \neq m}^{M} E\left[q_{m'}|\theta\right] - \gamma'_m E\left[q_m|\theta\right] - 2\gamma_m q_{i,m} - c_{i,m} \quad (3.2)$$

where $\lambda'_m = \lambda_m(N-1)$ and $\gamma'_m = \gamma_m(N-1)$. The Kuhn-Tucker conditions are invariant to a permutation of player indices and equilibrium strategies are symmetric across firms $\varphi_i\left(.,\theta\right) = \varphi_j\left(.,\theta\right) = \varphi\left(.,\theta\right) \quad \forall j \neq i$. We thus focus on the decisions of a representative firm i. The Kuhn-Tucker conditions imply that

$$q_{i,m} > 0 \iff c_{i,m} < \overline{c}_{i,m}\left(c_{i,-m}\right) \qquad \forall\, m = 1,...M \qquad where$$

$$\overline{c}_{i,m}\left(c_{i,-m}\right) = \alpha_m + \sum_{m' \neq m}^{M} (\beta_m + \beta_{m'})\, q_{i,m'} + \lambda'_m \sum_{m' \neq m}^{M} E\left[q_{m'}|\theta\right] - \gamma'_m E\left[q_m|\theta\right] \quad (3.3)$$

with $c_{i,-m} = (c_{i,1}, .., c_{i,m-1}, c_{i,m+1}, , .., c_{i,M})$. Firm i only enters into market m if its marginal cost $c_{i,m}$ is below $\overline{c}_{i,m}\left(c_{i,-m}\right)$. Note that the threshold value $\overline{c}_{i,m}\left(c_{i,-m}\right)$ is a function of firm $i's$ marginal costs on every market $m' \neq m$. Given that the model's demand and cost functions are linear in quantities, the value $\overline{c}_{i,m}\left(c_{i,-m}\right)$ is uniquely defined on each market m.

Inserting equation (3.3) into equation (3.2), we find that the solution to the optimization problem (2.3) verifies the following:

$$q_{i,m} = \left(\frac{\overline{c}_{i,m}\left(c_{i,-m}\right) - c_{i,m}}{2\gamma_m}\right) I_{\{c_{i,m} \leq \overline{c}_{i,m}(c_{i,-m})\}} \qquad \forall m = 1, ...M \quad (3.4)$$

where $I_{\left\{c_{i,m}\leq\overline{c}_{i,m}\left(c_{i,-m}\right)\right\}}$ is the indicator function defined as

$$I_{\{x\leq 0\}} = \begin{Bmatrix} 1 & when\ x \leq 0 \\ 0 & otherwise \end{Bmatrix}.$$

Now, inserting equation (3.4) into equation (3.3) leads to

$$\begin{aligned} 0 &= \alpha_m + \sum_{m'\neq m}^{M} (\beta_m + \beta_{m'}) \left(\frac{(\overline{c}_{i,m'}(c_{i,-m'}) - c_{i,m'})}{2\gamma_{m'}} \right) I_{\left\{c_{i,m'}\leq\overline{c}_{i,m'}\left(c_{i,-m'}\right)\right\}} \\ &\quad + \lambda'_m \sum_{m'\neq m}^{M} E[q_{m'}|\theta] - \gamma'_m E[q_m|\theta] - \overline{c}_{i,m}(c_{i,-m}) \qquad \forall m = 1, ...M \end{aligned} \tag{3.5}$$

To determine equilibrium quantities, we need to solve the system of equations (3.5) and then (3.4). Note that (3.5) depends upon $E[q|\theta] = (E[q_1|\theta], ..., E[q_M|\theta])$. In this case, unlike a complete information setting, firms cannot predict the exact quantities that their rivals produce at the Nash solution. To determine their best strategies, firms can rely only upon their rivals' expected quantities, $E[q|\theta]$. There is no analytically tractable way, however, to calculate $E[q|\theta]$.

3.2. A Numerical solution

To determine the Nash Equilibrium, we propose to replace $E[q|\theta]$ by an approximation $\widehat{E}[q|\theta]$. Intuitively, $\widehat{E}[q|\theta]$ is the fixed point solution of a problem matching a potential expected quantity to its empirical counterpart as calculated across Monte Carlo simulations.

For a given θ, we simulate S vectors of private types[4] (using the Common Random

Number technique) for the representative firm i, $\{\widetilde{c}_{i,s}\}_{s=1,...,S}$ with $\widetilde{c}_{i,s} = (\widetilde{c}_{i,s,1}, ..., \widetilde{c}_{i,s,M})$. The approximation $\widehat{E}[q|\theta]$ is then the solution of

$$\min_{\varepsilon} ||\varepsilon - \overline{q_i}(\varepsilon)|| \tag{3.6}$$

where $\varepsilon = (\varepsilon_1, ..., \varepsilon_M)$ is a potential value for $E[q|\theta]$; $\overline{q_i}(\varepsilon) = \frac{1}{S}\sum_{s=1}^{S} \widetilde{q}_{i,s}(\widetilde{c}_{i,s}, \varepsilon)$ is the empirical mean of simulated quantities; and $\widetilde{q}_{i,s}(\widetilde{c}_{i,s}, \varepsilon)$ is the numerical solution of the system of equations (3.5) and (3.4) given $E[q|\theta] = \varepsilon$ and $c_i = \widetilde{c}_{i,s}$.

In practice, (3.6) is solved numerically with the simplex method. $\widehat{E}[q|\theta] = \varepsilon$ is a reasonable approximation of the expected quantity $E[q|\theta]$ when ε becomes arbitrarily close to its simulated empirical counterpart $\overline{q_i}(\varepsilon)$. The calculation of $\widehat{E}[q|\theta]$ is time-consuming, but it is not computationally challenging. The equations to be solved numerically are linear up to an indicator function, and there exist numerous numerical procedures that solve these systems in a matter of seconds.

Once $\widehat{E}[q|\theta]$ has been determined, we can calculate from (3.5) and (3.4) the equilibrium quantities for a given cost vector c_i. Symmetrically, we can invert the strategy function and calculate $\{c_{i,m}(q_i), \overline{c}_{i,m}(q_{i,-m})\}_{m=1,...M}$ for a vector of observed equilibrium quantities q_i from (3.3) and (3.4). The econometric technique used in the application to the airline industry requires an inversion of the equilibrium strategy (see Section 5).

4. An Application to the Airline Industry

4.1. American Airlines and United Airlines at Chicago O'Hare

In this section, we examine how our model applies to the airline industry. We define an airline market as a pair of U.S. airports that can be linked by nonstop flights (hereafter flights).[5] A good on a market is a seat on a flight. If at least one carrier flies on a market, the market is said to be active. In the discussion that follows, we consider the competition between American Airlines (AA) and United Airlines (UA) at Chicago O'Hare. We justify the maintained hypotheses of Section 2's model according to the following facts:

(i) Chicago O'Hare is a major hub for both airlines.[6] By nature, a hub is at the center of a self-contained network with demand complementarities across markets, as discussed by Morrison and Winston (1995) and Hendricks, Piccione and Tan (1997).

(ii) Following Brander and Zhang (1990), AA and UA can be viewed as symmetric firms. They are major U.S. carriers with similar network-wide cost structures and brand images. In addition, their network of active markets is comparable at Chicago O'Hare.

(iii) At O'Hare, AA and UA are in duopoly competition, as assumed by Brander and Zhang (1990). They jointly account for 90% of passenger enplanements, and, together, they are present on all of approximately 125 active markets at the airport. By comparison, Delta Airlines, the third largest airline at O'Hare, has only 3.1% of passenger enplanements and offers flights on just 8 markets.

(iv) The internal structure of airline companies is such that a Marketing Group first determines the aggregate number of passengers that fly on each of the sample markets. In practice, changes in aggregated quantities are rare and costly, while we observe numerous price fluctuations. This is consistent with a Cournot model where firms commit to quantities and then prices adjust through a tatonement process. This assumption is common to most empirical studies on the airline industry (e.g. Reiss and Spiller (1989)). Note that we do not model capacity and flight frequency choices.

(v) There is incomplete information on costs. Average costs per passenger per mile for a given airline are made public ex-post on a network-wide basis (e.g. The Airline Monitor (1994)). While AA and UA have information on each other's leasing and servicing contracts, information about a market's main operating costs remains private information.

(vi) A static analysis of entry seems appropriate for this sample. The number of Chicago markets with flights, the number of flights per Chicago market, and the number of U.S. airlines with flights from O'Hare are stable through 1993-1994.

4.2. Data

Our data come from three databases: Databank 1A, Databank DS T-100, and the Official Airline Guide (OAG) publications. Databank 1A, from the Department of Transportation (DOT), is a 10% random sample of all airlines tickets sold quarterly. It provides the itinerary and the price per mile for each passenger.[7] We consider itineraries that include nonstop flights between O'Hare and another US airport and flights connecting two US airports with a stop at O'Hare. To determine $P_{i,m}$, we multiply the mileage of market

m with the average price per mile for all passengers flying with airline i on market m. Databank DS T-100 provides the number of passengers per major airline and per month on a market.

The sample data for our paper are from the 3rd quarter of 1993. There are $M = 100$ Chicago markets in our sample data (c.f. Appendix 1). Eighty-three have flights from one or both AA and UA. The other 17 are major markets without flights from any airline.[8] The sample does not include every Chicago market with flights. For lack of data, 17 markets are excluded. Another 27 markets are excluded as they are not part of the duopoly competition over the hub network for one of the following reasons: (i) a different airline dominates the market, (ii) the market links Chicago to another competitor's hub, or (iii) AA and UA have different numbers of hub airports on the market. The inclusion of these markets would require to consider every possible airline and every potential market. Such task is beyond the scope of the present paper. In Table 1, we present summary statistics of the 100 sample markets. Note that the average quantity and prices for AA and UA are slightly different. In an incomplete information framework, these differences are not incompatible with an assumption of symmetry.

[Table 1 roughly here]

4.3. Demand and Cost Specifications

We now turn to a discussion of the demand and cost specifications in the Chicago markets. We assume the demand functions are known to the firms and exogenously determined. Therefore, we need to estimate the demand function prior to the estimation of the structural model. We use data on the sample Chicago markets across seven consecutive quarters: the 1th quarter 1993 through the 3rd quarter 1994. The inverse demand function faced by airline i on a market m in quarter t is equal to

$$\begin{aligned} P_{i,m,t} &= \alpha_0 + \alpha_1 INC_m + \alpha_2 POP_m + \alpha_3 \ln(POP_m) + \alpha_4 MILES_m + \alpha_5 DPOP_m \\ &\quad + \alpha_6 QTR_t + \beta \sum_{m' \neq m}^{M} q_{i,m',t} + \lambda \sum_{m' \neq m}^{M} \sum_{j \neq i}^{N} q_{j,m',t} - \gamma \sum_{j=1}^{N} q_{j,m,t} + \varepsilon_{i,m,t} \end{aligned} \tag{4.1}$$

where $\alpha_0, ..., \alpha_6, \beta, \lambda, \gamma$ are parameters known to the airlines, and $\varepsilon_{i,m,t}$ is the error term. $MILES_m$ is the mileage of market m, INC_m and POP_m are, respectively, the median household income and the population for the metropolitan area paired to Chicago on market m. $DPOP_m$ is a dummy variable equal to 1 if that metropolitan area has more than 2,600,000 inhabitants (source: 1990 Census data). QTR_t is AA and UA's average number of passengers in quarter t on U.S. markets (other than the 100 markets in our sample) active during all seven quarters.

The theoretic model is sequential since firms choose quantities and then observe realized prices. Under the model's assumptions, there is therefore no endogeneity problem between prices and quantities. To allow for correlations between unobservable variables on duopoly markets, we use the Feasible Generalized Least–Squares method. A preliminary estimation of (4.1) reveals that λ (the level of complementarity across firms) is insignificant at a 5% level. This result is consistent with Morrison and Winston (1995) who find that, by 1994, less than 1% of all passengers switch airlines in their path of travel. We re-estimate the inverse demand function under the constraint that $\lambda = 0$. We present our results in Table 2. We subsequently derive firms' optimal strategies using this estimated demand function.

[Table 2 roughly here]

AA and UA have long-term leases on their facilities at O'Hare and we consider fixed airport costs (i.e., administrative costs, costs of leasing facilities and ground equipment) as sunk prior to the sample period. Following Brander and Zhang (1990) and Hendricks, Piccione, and Tan (1997), we assume that marginal operating costs per passenger on a market are constant. We define the marginal cost of airline i on market m as $c_{i,m} = cpm_{i,m} \times MILES_m$ where $cpm_{i,m}$ is the cost per passenger per mile.[9] $cpm_{i,m}$ is assumed to be log-normally distributed on $]0, \infty[$ with mean $\mu_m = \mu_0 - \mu_1 MILES_m$ and standard deviation σ. The mean of $cpm_{i,m}$ is known to decline with the mileage as most costs are incurred during take-off (c.f. Brander and Zhang (1990)). We estimate the distribution of the private types $cpm_{i,m}$ in the following section, using the structural econometric model.

5. Estimation of the Structural Model of Firms' Decisions

5.1. Inference Method

Estimating the distribution of airlines' private costs requires non-standard econometric techniques. Indeed, in models of incomplete information, as in the case of the airline industry, unobserved private types are transformed into observed actions through strategies that depend upon the underlying distribution of the types. This creates an identification problem in that we cannot jointly estimate the functional form of players' strategies and the distribution of types solely from observing their actions. This identification problem is solved by imposing that strategies are Nash Equilibrium solutions of the model.

Using the generic estimation principle proposed by Florens et al. (1999), we then estimate the distribution of unobserved types.[10] Within this estimation framework, one initially selects an 'unfeasible' estimator $\widetilde{\theta}(c)$, whereby one could estimate θ if the cost vectors for all firms on all markets, $c = (c_1, ...c_i, ..., c_N)$, were known. The corresponding 'feasible' estimator $\left(\widehat{\theta}(q), \widehat{c}(q)\right)$ of (θ, c) (where $q = (q_1, ...q_i, ..., q_N)$) is defined as the fixed point solution to

$$\widehat{\theta}(q) = \widetilde{\theta}(\widehat{c}(q)) \qquad \textit{and} \qquad \widehat{c}(q) = \varphi^{-1}\left(q; \widehat{\theta}(q)\right) \qquad i : 1 \rightarrow N \tag{5.1}$$

where $\varphi^{-1}\left(q; \widehat{\theta}(q)\right)$ is the inverse strategy function calculated using the algorithm in section 3.[11] To compute the fixed point solution in practice, we start from a value $\widehat{\theta}_0$ and iterate between the two equations in (5.1) until we obtain convergence (see Armantier and Richard (2000) for additional numerical considerations):

$$\widehat{\theta}_0 \rightarrow \widehat{c}_1 = \varphi^{-1}\left(q; \widehat{\theta}_0\right) \rightarrow \widehat{\theta}_1 = \widetilde{\theta}(\widehat{c}_1) \rightarrow ... \rightarrow \widehat{c}_i = \varphi^{-1}\left(q; \widehat{\theta}_{i-1}\right) \rightarrow \widehat{\theta}_i = \widetilde{\theta}(\widehat{c}_i) \rightarrow ...$$

The unfeasible estimator is given by the censored Maximum Likelihood estimator:

$$L\left(\theta\right|\widehat{c}\left(q\right)) = \prod_{i,m}\left(1 - F\left(\overline{cpm}_{i,m}\left(q_{i,-m}\right)|\,\theta\right)\right)^{I\left\{q_{i,m}=0\right\}}\left[f\left(\widehat{cpm}_{i,m}\left(q_i\right)|\theta\right)\right]^{I\left\{q_{i,m}>0\right\}} \quad (5.2)$$

where $\theta = (\mu_0, \mu_1, \sigma) \in \Re\times]0,\infty[^2$, $\overline{cpm}_{i,m}\left(q_{i,-m}\right) = \overline{c}_{i,m}\left(q_{i,-m}\right)/MILES_m$, $\widehat{cpm}_{i,m}\left(q_i\right) = \widehat{c}_{i,m}\left(q_i\right)/MILES_m$, and $f\left(.\right)$ and $F\left(.\right)$ are, respectively, the log-normal probability density function and cumulative distribution for $cpm_{i,m}$.

Computing is of the order of 274 minutes of CPU time on a recent SUN workstation. Standard deviations for the estimates are computed with a Monte Carlo simulation of size 5000.

5.2. Estimation Results

We find the estimates for the parameters of the cost distribution to be $\widehat{\theta} = (\widehat{\mu_0}, \widehat{\mu_1}, \widehat{\sigma}) =$ (0.217, 6.85E10^{-5}, 2.084) with a standard deviation of (3.94E10^{-2},6.10E10^{-6},8.32E10^{-4}). This corresponds to an aggregate average cost per passenger/mile of \$0.165 with a standard deviation of \$0.043. It is difficult to find benchmarks to compare these figures on a market basis; \$0.165, however, appears consistent with network-wide averages (c.f. The Airline Monitor (1994)). Note that the standard deviation of $cpm_{i,m}$ is non-negligeable. This indicates that network-wide averages are an imperfect measurement of the marginal cost on a given market. This finding reinforces our assumption of incomplete information at the market level in the case of the airline industry.

The simulations within the algorithm provide, for each market, expected quantities, prices, profits, and the probability that a firm will enter (see Tables 3 and 4).[12] The estimated probabilities of entry are consistent with the observed number of active firms or airlines on a sample market. Namely, the average probability that a firm enters a market is equal to 0.84 across markets in duopoly in our sample, 0.66 across sample markets in monopoly, and 0.36 across inactive sample markets. As shown in Table 4, estimated quantities and prices fit the observations for AA and UA well. We estimate that AA earned expected profits of $34,120,907, while UA earned $43,897,404 during the sample period, conditional upon observed entry decisions. Note that these figures do not include all sunk costs and that they are consistent with previous studies (c.f. Borenstein (1989), Brander and Zhang (1990)). A market's consumer surplus is equal to $\gamma\left(q_{AA}+q_{UA}\right)^2/2$ where q_{AA} (q_{UA}) is the quantity AA (UA) produced on that market. The disparity in expected quantities across markets explains the large standard deviation associated with the average consumer surplus in Table 3. Finally, a regression indicates that expected quantities do not have a significant effect on estimated marginal costs (the p-value=0.58). This result confirms that there are no economies of density in our sample markets.

[Tables 3 and 4 roughly here]

6. Exchanges of Cost Information in Airline Alliances

We now quantify the effects of exchanges of cost information as they pertain to the AA/UA duopoly at O'Hare.

Fried (1984), Gal-Or (1986), and Shapiro (1986) (hereafter FGS) analyze exchanges of cost information in single-market models of Cournot competition with linear demand and incomplete information on constant marginal costs of production. They find that expected profits and welfare increase when oligopolists choose to exchange costs information truthfully. Such exchanges increase efficiency by raising the market shares of lower cost firms and reducing the variability of aggregated output. The reduction of output volatility, however, decreases expected consumer surplus since the latter is a convex function of output.

Armantier and Richard (2000) show that this result need not hold in multi-market models with entry and complementarities across markets. When complementarities are different across firms, changes in production decisions may yield greater expected consumer surplus for firms that exchange cost information (see example in Appendix 2). The authors also find that consumers on smaller markets tend to benefit more.

Following Shapiro (1986), we assume that, before observing their own cost vector, firms agree to exchange cost information.[13] Under this agreement, firms truthfully reveal to each other their costs vector c_i and then compete under complete information by selecting an output level for each of the M markets. Following FGS, we assume that firms can transfer and verify each other's reports at no cost. All previous assumptions regarding demand and costs are maintained. Under complete information, the Nash Equilibrium obtains numerically from the first-order conditions of the firms' optimization problem. To estimate expected profits and consumer surplus, we simulate competition under the agreement over the 100 sample markets. Private signals are simulated from the distribution estimated in section 5.2. The results of these simulations are summarized in Table 5 and compared to those in Table 3.

[Table 5 roughly here]

There is a larger probability that a market is active under complete information. Markets having a low probability of entry under incomplete information see the largest relative increases. Markets are more likely active and in monopoly and less likely to be in duopoly under complete information. Expected profits are consequently larger on every market (expected aggregated profits increase by 30%). Hence, firms benefit by entering into an agreement to exchange cost information. Under complete information, expected aggregated consumer surplus decreases by only 4%. Consumer surplus is also larger on most markets (57%) under complete information. Consumers on small markets (i.e., markets with low expected quantities) benefit the most since these markets are more likely to be active. In summary, exchanges of cost information improve expected profits and increase consumer surplus on a majority of markets.

7. Conclusion

Our objective in this study was to extend the existing literature by analyzing the effect of exchanges of cost information in the airline industry. We consider a multi-market model of competition with entry and incomplete information. In addition, we developed a numerical method to calculate the equilibrium solution. The subsequent structural estimation and simulations revealed that exchanges of cost information increase profits and leave consumer surplus essentially unchanged. This result contrasts with previous findings in single-market industries.

Our results are limited to the American Airlines and United Airlines duopoly at Chicago O'Hare airport, and they may not generalize to alliances at other airports. Our model also pre-supposes the existence of a mechanism to truthfully and costlessly exchange information. Such a mechanism may be difficult to implement in practice. Finally, actual marketing alliances in the airline industry are not limited to exchanges of cost information. Other components, such as coordination of flight schedules for instance, may impair competition and affect our conclusions.

Agreements to exchange cost information may have either a positive or a negative effect on consumer surplus in multi-market settings. Policy-makers should therefore determine the nature of this effect before approving any such agreement. The combination of theory, econometrics, and numerical analysis in the present paper provides a powerful tool to quantify precisely how exchanges of cost information affect consumer surplus. The analysis of competition under incomplete information in the airline industry can be extended to the structural estimation of models with asymmetric airlines, endogenous demand and/or dynamic decision-making. The methodology can also be applied to other multi-market industries with demand complementarities, such as, for instance, the home electronics and the software industries. We are currently exploring these possibilities.

Tables

TABLE 1 SUMMARY STATISTICS OF SAMPLE DATA						
			Number of Markets	Average Quantity	Average Price	Average Mileage
State of the Market	Monopoly (only one firm enters)	American	14	13586.61 (8055.24)	92.74 (62.93)	441.14 (463.91)
		United	29	19191.53 (8699.98)	138.13 (39.90)	754.13 (385.78)
		Total	43	17366.67 (8809.43)	123.35 (52.44)	652.23 (433.42)
	Duopoly (two firms enter)	American	.	31302.64 (20481.25)	127.91 (65.19)	.
		United	.	36635.66 (26628.18)	128.71 (63.44)	.
		Total	40	33969.15 (22066.86)	128.31 (64.13)	698.17 (556.02)
	Active (at least one firm enters)	American	54	26709.59 (19646.95)	118.79 (65.88)	631.53 (541.49)
		United	69	29304.07 (22650.92)	132.67 (54.64)	721.69 (489.25)
		Total	83	25367.86 (18466.34)	125.74 (58.06)	674.37 (668.51)
Overall (with non-entry)		Per firm	100	.	.	715.28 (493.74)

Standard Errors in Parentheses

TABLE 2 ESTIMATES FOR THE DEMAND SPECIFICATION			
Variable	Parameter	Estimate	Std
Constant	α_0	-34.21	25.98
INC	α_0	1.72E10-3*	2.15E10-4
POP	α_0	1.03E10-5*	1.75E10-6
Ln(POP)	α_0	9.66*	1.73
MILES	α_0	0.11*	1.90E10-3
DPOP	α_0	37.30*	7.97
QTR	α_0	-2.28E10-3*	3.60E10-4
	β	3.05E10-6*	1.23E10-6
	γ	6.48E10-4*	5.19E10-5
$R^2_* = 0.898$			

Standard Errors in Parentheses. * indicates that the parameter is significant at a 5% Level

TABLE 3
INCOMPLETE INFORMATION
SIMULATION RESULTS
(Average across all Markets)

	State of the Market			
	Monopoly (only one Firm enters)	Duopoly (two Firms enter)	Active (at least one firm enters)	Overall (with non-entry)
Probability of	0.28 (0.2)	0.54 (0.37)	0.82 (0.29)	.
Expected Quantity per Firm	28050.34 (20938.50)	28031.25 (20902.11)	28038.04 (20918.46)	19161.054 (18249.65)
Expected Price	134.14 (61.71)	120.17 (56.58)	123.65 (58.15)	.
Expected Profit per Firm	801348.09 (1202672.49)	389471.11 (582152.93)	488018.65 (659506.62)	353311.28 (532420.05)
Expected Consumer Surplus	324148.47 (476243.36)	2157987.06 (3739249.33)	1207926.10 (2759713.88)	1052335.70 (2539180.6)

Standard Errors in Parentheses

TABLE 4
COMPARISON BETWEEN
OBSERVATIONS AND SIMULATIONS

		Relative Difference between Actual and Simulated Expected quantity (in %)	Relative Difference between Actual and Simulated Expected Price (in %)
Sample markets in Monopoly	American	-4.23 (13.78)	-2.79 (14.88)
	United	-3.51 (15.57)	0.33 (10.46)
	Total	-3.75 (14.85)	-0.69 (11.99)
Sample markets in Duopoly	American	-8.76 (27.91)	1.45 (9.69)
	United	1.67 (24.49)	2.78 (11.16)
	Total	-3.54 (9.90)	2.28 (9.64)
Active Sample markets	American	-7.59 (24.98)	0.35 (11.27)
	United	-0.51 (21.23)	1.75 (10.86)
	Total	-3.65 (12.63)	0.74 (10.95)
Overall	Per firm	-3.65 (12.63)	0.74 (10.95)

Standard Errors in Parentheses

TABLE 5 COMPLETE INFORMATION SIMULATION RESULTS (Average across all Markets)				
	State of the Market			
	Monopoly (only one Firm enters)	Duopoly (two Firms enter)	Active (at least one firm enters)	Overall (with non-entry)
Probability of	0.50 (0.24)	0.45 (0.32)	0.95 (0.21)	.
Expected Quantity per Firm	42261.86 (27655.23)	25140.34 (19874.17)	33693.13 (24657.36)	22226.10 (16534.72)
Expected Price	129.7 (60.29)	125.86 (57.96)	127.16 (58.26)	.
Expected Profit per Firm	1313347.56 (1806157.13)	570148.58 (823148.97)	820316.04 (1041073.47)	582526.72 (763672.42)
Expected Consumer Surplus	344456.21 (464135.72)	1952604.31 (3236446.74)	1119467.34 (2397022.90)	1009950.05 (2203489.7)

Standard Errors in Parentheses

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Endnotes

1. Unlike Matutes and Regibeau (1988), we do not attempt to model the strategic decisions associated with brand loyalty or brand compatibility.

2. Our objective is to develop the simplest structural model, with the least ad hoc assumptions, which provides realistic results. The linear specification, although overly simplistic on a theoretical level, provides an excellent structural model and there were no incentives to select a complex, non-linear specification.

3. The optimization problem is not well-defined if the number of markets, M, is sufficiently large. Indeed, there exists M_0 such that $\forall M > M_0 \lim_{q_{i,m} \to \infty} V_{im} > 0 \; \forall i$ and $\forall m$; i.e., the marginal profit on any market is positive for infinite quantities. We do not encounter this problem in our application as M is not large enough.

4. In practice, we select $S = 5000$.

5. Markets are assumed to be non-directional.

6. We consider the existence of a hub airport at Chicago O'Hare as given.

7. Following Borenstein (1989), we filter Databank 1A data for excessive fares (see Richard (2000) for ampler details on the preparation of the price data in our sample).

8. A market is said to be a major market if both metropolitan areas are larger than 350,000 inhabitants.

9. While there is some evidence of economies of density in the airline industry (c.f. Caves, Christensen, and Tretheway (1984), Brueckner and Spiller (1994)), we found no significant relation between marginal costs and quantities in our sample (see section 5.2).

10. The algorithm to determine numerically the Nash Equilibrium requires to simulate the first moment of the quantity produced on each market. This suggests to estimate the underlying structural parameters with the method of simulated moments. However, the optimal weighting matrix was quite time consuming to calculate and we opted for the Florens et al. (1999) technique.

11. Conditions for the local identification of θ from the sole observation of q and for the existence and (local) uniqueness of a fixed joint solution are found in Florens et al. (1999), together with characterizations of the asymptotic distributions of $\widehat{\theta}$ and $\widehat{c}$.

12. Detailed results are available upon request.

13. This agreement is purely hypothetical and we are not aware of any plans by AA and UA to form a marketing alliance on the U.S. market.

Appendix 1

#	Market with flights from 1 airline	Airline with flights	Miles		#	Markets with flights from AA and UA	Miles		#	Markets with no flights	Miles
1	Albuquerque, NM	AA	1118		44	Albany, NY	723		84	Wilkes-Barre/Scranton, PA	631
2	Bloomington, IL	AA	116		45	Austin, TX	972		85	Fresno, CA	1730
3	Champaign, IL	AA	135		46	Kalamazoo, MI	122		86	Greensville, SC	577
4	Dubuque, IA	AA	147		47	Hartford, CT	783		87	Bakersfield, CA	1732
5	El Paso, TX	AA	1236		48	Buffalo, NY	473		88	Little Rock, AR	552
6	Evansville, IN	AA	273		49	Iowa City, IA	196		89	Mobile, AL	779
7	Fargo, ND	AA	557		50	Columbus, OH	296		90	Tri-City Airport, TN	481
8	Flint, MI	AA	223		51	Wausau, WI	213		91	Chattanooga, TN	501
9	Lafayette, IN	AA	119		52	Dayton, OH	240		92	Bridgeport, CT	767
10	La Crosse, WI	AA	215		53	Washington National, DC	612		93	Baton Rouge, LA	810
11	Muskegon, MI	AA	118		54	Des Moines, IA	299		94	Melbourne, FL.	1040
12	Rochester, MN	AA	268		55	Sioux Falls, SD	462		95	Augusta, GA	677
13	Toledo, OH	AA	214		56	Fort Wayne, IN	157		96	Beaumont/Pt. Arthur, TX	897
14	Tucson, AZ	AA	1437		57	Green Bay, WI	174		97	Mc. Allen, TX	1238
15	Allentown, PA	UA	654		58	Grand Rapids, MI	137		98	Daytona Beach, FL	962
16	Appletown, WI	UA	160		59	Westchester County, NY	738		99	Santa Barbara, CA	1803
17	Bangor, ME	UA	978		60	Indianapolis, IN	177		100	Youngstown, OH	378
18	Birmingham, AL	UA	584		61	New-York Laguardia, NY	733				
19	Boise, ID	UA	1437		62	Kansas City, MO	403				
20	Burlington, VT	UA	763		63	Harrisburg, PA	594				
21	Columbus, SC	UA	666		64	Moline, IL	139				
22	Akron/Canton, OH	UA	344		65	Madison, WI	109				
23	Charleston, SC	UA	760		66	New Orleans, LA	837				
24	Colorado Springs, CO	UA	911		67	Oklahoma City, OK	693				
25	Ft. Lauderdale, FL	UA	1182		68	Omaha, NE	416				
26	Spokane, WA	UA	1498		69	Ontario, CA	1700				
27	Greensboro, NC	UA	590		70	Portland, OR	1739				
28	Huntsville/Decatur, AL	UA	510		71	Peoria, IL	130				
29	New Haven, CT	UA	778		72	Providence, RI	849				
30	Wichita, KS	UA	588		73	Rochester, NY	528				
31	Jacksonville, FL.	UA	865		74	San Diego, CA	1723				
32	Lexington, KY	UA	323		75	San Antonio, TX	1041				
33	Lincoln, NE	UA	466		76	Seattle/Tacoma, WA	1721				
34	Saginaw, MI	UA	222		77	San Jose, CA	1829				
35	Manchester, NH	UA	843		78	Sacramento, CA	1781				
36	Oakland, CA	UA	1835		79	Orange County, CA	1726				
37	Norfolk/ VA Beach, VA	UA	717		80	St. Louis, MO	258				
38	Portland, ME	UA	900		81	Syracuse, NY	607				
39	Richmond/Wmbg. VA	UA	642		82	Tampa/St. Petersburg, FL	1012				
40	Fort Myers, FL	UA	1120		83	Tulsa, OK	585				
41	Savannah, GA	UA	773								
42	Louisville, KY	UA	286								
43	Knoxville, TN	UA	475								

Appendix 2

The following example illustrates that expected profits and consumer surplus can be higher in multi-market models when firms truthfully exchange cost information.

There are two markets ($m = 1, 2$) and two symmetric firms ($i = 1, 2$). The inverse demand function for firm i on market m is common knowledge and linear: $p_{im} = 1 + 0.45\, q_{i,-m} + 0.1\, q_{-i,-m} - (q_{i,m} + q_{-i,m})$ where $q_{i,m}$ is firm i's quantity on market m and p_{im} is firm i's price on market m. The cost function of firm i on market m is given by $C(q_{i,m}) = c_{i,m} q_{i,m}$ where $c_{i,m}$ is uniformly and independently distributed over the interval $[0, 1]$. The distribution of marginal costs is common knowledge. The two firms simultaneously decide whether to enter and how much to produce on each of the two markets. We consider two scenarios: in the incomplete information scenario, $(c_{i,1}, c_{i,2})$ is known only to firm i, while in the complete information scenario, firms truthfully exchange cost information so that $c_{i,m}$ is common knowledge $\forall i, m = 1, 2$. The optimization problem under each scenario is solved numerically with the algorithm introduced in section 3.2. Tables A1 and A2 summarize 50,000 Monte Carlo simulations. Under complete information, expected profits and expected consumer surplus increase respectively by 32% and 8%. Note also that under complete information, the probability that a firm is in monopoly (duopoly) increases (decreases) and the quantity produced by a monopolistic (duopolistic) firm increases (decreases) sharply.

TABLE A1 COMPLETE INFORMATION SIMULATION RESULTS (Average across all Markets)			
	State of the Market		
	Monopoly (only one Firm enters)	Duopoly (two Firms enter)	Overall (with non-entry)
Probability of	0.276	0.393	0.669
Expected Cost	0.315	0.415	0.499
Expected Quantity per Firm	0.593	0.278	0.274
Expected Price	0.660	0.577	0.579
Expected Profit per Firm	0.221	0.0676	0.0878
Expected Consumer Surplus	0.188	0.175	0.177

TABLE A2 INCOMPLETE INFORMATION SIMULATION RESULTS (Average across all Markets)			
	State of the Market		
	Monopoly (only one Firm enters)	Duopoly (two Firms enter)	Overall (with non-entry)
Probability of	0.101	0.761	0.869
Expected Cost	0.503	0.498	0.499
Expected Quantity per Firm	0.297	0.296	0.257
Expected Price	0.838	0.572	0.629
Expected Profit per Firm	0.139	0.0578	0.0597
Expected Consumer Surplus	0.0585	0.199	0.164

Standard Errors in Parentheses