Price Discrimination in International Airline Markets

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Airline Pricing

Two sources of inefficiencies in airline markets:

- Private info of heterogeneous willingness-to-pay.
- Gradual realization of uncertain demand.

Airlines are fairly sophisticated price-setters:

- Price discriminate:
  - Intra-temporal PD (service classes): passengers w/ het. wtp.
  - Inter-temporal PD: Reason-for-travel correlates with arrival time.
- Dynamically price and ration seats.
Misallocation in Airline Demand

Misallocation a consequence of asymmetric info and stochastic demand:

- Cross-cabin: some passengers are in the “wrong” cabin given preferences.
- Exclusion from flight: some passengers should (or should not) be on the plane.

Creates opportunities for welfare improvements

- ex-ante: information acquisition to discriminate.
- ex-post: re-optimize after initial allocation.

What are welfare consequences of improving allocation?

Distributional consequences of price discrimination generally unclear.
Our Environment: International Airline Markets

- International flights to and from the U.S.

- Our data (SIAT) has substantial advantages over more common airline data (DB1B).
  - Flight and passenger specific information.

- Clear dichotomy of passenger types: business/leisure.

- Regulation limits entry, leading to concentrated markets.

- Limited over-booking due to low flight frequency.

Airlines busy seeking to resolve inefficiencies and extract resulting surplus.
“Brute Force” Ex-Post Reallocation
“Brute Force” Ex-Post Reallocation
Your chance to upgrade

Booking reference 5237XG

Dear Sarah,
We're inviting you to make an offer for an upgrade to Business on your upcoming Qantas flight(s) below.

Make an upgrade offer with Bid Now Upgrade

Simply offer the amount of money you would like to pay (within a given range) to upgrade to Business.
## Ex-Post Reallocation via Upgrades

<table>
<thead>
<tr>
<th>Your flight information</th>
<th>Upgrade cabin</th>
<th>Your offer for this segment</th>
<th>Offer range indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas (DFW) → Sydney (SYD)</td>
<td>Business □</td>
<td>$1,130 USD per passenger (2)</td>
<td>No Offer to $2,540</td>
</tr>
<tr>
<td>11 Jan 2017</td>
<td></td>
<td></td>
<td>The indicator shows the position of your offer between the minimum and maximum amounts</td>
</tr>
</tbody>
</table>

- Breeze through the airport with access to dedicated Check-in and priority boarding
  - Relax before your flight in the Business Lounge
  - Enjoy the comfort of a luxurious seat, bed or suite ±
  - Neil Perry designed menus with award winning wines~
  - Experience a wide range of entertainment options including the latest on-demand inflight entertainment systems#
  - Additional baggage allowance**

<table>
<thead>
<tr>
<th>Sydney (SYD) → Christchurch (CHC)</th>
<th>Business □</th>
<th>$510 USD per passenger (2)</th>
<th>No Offer to $660</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Jan 2017</td>
<td></td>
<td></td>
<td>The indicator shows the position of your offer between the minimum and maximum amounts</td>
</tr>
</tbody>
</table>
Ex-Post Solicitation of Failed Searchers

Hello Gaurab,

AAvantage® Number: 82VR6K8

Still looking for great prices from Charlottesville, VA, to Nashville, TN?

Here's the most recent^ price for travel departing Apr 21, 2017, and returning Nov 04, 2017.

Round-trip price per person
CHO to BNA

$400

Includes taxes and carrier-imposed fees

American Airlines
Reservations  Redeem Miles  My Account  Deals

Nashville is calling

Flights  Vacations
Lots of other information available (credit cards, FFPs, etc)
Research Questions

- How well does 2nd deg + dynamic pricing resolve inefficiencies?
- How does role of inefficiencies depend on passenger composition?
Research Strategy

1. Provide unique descriptive insights into demand for air travel.
   ▶ timing of arrivals, composition of passengers, fare dynamics, etc.

2. Model air-travel demand and supply with following features:
   ▶ Stochastic arrivals of passengers with heterogeneous WTP.
   ▶ Dynamically adjust prices and seats released to sell fixed capacity.

3. Exploit richness of data to estimate model of demand, accounting for (unobserved) across-market heterogeneity.
   ▶ Demand: WTP and arrival process.
   ▶ Supply: Shadow cost of a seat.
   ▶ Apply Ackerberg (2009) importance sampling estimator to recover distribution of preferences in our data.
Welfare Triangle

A: (1st-best; full extraction)

E: (1st-degree)

G: (VCG)

D: (3rd-degree)

C: (Data)

B: (1st-best; zero price)

(1st-degree; zero price)

Producer Surplus

Consumer Surplus
Literature Review

● Stochastic Demand and Private Info:

● Quantifying Price Discrim. and Dynamic Pricing:
  ▶ Sweeting (2012), Nevo et al (2016), Kevin Williams (wp)

● Price Dispersion in Airline Markets

● Importance Sampling Estimation
  ▶ Ackerberg (2009), Bajari et al (2010), Sweeting et al. (wp)
Outline

- Introduction
- Data
- Model
- Estimation + Results
- Evaluating Pricing Inefficiencies
Survey of International Air Travelers (SIAT)

- Surveys domestic and intl. carriers (in gate and on plane).
- Stratified by flight.
- Approx. 0.7% sample of departing international travel (no Can.).

Flight-based sampling of SIAT is crucial:

- Deep insight into individual flight.
- Includes flight number, link to OAG (capacity) and T-100 (load factors).
- Limits ability to study strategic interaction.
Information Included in SIAT

For each passenger we observe:

1. Itinerary (e.g., RDU-CDG/CDG-RDU).
2. Cabin and fare paid.
3. Timing of purchase.
4. Reason for travel (e.g., work conference, vacation, etc).
   - Clear business/leisure categorization.

Sample Selection – Monopoly non-stop routes.

- Select only “monopoly” markets.
- Drop flights with small nonstop response.

**Our sample:** 3 years (2009-2011) 62,577 individual passenger itineraries, 2,158 fights, 381 markets, and 84 carriers.
Does this Survey Actually Exist?

Our very own Gaurab Aryal taking the survey en route to Nepal.
### Summary Statistics for Non-stop Itineraries

<table>
<thead>
<tr>
<th>Ticket Class</th>
<th>Proportion of Sample</th>
<th>Fare</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>First</td>
<td>9.00</td>
<td>818.48</td>
</tr>
<tr>
<td>Economy</td>
<td>91.00</td>
<td>425.16</td>
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<table>
<thead>
<tr>
<th>Advance Purchase</th>
<th>Proportion of Sample</th>
<th>Fare</th>
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<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>0-7 Days</td>
<td>9.68</td>
<td>575.79</td>
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<tr>
<td>8-21 Days</td>
<td>14.56</td>
<td>534.27</td>
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<td>22-35 Days</td>
<td>16.90</td>
<td>471.21</td>
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<tr>
<td>36-85 Days</td>
<td>21.60</td>
<td>439.99</td>
</tr>
<tr>
<td>≥ 85 Days</td>
<td>37.27</td>
<td>408.92</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Travel Purpose</th>
<th>Proportion of Sample</th>
<th>Fare</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Leisure</td>
<td>86.55</td>
<td>426.70</td>
</tr>
<tr>
<td>Business</td>
<td>13.45</td>
<td>678.28</td>
</tr>
</tbody>
</table>
Leisure v. Business Passengers

![Graph showing the share of purchases by weeks until flight and fare by days until flight for leisure and business passengers.]

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PD in Intl Airline Mkts

October 15, 2018
Across-Market Variation in Business Travel (BT) Index

![Histogram showing the distribution of percent of business travel in a market. The x-axis represents the percent of business travel ranging from 0 to 1, and the y-axis represents frequency ranging from 0 to 100. The histogram peaks at around 0.2 percent of business travel.]
Evidence of Price Discrimination

Economy-Class Fares by Advance Purchase and Business Traveler Index

(a) Economy Class

(b) 1st-Class

3D surfaces
Proportion of Business Travelers by Ticket Class

- Over-represented in first class (quality preference)
- Tend to arrive late regardless of cabin

(c) 1st-Class

(d) Econ Class
Flight-level Price Dispersion

Sweeting 2012:
Unchanging demand + perishable good $\implies$ decreasing prices.

- Option value of seat decreases as event nears.
- But in airline markets:
  - demand changes as flight nears.
  - potentially large “shocks” relative to capacities.

![Graph of Ratio to Initial Fare vs Advance Purchase (Days)]

- 10% Price Path
- 25% Price Path
- 75% Price Path
- 90% Price Path
- Mean Price Path
Data Takeaways for Modeling

Arrival process
- Cross-market variation in rate of arrival, driven by passenger mix.

Consumer Types
- Leisure/business dichotomy effective at capturing arrival timing and difference in quality preference.
- Higher WTP for business travelers.
- Cross-market variation in passenger mix.

Pricing dynamics
- Substantial variation in price paths, increasing/decreasing
Outline

- Introduction
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Model Introduction

- Time is discrete and $t \in \{1, \ldots, T\}$ periods before flight.

- Fixed economy-class ($K^e$) and first-class ($K^f$) capacity.

- Monopolist chooses $\sigma_t$:
  - economy: fare $p^e_t$ and number of seats to sell $q^e_t$.
  - first-class: fare $p^f_t$ and number of seats to sell $q^f_t$.

- Airline knows the demand process. Not realization.

- Every period, passengers “arrive” and choose from {economy, first-class, not-buy}.

- Those who do not buy exit forever (short lived / not strategic).
Model Introduction

Model Caveats

- Assume nonstop and connecting optimization problems are separable (i.e., aircraft is a-priori divided).

- Focus solely on within-flight dynamics, do not account for competitor’s actions (or own other flights)
Passenger Arrival Process

- Poisson arrival: $N_t \sim \mathcal{P}(\lambda_t)$ potential passengers arrive.

- In period $t$ on average $\lambda_t = \mathbb{E}(N_t)$ many passengers arrive.

- Binomial type: the number of business passengers in period $t$ is $\sim \mathcal{B}(N_t, \theta_t)$. 
Passenger Preferences

- Indirect utilities:
  - Economy: \( u(v, p, \xi) = v - p^e \)
  - 1st-Class: \( u(v, p, \xi) = v \times \xi - p^f, \quad \xi \geq 1 \)

- \( \xi \) captures the 1st-class utility premium.
- Business passenger WTP: \( N(\mu^b, \sigma^b) \)
- Leisure Passenger WTP: \( N(\mu^l, \sigma^l) \).
- Passenger mix at \( t \) gives \( v \sim \theta_t N(\mu^b, \sigma^b) + (1 - \theta_t) N(\mu^l, \sigma^l) \).
- Parameters: \( \mu^b, \sigma^b, \mu^l, \sigma^l \)
Passenger Arrival Process

- **Poisson arrival**: $N_t \sim \mathcal{P}(\lambda_t)$ potential passengers arrive.

- In period $t$ on average $\lambda_t = \mathbb{E}(N_t)$ many passengers arrive.

- **Binomial type**: # of business passengers in period $t$ is $\sim \mathcal{B}(N_t, \theta_t)$.

**Arrival Parameters**:

- $\lambda_t = \lambda_1 + \Delta^\lambda \times (t - 1)$
- $\theta_t = \min\{\Delta^\theta \times (t - 1), 1\}$
Supply

Timing and information:

- Airline knows the demand process $\Psi$.
- $T = 5$ periods before departure to sell $K^e$ and $K^f$ seats.
- Sets cabin prices $(p^e_t, p^f_t)$ and commits to selling no more than $(\bar{q}^e_t, \bar{q}^f_t)$ seats each period, before demand is realized.
  - Second-degree discrimination within period.
  - Inter-temporal discrimination across periods.
- Marginal “peanut costs”, $c^e = 14$ and $c^f = 40$, taken from industry accounting estimates.
  - Economically irrelevant given opportunity costs of seat (intl. travel)
Airline’s Objective Function

- In period $t$ available capacities, $\omega_t = (K^e_t, K^f_t)$ are given.
- Airline maximizes sum of expected profits by choosing

$$\sigma_t = (p_t^e, p_t^f, \bar{q}_t^e, \bar{q}_t^f),$$

- Optimal policy, $\{\sigma_t : t = 1, \ldots, T\}$, maximizes

$$\sum_{t=1}^{T} \beta^t E_t \left\{ \pi(\sigma_t, \omega_t, \Psi) = (p_t^f - c^f)q_t^f + (p_t^e - c^e)q_t^e \right\}$$

- subject to:
  
  1. $p \geq 0$.
  2. Integer seat-release policy: $\bar{q}_t^e \leq K_t^e$ and $\bar{q}_t^f \leq K_t^f$. 

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Optimal policy in periods $t \in \{1, \ldots, T - 1\}$ is characterized by the solution to the Bellman equation,

$$V_t(\omega_t, \Psi) = \max_{\sigma_t} \mathbb{E}_t \left\{ \pi(\sigma_t, \omega_t, \Psi) + \beta \sum_{\omega \in \Omega_{t+1}} V_{t+1}(\omega_{t+1}, \Psi) Q(\omega_{t+1}|\omega_t, \sigma_t, \Psi) \right\}$$

Solution induces a non-stationary transition process between states, $Q_t(\omega_{t+1}|\omega_t, \sigma_t, \Psi)$ where $\Omega_{t+1}$ is set of reachable states.

In period $T$, optimal policy maximizes

$$V_T(\omega_T, \Psi) = \max_{\sigma_T} \mathbb{E}_T \left\{ \pi(\sigma_T, \omega_T, \Psi) \right\}$$

No inter-temporal tradeoffs in last period, only across cabins.

Opportunity cost of selling a seat is zero.
Characterizing Optimal Prices

For a given seat release policy

\[
\begin{pmatrix}
E_t(q^e; \sigma_t) \\
E_t(q^f; \sigma_t)
\end{pmatrix}
+ 
\begin{pmatrix}
\frac{\partial E_t(q^e; \sigma_t)}{\partial p^e_t} & -\frac{\partial E_t(q^f; \sigma_t)}{\partial p^e_t} \\
-\frac{\partial E_t(q^e; \sigma_t)}{\partial p^f_t} & \frac{\partial E_t(q^f; \sigma_t)}{\partial p^f_t}
\end{pmatrix}
\begin{pmatrix}
p^e_t - c^e \\
p^f_t - c^f
\end{pmatrix}
= 
\begin{pmatrix}
\frac{\partial E_t V_{t+1}}{\partial p^e_t} \\
\frac{\partial E_t V_{t+1}}{\partial p^f_t}
\end{pmatrix}
\]

- LHS: multi-product firm (with uncertain demand) internalizing cannibalization across seats.
- RHS: shadow or opportunity cost of selling seat today
Numerical Solution of Dynamic Program

Consider a demand process, $\Psi$:

- Recursively solve finite horizon dynamic program
- Simulate demand process
- Solve for policy function
- Compute $EV_{t+1}$ by simulation (every period – computationally intensive)
- Solution given by policy function, $\sigma_t(\omega; \Psi)$ and value function, $V_t(\omega; \Psi)$, for $t = 1, ..., T$ and $\forall \omega$
- In practice we solve the problem exactly on a reduced grid of points in the state space ($\omega$) and interpolate the $EV$ and $\sigma$.
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Estimation: Parameters

The model is a data-generating process (DGP) with 8 parameters:

- $\Psi := (\Delta \theta, \lambda_1, \Delta \lambda, \mu_l, \mu_b, \sigma_l, \sigma_b, \mu_\xi)$.

Willingness-to-Pay (5 parameters):

- $\mu^l$: mean willingness to pay for leisure.
- $\delta_b = \frac{\mu_b}{\mu^l} (\geq 1)$: mean willingness to pay for business.
- $\frac{\mu^b}{\mu^l}$: business passenger premium.
- $\mu_\xi$: first class premium ($\xi \sim Exp(\mu_\xi)$).
- $\frac{\sigma^l}{\mu^l}$ and $\frac{\sigma^b}{\mu^b}$ coefficient of variation for leisure and biz.

Arrival (3 parameters):

- $\lambda_t = \lambda_1 + \Delta \lambda \times (t - 1)$
- $\theta_t = \min\{\Delta \theta \times (t - 1), 1\}$
Common Delta configuration for B757 is (24, 156) and for a B747 is (48, 328) (for nonstop + connecting).
Observe detailed fare information for many (very) heterogenous flights.

- Complex relationship between model primitives and observed/unobserved market-specific variables.

Solving the model is very computationally difficult.

- Crucial to limit number of times model is solved.

Combine Fox et al. (2016), and Nevo et al. (2016) and Ackerberg (2009):

- Method-of-moments approach seeks to identify mixture of markets that match variation in equilibrium across markets.
- Use importance sampling technique to reduce number of times model must be solved.
Estimation Overview: Methodology

Three separable steps for given initial capacity, $\omega_1 = (K_1^f, K_1^e)$:

1. Data:
   - Kernel regression to estimate flight-specific moments
   - Calculate $M \times 1$ vector of moments capturing price variation and passenger composition across flights, $\hat{\rho}(\omega_1)$.

2. Computational:
   - Solve model for fixed grid ($H = 15,000$) of candidate types, $\Psi_h$: store policy function, $\sigma_t(\omega)$.
   - Simulate all candidate types, calculate moments analogous to those constructed from the data for each.
   - Result is $(M \times H)$ matrix, $\tilde{\rho}(\omega_1)$, where columns correspond to moments for candidate types.

3. Method of Simulated Moments: requires integrating theoretical moments across $\omega_1$ for population density.
Estimation: Econometric Objective Function

- Econometrics model:

$$
\widehat{\rho}(\omega_1) = \int_{\Psi} \rho(\Psi; \omega_1) h(\Psi|\omega_1) d\Psi,
$$

- **Objective**: To estimate the mixing density \( h(\Psi|\omega_1) = TrN \).

- Estimates minimize least-squares criterion:

$$
\left( \hat{\mu}(\omega_1), \hat{\Sigma}(\omega_1) \right) = \arg \min_{(\mu, \Sigma)} \left( \hat{\rho}(\omega_1) - \overline{E}(\rho(\mu, \Sigma; \omega_1)) \right)^\top \\
\left( \hat{\rho}(\omega_1) - \overline{E}(\rho(\mu, \Sigma; \omega_1)) \right)
$$
Estimation: Importance Sampling

- Dimensionality of integral requires solving model large \( S = 15,000 \) number of times until minimum is found, prohibitive given complexity of model and dimensionality of parameter space.

- Importance-sampling approach, Ackerberg (2009), rewrite integral:

\[
\int_{\Psi} \rho(\Psi; \omega_1) \frac{h(\Psi|\omega_1; \mu, \Sigma)}{g(\Psi)} g(\Psi) d\Psi,
\]

where density \( g(\Psi) > 0 \) only on \( \Psi \in \left[ \underline{\Psi}, \overline{\Psi} \right] \), like \( h(\Psi|\omega_1; \mu, \Sigma) \).

- Approximate integral as though sampling was done from \( h \):

\[
\approx \frac{1}{S} \sum_{j=1}^{S} \rho(\Psi_j; \omega_1) \frac{h(\Psi_j|\omega_1; \mu, \Sigma)}{g(\Psi_j)}
\]
Moments and Identification

1. Joint density of \((p^f_t, p^e_t)\) for \(t = 1, \ldots, T\)
   - Identifies distribution of \(v\) and \(\xi\), cross-flight variation in fares maps to different mean shadow costs in model, revealing preference distribution

2. Marginal densities of \(\Delta_t(p^f_t), \Delta_t(p^e_t), \Delta_t(p^f_t - p^e_t), t = 1, \ldots, T\)
   - Identification of \(\lambda\), within-flight variation in fares maps to variation in shadow costs in model, revealing volatility and trend in arrival process.

3. Marginal densities of fraction business and \(\Delta_t\) of fraction business.
   - Identification of \(\theta\), cross-flight and within-flight variation in realized passenger maps to different slope in shadow costs in model as flight date approaches, revealing for-business fraction.

4. Price path
Flight level heterogeneity

- Four flights in SFO-HND market.

(e) Economy Fares

(f) Proportion of Business Travelers
Results: Overview

- Importance sampling works extremely well
- Results are difficult (and perhaps uninteresting) to summarize for every market type.
- Means and variances all in plausible and intuitive range
- Joint normality assumption makes densities perhaps less interesting with few exceptions, strong positive covariance between $\Delta_\lambda$ and $\Delta_\theta$
Mkt Heterogeneity: Marginal CDFs of Demand Parameters

**Figure 1:** CDFs of $\mu^l$ and $\delta^b$
Mkt Heterogeneity: Marginal CDFs of Demand Parameters

Figure 2: CDFs of $\xi$ and $\Delta^\theta$
Market Heterogeneity: Joint PDF of $(\Delta^\theta, \Delta^\lambda)$
Estimation: Modal demand type with Modal Capacity Means

\[
\begin{pmatrix}
\mu^l \\
\sigma^l \\
\mu^b \\
\sigma^b \\
\mu_\xi \\
\lambda \\
\Delta^\lambda \\
\Delta^\theta
\end{pmatrix}
= 
\begin{pmatrix}
477 \\
0.31 \\
792 \\
0.71 \\
0.27 \\
49 \\
0.00 \\
0.098
\end{pmatrix}
\]
Evolution of State

![Graph showing the evolution of state over time with plots for Economy and First-Class seats remaining.](image_url)
Distribution of Marginal Cost of a Seat

![CDF of Economy Marginal Cost](image1)

![CDF of First-Class Marginal Cost](image2)
Counterfactuals
Quantifying Inefficiencies

Continuum of potential 1st-best allocations that gather all consumers that “arrive” prior to flight.

Resolve the model for three scenarios:

1. 1st-degree price discrimination with max revenue.
2. Zero prices with efficient allocation.
3. Vickery-Clarke-Groves (VCG) auction:
   - Price paid equals the harm that an individual inflicts on others by participating in auction (i.e., exclude passenger and recalculate welfare from auction).
   - All seats, both cabins, are allocated efficiently.

Provides baseline to quantify sources of inefficiency
Varying Degrees of Price Discrimination

Progressively remove forms of asymmetric information until all that remains is inter-temporal demand uncertainty to identify role of each in determining inefficiency

Resolve the model for three scenarios (increasing information for airline):

1. **Second-Degree**: sets price and seat-release for each cabin in each period

2. **Third-Degree**: observes reason for travel, sets two prices for each cabin (biz/leisure) and a common seat-release policy (high-price passenger receives seat first)

3. **First-Degree**: observes valuations each period, price equals valuation and decides on number to give seats in each cabin
Producer surplus increases from D to E to F, distributional implications for consumers is empirical question.
## Welfare Results

### Modal capacity

<table>
<thead>
<tr>
<th></th>
<th>1\textsuperscript{st} Best</th>
<th>2\textsuperscript{nd} Degree</th>
<th>3\textsuperscript{rd} Degree</th>
<th>1\textsuperscript{st} Degree</th>
<th>VCG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Producer Surplus</strong></td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>F</td>
<td>G</td>
</tr>
<tr>
<td>Business</td>
<td>92,074</td>
<td>16,215</td>
<td>13,792</td>
<td>86,229</td>
<td>13,224</td>
</tr>
<tr>
<td>Leisure</td>
<td>72,702</td>
<td>9,134</td>
<td>9,586</td>
<td>69,336</td>
<td>8,470</td>
</tr>
<tr>
<td>Total Welfare</td>
<td>92,074</td>
<td>75,211</td>
<td>81,365</td>
<td>86,229</td>
<td>86,229</td>
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<tr>
<td><strong>Consumer Surplus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business</td>
<td>19,372</td>
<td>7,081</td>
<td>4,206</td>
<td>16,893</td>
<td>4,754</td>
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<tr>
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<td>72,702</td>
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### Price Dispersion

<table>
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</thead>
<tbody>
<tr>
<td><strong>–IQR</strong></td>
<td>296</td>
</tr>
</tbody>
</table>
Counterfactual Results: Summary

- Current pricing yields 81% of total welfare ($483 of max $597/seat).
- On average welfare/efficiency of $113.4/seat is lost.
- Asymmetric information and inter-temporal demand uncertainty explain 35% and 65% of gap, respectively.
- 3\textsuperscript{rd}-degree pricing ↓ business travelers’ CS by 41%, ↑ leisure travelers’ CS by 1.2% and welfare ↑.
- VCG does very well in terms of revenue.
- Price dispersion increases with price discrimination but also leads to greater welfare.
Conclusions

- Substantial inefficiencies despite sophisticated pricing by airlines
  - Shortfall of 19% from first-best (perhaps unattainable) outcome
  - Information to airline is powerful at resolving inefficiencies, but has important distributional consequences
  - Pushing privacy boundaries (ip address, purchasing history, reason for travel, etc) and moving towards personalized pricing are very profitable next steps for airlines

- To think about...
  - Design of secondary market?
  - Ticket auctions?
Appendix
Evidence of Price Discrimination

Surfaces relate fares for each class to advance purchase and BT index:

- Steep slope along BT-index dimension.
- Steeper slope along advance-purchase dimension for higher BT-index.
  - Inter-temp pd: Biz passengers exerting externality on leisure travelers.

(a) 1st-Class
Model solution with efficient (random) rationing provides lower (upper) bound on inefficiency from dynamic pricing with stochastic demand.
## Table 1: Market Structure, SIAT vs. DB1B.

<table>
<thead>
<tr>
<th></th>
<th>SIAT</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td># Firms</td>
<td>1.089</td>
<td>0.232</td>
<td>916</td>
<td></td>
</tr>
<tr>
<td>HHI</td>
<td>0.896</td>
<td>0.232</td>
<td>916</td>
<td></td>
</tr>
<tr>
<td>Gini</td>
<td>0.251</td>
<td>0.08</td>
<td>1,135</td>
<td></td>
</tr>
<tr>
<td>Price ($)</td>
<td>622.04</td>
<td>428.49</td>
<td>93,169</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DB1B</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td># Firms</td>
<td>1.396</td>
<td>0.794</td>
<td>692</td>
<td></td>
</tr>
<tr>
<td>HHI</td>
<td>0.611</td>
<td>0.239</td>
<td>692</td>
<td></td>
</tr>
<tr>
<td>Gini</td>
<td>0.274</td>
<td>0.055</td>
<td>966</td>
<td></td>
</tr>
<tr>
<td>Price ($)</td>
<td>582.88</td>
<td>419.86</td>
<td>707,907</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Number of Firms and HHI are at the market-year-quarter level. Gini is at the market-year-quarter-carrier level. Fares are at the individual passenger level.
Filters Applied to Data

- Discard responses with no fares, package purchases, “non-revenue” fares.
- Discard month-markets where there does not exist a single dominant airline (over 50% capacity) and not both US carriers in case of duopoly.
- We estimate fare paths within a flight: min of 10 obs for a flight.
# Top Markets

<table>
<thead>
<tr>
<th>Market</th>
<th>No. Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFBMAN</td>
<td>2,706</td>
</tr>
<tr>
<td>SFOTPE</td>
<td>2,389</td>
</tr>
<tr>
<td>LAXPVG</td>
<td>1,713</td>
</tr>
<tr>
<td>SFBLGW</td>
<td>1,571</td>
</tr>
<tr>
<td>SFOAKL</td>
<td>1,511</td>
</tr>
<tr>
<td>JFKLHR</td>
<td>1,509</td>
</tr>
<tr>
<td>JFKMAD</td>
<td>1,453</td>
</tr>
<tr>
<td>JFKHEL</td>
<td>1,161</td>
</tr>
<tr>
<td>JFKGCM</td>
<td>1,096</td>
</tr>
<tr>
<td>JFKICN</td>
<td>1,032</td>
</tr>
</tbody>
</table>
**Expected Demand**

\[ E_t(q^e; \sigma_t) := \sum_{n=0}^{\infty} \left\{ n \times \Pr(N_t = n) \Pr(\nu - p_t^e \geq \max\{0, \nu \times \xi - p_t^f\}) \right\} := P_t^e(\sigma_t) \]

\[ = \lambda_t \times P_t^e(\sigma_t) \]

\[ E_t(q^f; \sigma_t) := \sum_{n=0}^{\infty} \left\{ n \times \Pr(N_t = n) \Pr(\nu \times \xi - p_t^f \geq \max\{0, \nu - p_t^e\}) \right\} := P_t^f(\sigma_t) \]

\[ = \lambda_t \times P_t^f(\sigma_t) \]
Details of Computation

- Max size of a plane is \((K_0^f, K_0^e) = (50, 250)\).
  - Common Delta configuration for B757 is \((24, 156)\) and for a B747 is \((48, 328)\) (for nonstop + connecting).
- We solve for exact solutions at a fixed number of states: about every 8 seats except near \(\omega = 0\).
- We use \(R = 100\) simulation draws for demand.
  - Each draw is a realization of \(N_t (\sim Pois(\lambda))\) and the associated willingnesses to pay.
- At each step backwards we interpolate the value function and policy functions across states.
- We use a combination of mixed integer programing (for seat release) and non-linear programing to solve for state dependent policy function. (MINLP implementation in Matlab using NOMAD solver)

Back to Dynamic Program
Capacity Details

Common Delta configuration for B757 is (24, 156) and for a B747 is (48, 328) (for nonstop + connecting).

Figure 4: Density of Initial Capacities