Discriminatory Pricing In The Airline Industry

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Introduction

Firms often use discriminatory pricing strategies to increase profits through surplus extraction.

- Technological innovation allows for increasingly sophisticated discriminatory pricing.

The welfare implications of such strategies is often ambiguous [Bergemann et al., 2015] and empirical research is needed to understand impact to profits and consumers.

Using novel data obtained from a partnership with a North American airline, my dissertation seeks to understand discriminatory pricing strategies in the airline industry.

My dissertation consists of two chapters that:

1. Analyze the role of "upgrades" to airlines and quantifies their effect on profit and welfare.
2. Examine what search data reveals to airlines and researchers about consumer behavior.

Data

1. Search Data:
   - Web traffic data from the airline's website
   - All flight searches and purchases from the airline's website, including redirected traffic e.g. Google Flights, Kayak
2. Revenue Management Data:
   - Aircraft cabin capacities and flight information
   - Daily ticket sales and transaction prices
3. Upgrade Data:
   - Bids placed for upgrades, outcomes of bids, and other auction info
   - Upgrades purchased at check-in including price

Chapter 2: Should I Stay or Should I Go? An Empirical Analysis of Consumer Behavior Using Airline Web-Traffic Data

"If I go, there will be trouble, and if I stay, it will be double,
So come on and let me know, this indecision's bugging me"

— The Clash

What Can We Learn About Consumers From Searches?

Consumers often search for products online with search engines or on company websites.

- Generates web-traffic data that may reveal information about consumer demand and behavior

Search data can serve a unique role in demand estimation by identifying increasing arrivals separately from more inelastic demand.

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> "The key identification challenge of the paper is to separately identify the demand parameters from the arrival process. This challenge was pointed out in Talluri and van Ryzin [2004], for example. The issue arises because without proprietary search data to pin down the arrival process, an increase in arrivals could instead be inferred as inelastic demand."
>
> — Williams [2022]

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This research uses proprietary web-traffic data from a North American airline's website as well as Google Flights to examine what it reveals about consumers.

Contributions:

1. Shows how revenue-management practices impact consumers
2. Test assumptions used in empirical models of airlines and consumer search
3. Measure the importance of factors influencing consumer choice

Methodological Approach and Notable Findings

To understand how consumer characteristics affect timing, purchase, and pricing, we

- Describe how consumer observables are related to each outcome.
- Regress search timing, purchase decisions, and prices on observables.

Notable findings include:

1. Searches, bookings, and conversion rates increase approaching departure
   - Explained mostly by consumer observables
2. Searches for one-way, premium tickets and by solo frequent fliers are closer to departure
   - Purchase at highest rate
3. Families and multi-adult parties arrive much earlier to pay lower fares
   - Purchase at lowest rate
4. Strong heterogeneity in purchased prices across consumer and market characteristics
   - Markets with more competition see lower conversion rates

Chapter 1: Revenue Management with Reallocation

"On my way home I'll bump this seat right up to first class,
So I can drink that cheap champagne out of a real glass."

— Dierks Bently, *Drunk On A Plane*

Price Discrimination Using Upgrades

Firms in the travel and leisure industries often allow consumers to "upgrade"

- Swap their initial purchase with a higher quality good
- Mechanisms include loyalty programs, fixed prices, and auctions.

Upgrades present a trade-off to the firm:

- Allows for reallocation of remaining capacities while collecting additional revenue (+)
- Risks drawing consumers away from purchasing higher quality good at full price (–)

This research estimates an equilibrium model of airline and consumer behavior to quantify the impact of upgrades on profits and welfare.

Contributions:

1. First to analyze upgrade auctions and quantify welfare impacts of upgrades
2. Developed novel algorithm for solving equilibrium beliefs which can be used in future work

Structural Model Overview

Monopoly airline sells seats in two vertically differentiated cabins to maximize expected profits

- Sets cabin-specific prices and releases seats each period before departure
- Permits bids for upgrades at time of purchase and chooses winning bids at pre-determined time before departure
- Offers remaining premium seats for fixed price at departure

Consumers decide between premium, economy, and no purchase.

- Upgrades create option value for economy purchases
- Consumers are strategic and choice based on beliefs about others' actions and airline's pricing and bid-acceptance policies

Solution to Structural Model

A solution to the model yields two sets of objects:

1. Policies, $\boldsymbol{p}_t(\boldsymbol{k})$ and $\overline{\boldsymbol{q}}_t(\boldsymbol{k})$, that solve pricing team's dynamic program.
2. Beliefs, $\boldsymbol{\varrho}_t(\boldsymbol{k})$ and $\varphi_t(\boldsymbol{k})$, that form a PBNE in game between upgrade team and consumers.

Consistent with airline's DGP, first solve for $\boldsymbol{p}_t(\boldsymbol{k})$ and $\overline{\boldsymbol{q}}_t(\boldsymbol{k})$, then solve $\boldsymbol{\varrho}_t(\boldsymbol{k})$ and $\varphi_t(\boldsymbol{k})$

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- Solving for $\boldsymbol{p}_t(\boldsymbol{k})$ and $\overline{\boldsymbol{q}}_t(\boldsymbol{k})$ is the same as in Aryal et al. [2023]
- However, solving for $\boldsymbol{\varrho}_t(\boldsymbol{k})$ and $\varphi_t(\boldsymbol{k})$ requires some innovation

Overcoming Challenge of Solving Equilibrium Beliefs

Consumers' beliefs of being upgraded in the future influence *expected utility* of economy

$$\overbrace{\mathcal{U}_t^e}^{\text{Economy Expected Utility}} = \underbrace{\nu - p_t^e}_{\text{Certain utility}} + \underbrace{\varrho_t^*(\boldsymbol{k})(\nu(\xi-1) - b^*)}_{\text{Auction utility}} + \overbrace{\Big(1 - \varrho_t^*(\boldsymbol{k})\Big)\varphi_t(\boldsymbol{k}) \underbrace{\max\{0, \nu(\xi-1) - r\}}_{\text{Willing to pay check-in}}}^{\text{Check-in utility}}$$

Cabin choice compares $\mathcal{U}_t^e$ with certain utilities $u_t^f \equiv \nu\xi - p_t^f$ and $u_t^o \equiv 0$

- Therefore, upgrade beliefs can alter initial choice of cabin

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Developed an iterative forward-simulation procedure to solve numerically:

1. Forward simulate R sequences of decisions given initial beliefs
2. Calculate upgrade probabilities given airline's bid-acceptance policy
3. Update initial beliefs to equal upgrade probabilities
4. Iterate steps 1, 2, and 3 until convergence to a fixed point

Estimation: Overview

Model's data-generating process (DGP) for a flight has two components:

1. Market arrival process: $\mathbf{\Lambda}_m = \{\lambda_{mt}\}_{t=1}^{T}$
   - λ_{mt} is period t's arrival rate for market $m \in \{1, ..., 27\}$

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2. Consumer parameters: $\boldsymbol{\psi} = (\mu_\nu^L, \mu_\xi^L, \mu_\nu^B, \mu_\xi^B, \Delta_\gamma)$
   - For travelers $\omega \in \{L, B\}$, μ_ν^ω is mean WTP for travel, μ_ξ^ω is mean preference for quality
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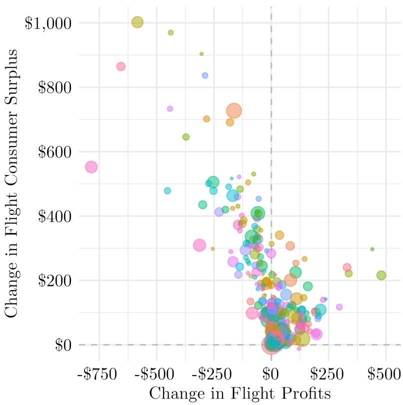
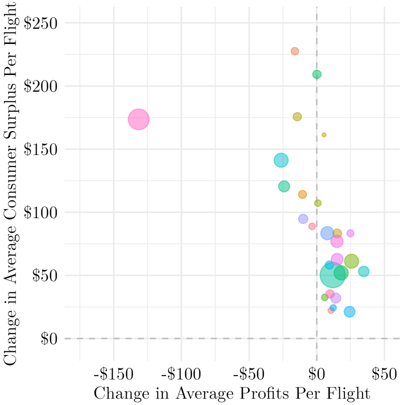
Estimate flexible distribution of demand across flights *within each market* using moment-based approach of Fox et al. [2016], Nevo et al. [2016]

- Separates computation and estimation steps:
  1. First solve model for grid of "candidate" DGPs (entirely computation)
  2. Estimate weights by averaging across simulated model moments to match data moments
- Results in a discrete distribution of flights that captures heterogeneity in market

Counterfactual: Impact of Upgrades on Profits and Consumer Surplus



a Candidate DGPs



b Market Averages

- Upgrades modestly increase welfare, split between profit and CS depends
- Change to average profits in a market depends but is modest

Conclusion

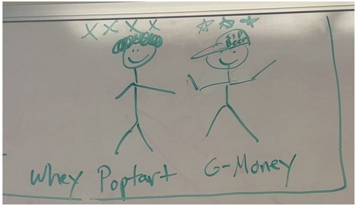
This work makes multiple contributions to our understanding of price discrimination.

- I am particularly proud of the code that solves the equilibrium beliefs.

Future plans for this work:

- Chapter 2 has been accepted at *Economics of Transportation*
- Tweak structural model in Chapter 1 to better fit data and run additional counterfactuals.
    - Plan to submit to top journals.
- Finish companion paper to Chapter 1 that extends model to uninformed consumers.

Thank You!



Appendix

Price Descriptives

	Domestic							
	Transactions				**Quotes**			
Variable	**Mean**	25^{th}	50^{th}	75^{th}	**Mean**	25^{th}	50^{th}	75^{th}
Economy:								
Fare (*per direction*)	212.46	122.44	183.59	269.42	231.88	139.49	205.11	288.32
Observations	732,859				3,870,043			
Premium:								
Fare (*per direction*)	521.73	377.68	481.38	623.40	617.05	416.42	534.68	760.04
Observations	37,810				139,821			

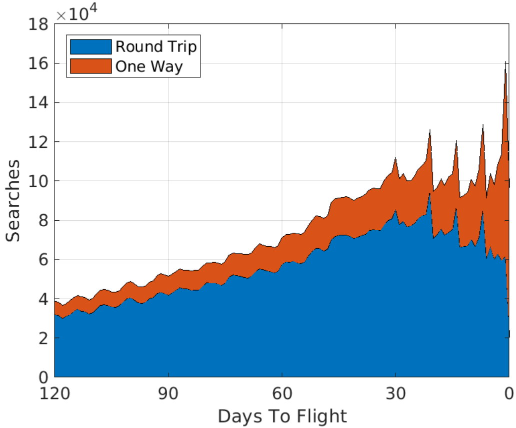
- Economy prices lower than premium prices (same true for international)
- Transaction price lower than quoted prices with larger upper tail

Conversion Rate Descriptives

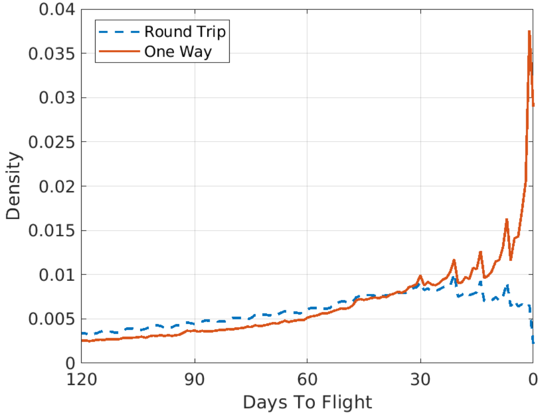
Variable	Share	Conversion Rate $\mathbb{I}=1$	Conversion Rate $\mathbb{I}=0$
Itinerary:			
Domestic	0.396	0.161	0.072
Economy	0.948	0.106	0.124
Round Trip	0.782	0.082	0.197
Travel Party:			
Single Adult	0.519	0.132	0.081
Family	0.110	0.067	0.112
Loyalty Status:			
Not Logged In	0.599	0.048	0.196
Tier 1	0.336	0.188	0.067
Tier 2	0.027	0.203	0.105
Tier 3+	0.019	0.238	0.105

– Substantial variation in conversion rates by groups.

Increasing Arrival Rates: One way vs Round Trip



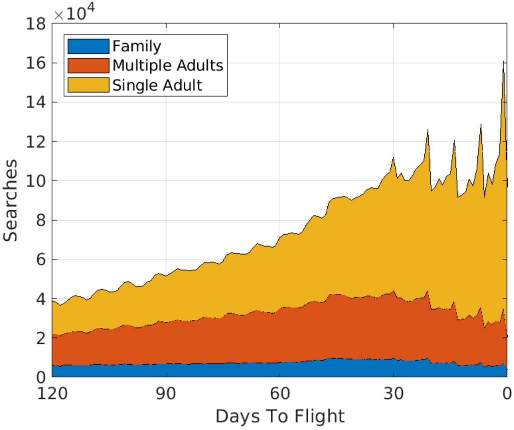
Searches



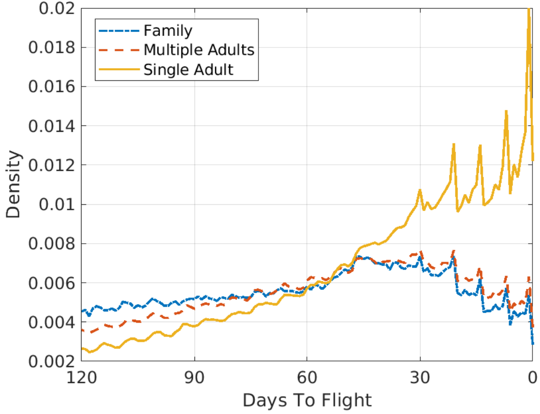
Density

– Total searches peak around 30 days out. One way trips peak at departure.

Increasing Arrival Rates: Party Size



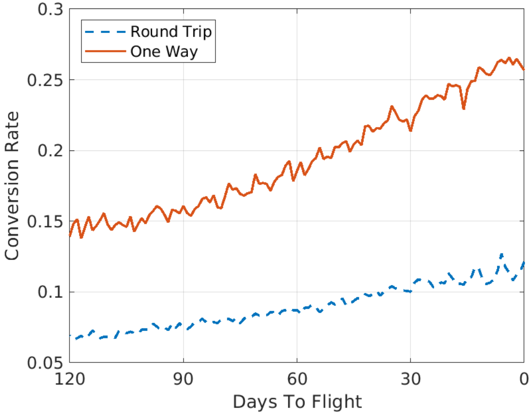
Searches



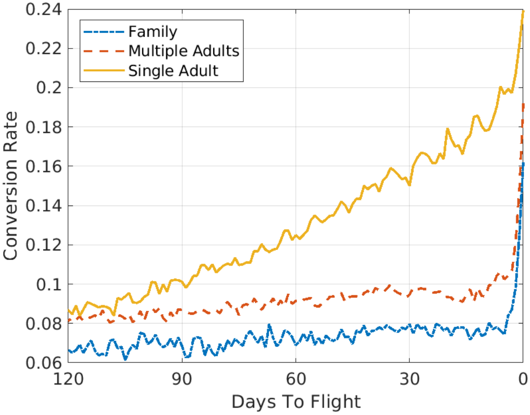
Density

- Total Searches peak around 50 days out. Single adult density increase towards departure.
- Single adults resembles one way travelers (unsurprising)

Evidence of Higher WTPs Near Departure: Conversion Rates



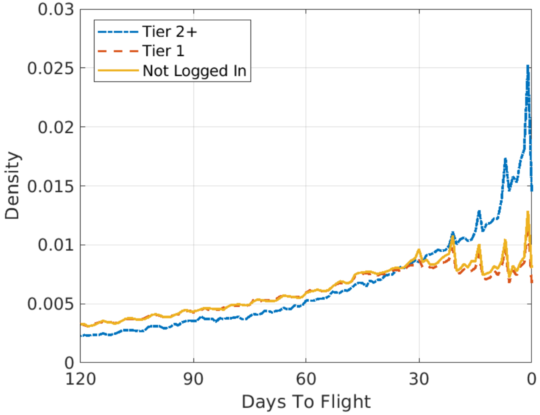
Trip Type



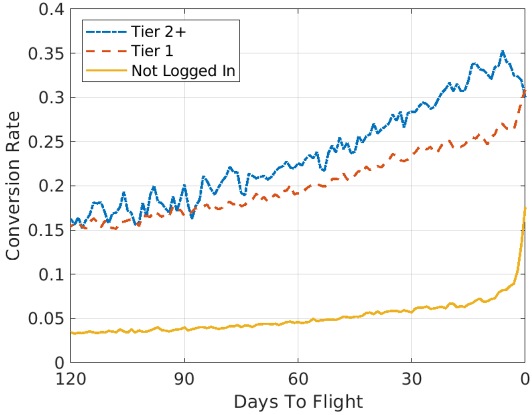
Party Size

- Conversion rates increase approaching departure
- Large parties have lower conversion rates that peak near departure

Different Types of Consumers: Frequent Fliers



Density



Conversion Rate

- Frequent fliers arrive to purchase later with a higher overall conversion rate.

Estimation: Details

For each market $m \in \{1, ..., 27\}$:

1. Estimate arrival process $\mathbf{\Lambda}_m = \{\lambda_{mt}\}_{t=1}^{T}$ with search data
2. Solve model for fixed grid of $H = 1,500$ candidate DGPs
   — A candidate DGP is a vector of demand primitives $\boldsymbol{\psi} = (\mu_\nu^L, \mu_\xi^L, \mu_\nu^B, \mu_\xi^B, \Delta_\gamma)$
3. Compute vector of aggregate market-specific moments $\hat{\boldsymbol{g}}_m$ from data and equivalent moments via simulation for each candidate DGP in matrix $\tilde{\boldsymbol{G}}_m$
4. Estimate weights $\hat{\boldsymbol{\theta}}_m$ of each DGP using constrained least squares:

$$\hat{\boldsymbol{\theta}}_m = \arg\min_{\boldsymbol{\theta}} \, (\hat{\boldsymbol{g}}_m - \tilde{\boldsymbol{G}}_m \boldsymbol{\theta})'(\hat{\boldsymbol{g}}_m - \tilde{\boldsymbol{G}}_m \boldsymbol{\theta})$$

$$\text{subject to } \sum_{h=1}^{H} \theta_h = 1 \text{ with } \theta_h \geq 0$$

Estimation: Visualization

$$\hat{\boldsymbol{g}} = \underbrace{\begin{bmatrix} \hat{g}_1 \\ \hat{g}_2 \\ \vdots \\ \hat{g}_{N_g} \end{bmatrix}}_{\text{Moments from data}} \quad \tilde{\boldsymbol{G}} = \overbrace{\begin{bmatrix} \tilde{G}_{11} & \tilde{G}_{12} & \cdots & \tilde{G}_{1H} \\ \tilde{G}_{21} & \tilde{G}_{22} & \cdots & \tilde{G}_{2H} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{G}_{N_g 1} & \tilde{G}_{N_g 2} & \cdots & \tilde{G}_{N_g H} \end{bmatrix}}^{\text{Columns are equivalent moments for each candidate DGP}} \quad \text{and } \boldsymbol{\theta} = \underbrace{\begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_H \end{bmatrix}}_{\text{Weight for each DGP}},$$

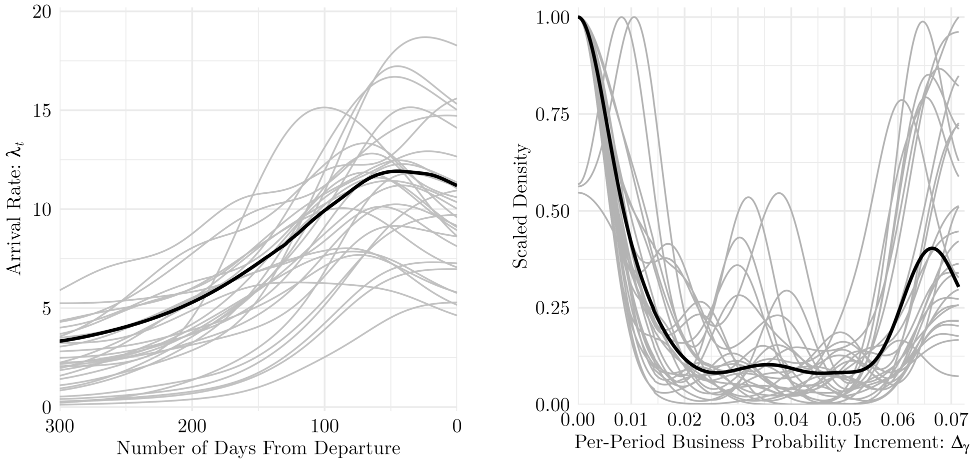
Solution minimizes squared differences between data and weighted average of candidate-DGP moments

$$\hat{\theta} = \arg\min_{\boldsymbol{\theta}} ||\hat{\boldsymbol{g}} - \tilde{\boldsymbol{G}}\boldsymbol{\theta}||$$

$$\tilde{\boldsymbol{G}}\boldsymbol{\theta} = \theta_1 \tilde{\boldsymbol{G}}_1 + \theta_2 \tilde{\boldsymbol{G}}_2 + \cdots + \theta_H \tilde{\boldsymbol{G}}_H$$

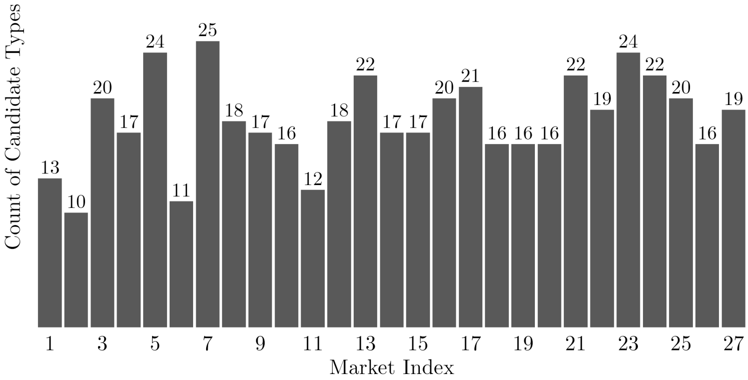
where $\tilde{\boldsymbol{G}}_k$ is the k^{th} column of $\tilde{\boldsymbol{G}}$.

Results: Arrival Process



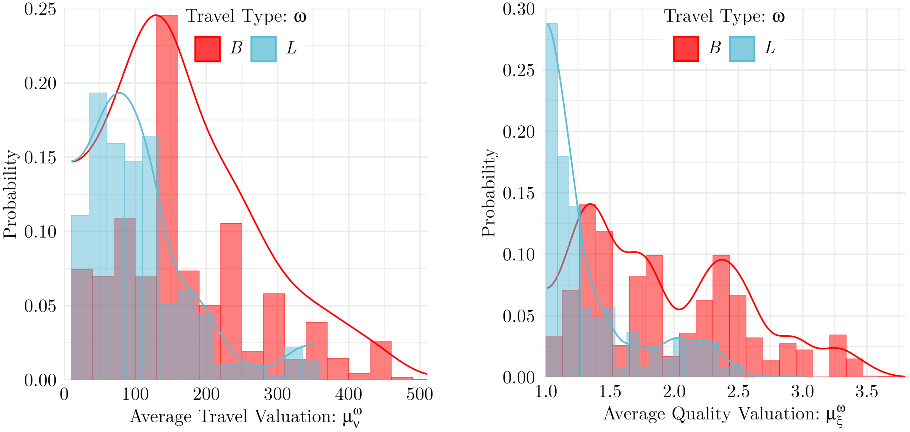
- Market-specific heterogeneity in number of arrivals and type probabilities

Results: Surviving Types



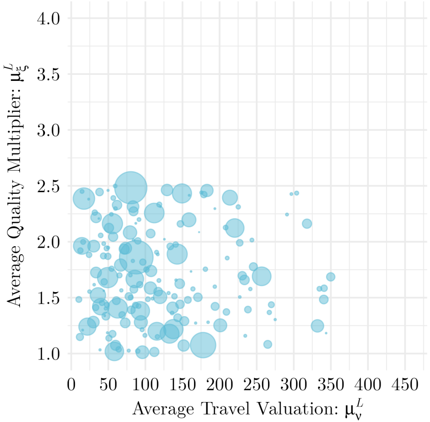
- Each market is described by few DGPs (i.e. 99.99% of the weight)
- Market-specific mixture captures heterogeneity across flights

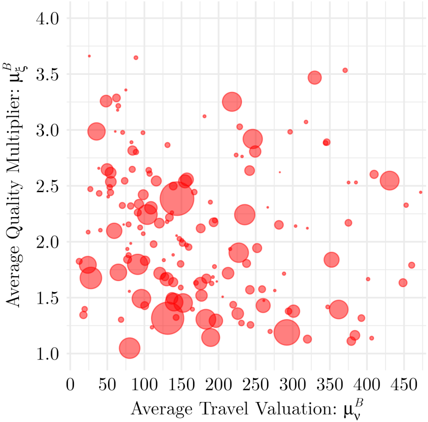
Results: Consumer Heterogeneity - Marginal Distributions



- Marginal distribution of air-travel and premium-cabin valuations aggregating across markets (business FOSD leisure)

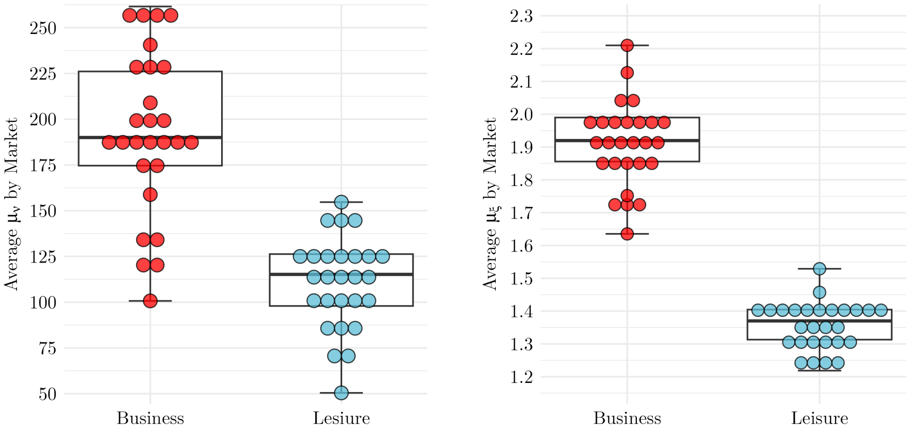
Results: Consumer Heterogeneity - Joint Distributions





- Joint type-specific distribution of air-travel and premium-cabin valuations aggregating across markets (business more variable than leisure)

Results: Market Heterogeneity



- Distribution of market-specific mean of air-travel and premium-cabin valuations by consumer type (wide variety of preferences across markets)