Airport Congestion: Implementing a Two-Part Landing Fee at the San Francisco International Airport

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Introduction

- Flight delay is a serious and widespread problem in the US

Table : On-Time Arrival Performance National (Jan - Jun, 2013)

Arrivals over 15 min late	**22%**
National Aviation System Delays	29%

Source: BTS

- Direct Cost of Air Transportation Delay (2007) = \$32.9 billion
- Solutions:
  - Investment in infrastructure
  - Policies that discourage overscheduling
    - slot constraints
    - congestion pricing

Introduction

- “The Policy Regarding the Establishement of Airports Rates and Charges”
  - Landing Fees
  - Rental of Terminals
- (2008 Amd) Two-part landing fee: weight based charge + congestion charge
  - Landing fees depending on the level of congestion
  - Divert operations to off-peak hours and increase the size of aircraft
- No US airport has implemented this type of pricing scheme

Objective:

Study the effects of implementing a two-part landing fee scheme at SFO

Introduction

- Contributions
  - First study that quantifies the effects of implementing a two-part landing fee.
  - Rich specification of the supply side
    - Endogenous airport charges
    - Two decision variables for carriers (price, frequency)
    - Correlation across markets
  - Spatially-based consumer characteristics

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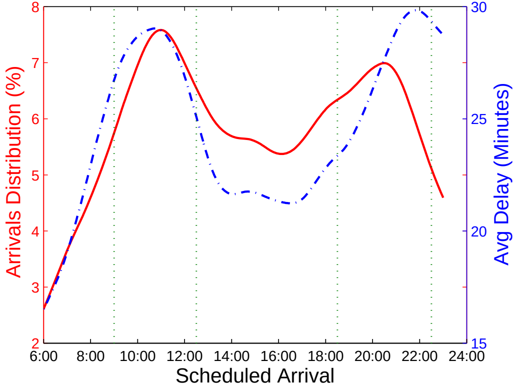
- Results
    - Simulations suggest that a congestion charge (for instance, \$2000)
        - Decreases the number of landings (-3.86%)
        - Increases the size of aircraft (9.19%)
        - Decreases the level of congestion at SFO (-12.16%)
    - Peak demand is partly diverted to off-peak hours, but total demand at SFO decreases (-2.61%)

Introduction

Why SFO?

- Congested airport (FAA)

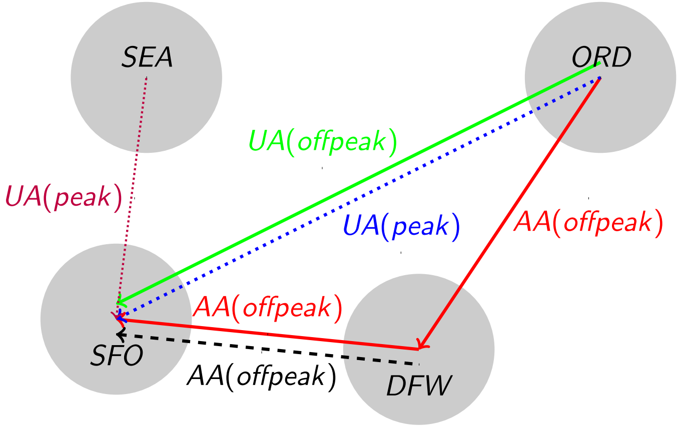


- 2006 Airline Passenger Survey by the MTC

Outline:

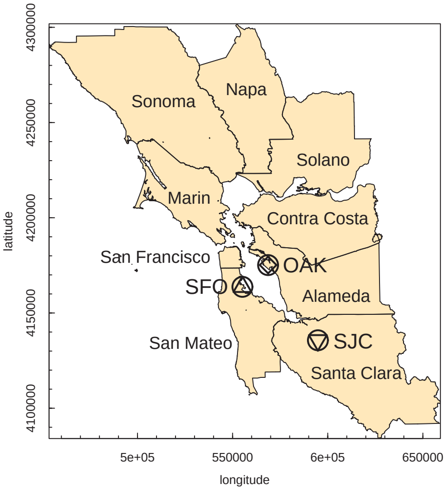
- Model: demand and supply specification
- Solving the Model: fares and flight frequencies
- Data
- Estimation Procedure
- Estimation Identification
- Estimation Results
- Counterfactual - Implementing an operation charge in peak hours
- Conclusions

Model: Markets and Products



- Markets - round trip directional city-pair
- Products - bundle of characteristics for each period: fare, carrier, frequency, itinerary, delay, direct, and slot constraints
- Spoke-Routes: direct routes operated by at least one carrier
- Markets are **NOT** independent. Sources: SFO delays and sharing aircraft

Model: SFO Bay



Model: Demand

- Utility of individual *i* obtained from product *j* in market *t*

$$\begin{aligned} u_{ijt} &= \beta_{i0} + \underbrace{\left(\alpha_p + \alpha_y y_i + \sigma^p \nu_i^p\right)}_{\alpha_{ip}} p_{jt} + \alpha_{if}\hat{f}_{jt} + \alpha_{id}\hat{D}_{jt} + \alpha_{peak}\hat{I}_{jt}^{peak} + \\ &\quad + x_{jt}\beta + \xi_{jt} + \lambda d(L_i) + \epsilon_{ijt} \end{aligned}$$

  - p_{jt}: ticket price (endogenous)
  - $\hat{f}_{jt}$: mean frequency of trip segments (endogenous)
  - $\hat{D}_{jt}$: mean delay at connecting/final airports
  - $\hat{I}_{jt}^{peak}$: dummy for peak flights
  - ξ_{jt}: index of unobserved product characteristics
  - y_i: household income
  - $d(L_i)$: distance from *i* location to SFO in the Bay Area
  - $\nu' s$: unobserved taste of travelers for product characteristics
  - ϵ_{jt}: error term Type I Extreme Value distribution

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- Market shares

$$s_{jt}(\xi, \theta) = \int \underbrace{\frac{exp[\delta_{jt} + \mu_{ijt}]}{1 + \sum_{m \in J_t} exp[\delta_{mt} + \mu_{imt}]}}_{P(u_{ijt} \geq u_{ilt}, l \neq j)} dP_\nu(\nu_i) dP_L(L_i) dP_Y(y_i)$$

Model: Carriers and Airport Charges

- Carrier's Profits

$$\begin{aligned}
\Pi_c &= \sum_{t\in T}\sum_{j\in\mathcal{J}_{ft}}([p_{jt}-m_{jt}]s_{jt}(p,f)\times M_t)- \\
&- \underbrace{\sum_{r\in\Omega_c}\sum_{l\in\{\mathcal{L},\mathcal{H}\}}\tilde{f}_{lrc}(FCost_{lrc}+\beta^d D_l(f)+\underbrace{fees(s,p,f)\times weight_{lrc}(s,p,f)+\rho_l}_{\text{Two-Part Landing Fee}})-}_{\text{Total Operating Flight Cost}} \\
&- RC_c(s,p,f)
\end{aligned}$$

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- Delays (Morrison and Winston (1989,2007))

$$D_l = \begin{cases} exp(\omega^d_{\mathcal{H}}\bar{f}_{\mathcal{H}}) & if \quad l=\mathcal{H} \\ exp(\omega^d_{\mathcal{L}}\bar{f}_{\mathcal{L}}) & if \quad l=\mathcal{L}\end{cases}$$

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- Airport Charges:
  - $fees(s,p,f)$: weight-based fee

$$fees(s,p,f)=\frac{ARCost+\frac{1}{2}\left[TCost(s,p,f)+GCost(s,p,f)\right]}{TWeight(s,p,f)}$$

  - ρ_l: congestion charge
  - $RC_c(s,p,f)$: rental charge of terminals

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\end{aligned}
$$

- Estimated: m_{jt}, $FCost_{lrc}$, β^d, demand and weight parameters

Solving the Model

- Carriers: profit maximizing firms with respect to fares, frequencies and schedule of their flights

$$\max_{p,f} \Pi_c$$

- Equilibrium concept: subgame perfect Nash Equilibrium
- Two stage game solved backwards:
  - 1st stage) Frequency of flights,
  - 2nd stage) Fares.
- Weight of aircraft is the result of the interaction between optimal fares and frequencies

Solving the Model

Second Stage: Fares

- F.O.C. with respect to fares taking frequencies as given

$$\begin{aligned}\frac{\partial \Pi_c}{\partial p_{j't'}} &= \sum_{t\in T}\sum_{j\in\mathcal{J}_{ct}}(p_{jt}-m_{jt})\frac{\partial s_{jt}}{\partial p_{j't'}}M_t + s_{j't'}M_{t'} - \\ &- \sum_{r\in\Omega_c}\sum_{l\in\{\mathcal{L},\mathcal{H}\}}\tilde{f}_{lrc}\left[\frac{\partial fees}{\partial p_{j't'}}weight_{lrc} + fees\frac{\partial weight_{lrc}}{\partial p_{j't'}}\right] - \frac{\partial RC_c}{\partial p_{j't'}} = 0\end{aligned}$$

- Optimal Fares
- **NO** congestion charge (ρ_l) or frequency costs ($FCost_{lrc}$)
- Identification of parameters and estimation of marginal costs

Solving the Model

First Stage: Frequencies

- F.O.C. with respect to frequencies knowing the response of fares

$$\begin{aligned}\frac{\partial \Pi_c}{\partial f_{l'r'c}} &= \sum_{t\in T}\sum_{j\in\mathcal{J}_{ct}}\left[(p_{jt}-m_{jt})\frac{\partial s_{jt}}{\partial f_{l'r'c}}M_t + \frac{\partial p^*_{jt}}{\partial f_{l'r'c}}s_{jt}M_t\right] - \\ &- 92\left[fees \times weight_{l'r'c} + \beta^d D_{l'} + FCost_{l'r'c} + \rho_{l'}\right] - \\ &- \sum_{r\in\Omega_c}\sum_{l\in\{\mathcal{L},\mathcal{H}\}}\tilde{f}_{lrc}\left[\frac{\partial fees}{\partial f_{l'r'c}}weight_{lrc} + fees\frac{\partial weight_{lrc}}{\partial f_{l'r'c}} + \beta^d\frac{\partial D_l}{\partial f_{l'r'c}}\right] - \frac{\partial RC_c}{\partial f_{l'r'c}} = 0\end{aligned}$$

- Source of dependence across markets
- Estimation of $FCost_{lrc}$ and β^d
- Counterfactual (ρ_l)
- $\frac{\partial p^*_{jt}}{\partial f_{l'r'c}}$ and $\frac{\partial s_{jt}}{\partial f_{l'r'c}}$ difficult to compute. ▸ more

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Data and Statistics

Data Sources

- 3rd Quarter of 2006
- Product and Spoke Characteristics:
  - Airline Origin and Destination (DB1B)
  - Rita T-100
  - Airline On-Time Performance
  - Schedule B-43 Aircraft Inventory
  - Technical Specifications of Aircraft
- Airport Financial Reports:
  - FAA Summary Report 127
  - 2006 Annual Operating Budget for the San Francisco International Airport
- American Community Survey (ACS)
- 2006 Airline Passenger Survey by the MTC

▸ more

Data and Statistics

Table : Product Statistics for 3rd Quarter 2006

	Off-Peak		**Peak**		**Both**	
	Mean	**Sd**	**Mean**	**Sd**	**Mean**	**Sd**
Fare (p) ($100)	4.29	2.09	4.27	2.08	4.28	2.09
Nb Passengers	95.97	662.03	149.24	950.81	124.04	827.26
Direct Flight	0.02	0.15	0.03	0.16	0.02	0.15
Daily Flight Frequency ($\hat{f}$)	1.74	0.72	1.98	0.70	1.86	0.72
Distance (1000 miles)	4.51	1.27	4.55	1.23	4.53	1.25
AA	0.17	0.37	0.17	0.37	0.17	0.37
CO	0.05	0.22	0.06	0.24	0.06	0.23
DL	0.17	0.37	0.16	0.36	0.16	0.37
NW	0.08	0.28	0.09	0.28	0.09	0.28
UA	0.38	0.48	0.37	0.48	0.37	0.48
US	0.13	0.34	0.12	0.33	0.13	0.33
Others	0.02	0.15	0.04	0.19	0.03	0.17
Slots	0.30	0.46	0.30	0.46	0.30	0.46
Delay ($\hat{D}$) (minutes)	16.11	1.78	16.99	1.73	16.57	1.81
Nb Products	5,353	-	5,963	-	11,316	-

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Estimation

Estimation Procedure

1. Weight equation of aircraft (TSLS)
2. Demand parameters and pricing equation (GMM) (Berry, Levinsohn, and Pakes (1995), Petrin (2002))
3. Frequency F.O.C. (β^d, $FCost$) (OLS)

▸ more

Estimation

Identification

- Identifying Travelers Heterogeneity
    - Variation of product characteristics and demographics across markets
    - Match model predictions with 2006 MTC Survey probabilities conditional on travelers demographics and period of departure
    - Bertrand-Nash equilibrium with respect to fares

- Endogeneity of ticket prices and frequencies: Berry, Levinsohn, and Pakes (1995), and Berry and Jia (2010) instruments

- Identification of *FCost* and β^d

Estimation Results: Demand

	RCM	**Std**			**RCM**	**Std**	
Intercept	-6.924	(0.272)	*	**Rnd Ct. (σ^{ν})**	-0.874	(0.145)	*
Fare (α_p)	-1.236	(0.079)	*	**Rnd Price (α_p^{ν})**	-0.066	(0.004)	*
Dist. (1000 miles)	1.692	(0.098)	*	**Distance (λ)**	-0.283	(0.081)	*
Dist. Squared	-0.191	(0.011)	*	**Rnd Income (α_y)**	0.054	(0.001)	*
Frequency (α_f)	0.384	(0.032)	*	**Rnd Freq (α_f^{ν})**	0.122	(0.131)	
Direct	4.413	(0.108)	*	**Rnd Delay (α_d^{ν})**	-0.155	(0.001)	*
Peak (α_{peak})	0.430	(0.038)	*	**Sfo-Mateo**	1.129	(0.249)	*
CO	0.418	(0.101)	*	**Sta Clara**	-1.564	(0.128)	*
DL	-0.255	(0.074)	*	**Alameda-Costa**	0.142	(0.418)	
NW	-0.259	(0.078)	*	**Sonoma-Marin**	-0.448	(0.329)	
UA	0.374	(0.081)	*	**Nb Observations**	11,316		
US	-0.225	(0.066)	*				
Others	0.714	(0.112)	*				
Slots	-0.279	(0.048)	*				
Delay (α_d)	-0.409	(0.017)	*				

* Significant at the 5 percent level

- Own-price elasticity: -3.44 (1.04)
- Frequency semi-elasticities: 7.32 (3.19)

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DL	-0.255	(0.074)	*	**Alameda-Costa**	0.142	(0.418)	
NW	-0.259	(0.078)	*	**Sonoma-Marin**	-0.448	(0.329)	
UA	0.374	(0.081)	*	**Nb Observations**	11,316		
US	-0.225	(0.066)	*				
Others	0.714	(0.112)	*				
Slots	-0.279	(0.048)	*				
Delay (α_d)	-0.409	(0.017)	*				

* Significant at the 5 percent level

- Own-price elasticity: -3.44 (1.04)
- Frequency semi-elasticities: 7.32 (3.19)

Estimation Results: Demand

	RCM	Std			RCM	Std	
Intercept	-6.924	(0.272)	*	**Rnd Ct. (σ^{ν})**	-0.874	(0.145)	*
Fare (α_p)	-1.236	(0.079)	*	**Rnd Price (α_p^{ν})**	-0.066	(0.004)	*
Dist. (1000 miles)	1.692	(0.098)	*	**Distance (λ)**	-0.283	(0.081)	*
Dist. Squared	-0.191	(0.011)	*	**Rnd Income (α_y)**	0.054	(0.001)	*
Frequency (α_f)	0.384	(0.032)	*	**Rnd Freq (α_f^{ν})**	0.122	(0.131)	
Direct	4.413	(0.108)	*	**Rnd Delay (α_d^{ν})**	-0.155	(0.001)	*
Peak (α_{peak})	0.430	(0.038)	*	**Sfo-Mateo**	1.129	(0.249)	*
CO	0.418	(0.101)	*	**Sta Clara**	-1.564	(0.128)	*
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Sonoma-Marin	-0.448	(0.329)	
Nb Observations	11,316		

* Significant at the 5 percent level

- Own-price elasticity: -3.44 (1.04)
- Frequency semi-elasticities: 7.32 (3.19)

Estimation Results: Supply

- Marginal cost per passenger-mile: **6 cents**
- Lerner Index: **31%** (Berry and Jia (2010))
- Weight Estimates (TSLS)

Weight (10^3 pounds)	**Estimate**	**Std**	
Daily Pax (τ_1)	0.439	(0.054)	*
Daily Frequency (τ_2)	-12.974	(3.748)	*
Distance (τ_3) (1000 miles)	17.295	(2.899)	*
⋮	⋮		
Nb Observations	165		

Estimation Results: Supply

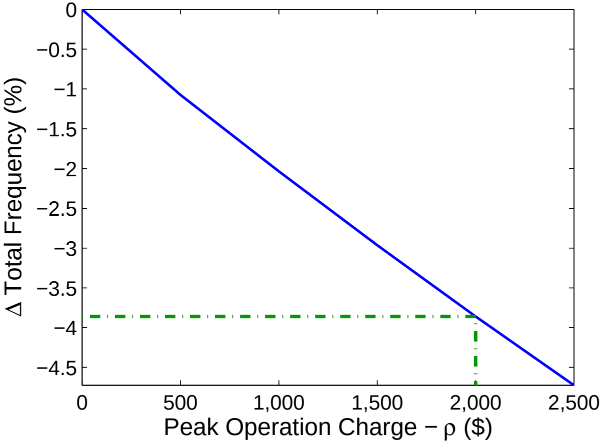
- Marginal cost per passenger-mile: **6 cents**
- Lerner Index: **31%** (Berry and Jia (2010))

- Undelayed Cost Frequency Estimates ($\hat{FCost}$): **10,573 (1,145)**

\$100	**Estimate**	**Std**	
Distance (1000 miles)	7.883	(3.052)	*
Distance2	-1.064	(0.821)	
β^d	-3.252	(0.211)	*
⋮	⋮		
Nb Observations	165		

Counterfactual: Two-Part Landing Fee

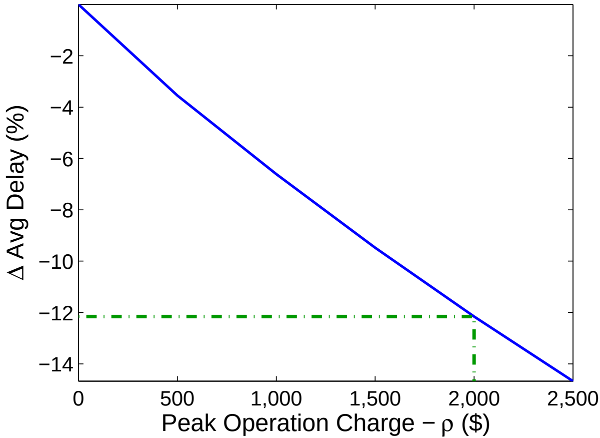
Figure : Δ Total Daily Flights - Peak (%)



$2000: 217 → 208

Counterfactual: Two-Part Landing Fee

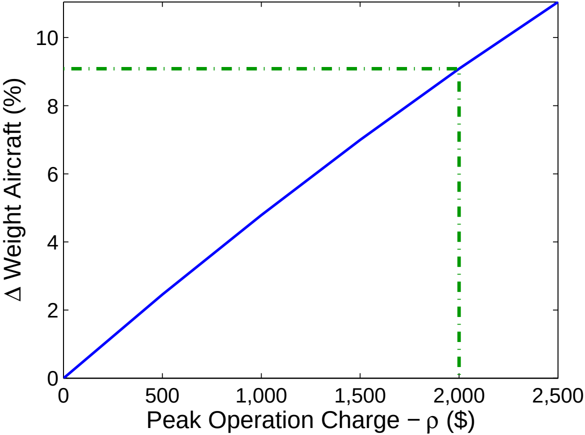
Figure : Δ Average Delay - Peak (%)



$2000: $28'45'' \rightarrow 25'15''$

Counterfactual: Two-Part Landing Fee

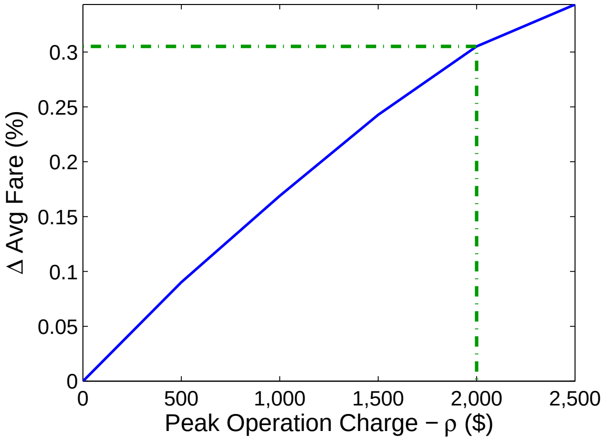
Figure : Δ Aircraft Weight - Peak (%)



$2000: $137,940 \rightarrow 150,492$

Counterfactual: Two-Part Landing Fee

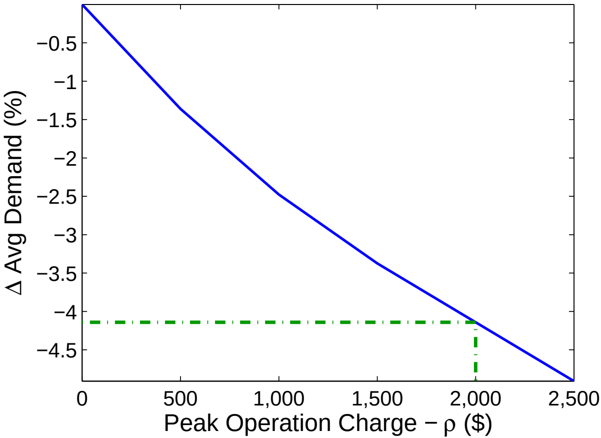
Figure : Δ Fares - Peak (%)



$2000: $427.47 → $428.75

Counterfactual: Two-Part Landing Fee

Figure : Δ Demand - Peak (%)



\$2000: 149.24 → 143.06

Counterfactual: Two-Part Landing Fee

Figure : Δ Demand - Off-Peak (%)

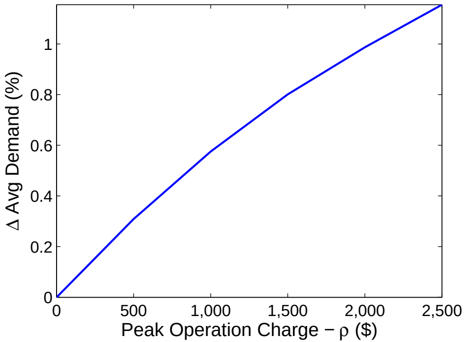
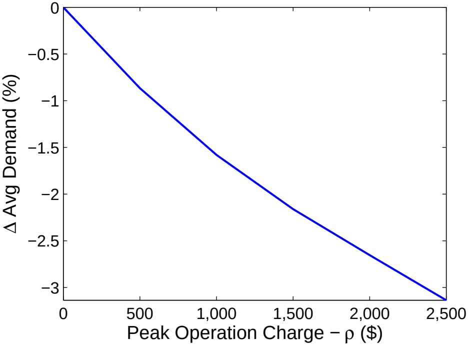


Figure : Δ Demand - SFO (%)



- Increase in frequency and size of aircraft during off-peak hours

▸ more

Conclusions

- Quantify the effects of implementing of a two-part landing fee during peak hours at SFO
- Results are in line with DoT's expectations. However, total demand for SFO decreases
- Directions for future work
  - Compare the two-part landing fee with optimal congestion fee
  - More general-equilibrium type of model
  - Congestion charge to divert operations to secondary airports (LAX-ONT)

Solving the Model

Derivative of fares with respect to frequencies

- Total Differentiation of the fare F.O.C.

$$\underbrace{\sum_k \Psi_c^p(j't',k)\frac{\partial^2 \Pi_c}{\partial p_{j't'}\partial p_k}}_{G_c^p(j't',k)} dp_k + \underbrace{\sum_b \Psi_c^f(j't',b)\frac{\partial^2 \Pi_c}{\partial p_{j't'}\partial f_b}}_{H_c^p(j't',b)} df_b = 0$$

where $k = \{1, ..., J\}$ and $b = \{1, ..., |\Omega \times \{\mathcal{L}, \mathcal{H}\}|\}$

$$G_p dp + H_f df = 0$$

- Matrix of derivatives of optimal fares with respect to frequencies

$$\frac{dp^*}{df} = -G_p^{-1} H_f$$

Solving the Model

Derivative of market shares with respect to flight frequencies

$$\frac{\partial s_{jt}}{\partial f_{l'r'c}} \quad = \quad \int s_{ijt} \left(\kappa_{ijt}^{l'r'c} - \sum_{n=1}^{J_t} \kappa_{int}^{l'r'c} s_{int} \right) dP_\nu(\nu_i) dP_L(L_i) dP_Y(y_i)$$

where

$$\kappa_{i\Theta t}^{l'r'c} = \alpha_{ip} \frac{\partial p^*_{\Theta t}}{\partial f_{l'r'c}} + \frac{1}{e_{\Theta t}} \left(\alpha_f \mathbb{1}\{ r_{\Theta t} = r' \ \cap \ \Theta \in \mathcal{J}_{ct} \ \cap \ l_{\Theta t} = l' \} + \alpha_d \frac{\partial D_l}{\partial f_{l'r'c}} \right)$$

for $\Theta \in \{j, n\}$.

return

Estimation Procedure: GMM Discussion

BLP Set of Moments

- Match the predited market shares with observed data

$$s_{jt}(\delta(\theta), \cdot; \theta) = s_{jt}$$

where

$$s_{jt}(\delta(\theta), \cdot; \theta) = \frac{1}{g} \sum_{i=1}^{g} \frac{exp\left[\delta_{jt} + \mu_{ijt}\right]}{1 + \sum_{m \in J_t} exp\left[\delta_{mt} + \mu_{imt}\right]}$$

- Contraction mapping. Berry (1994)

$$\delta_{jt}^{h+1} = \delta_{jt}^{h} + ln(s_{jt}) - ln(s_{jt}(\delta(\theta), \cdot; \theta))$$

- Simulated market shares

$$\xi_{jt} = \delta_{jt} - \alpha_{peak} \hat{I}_{jt}^{peak} - \alpha_p p_{jt} - \alpha_f \hat{f}_{jt} - \alpha_d \hat{D}_{jt} - x_{jt}\beta$$

- Demand moment condition

$$E[z_{jt}^{d} \xi_{jt}] = 0$$

- Marginal cost moment condition

$$E[z_{jt}^{m} \omega_{jt}^{m}] = 0$$

Estimation Procedure: GMM Discussion

Additional Demand Information Moments

- Extra moments

$$\eta_c(\mathcal{C}, l) = E\left[L_i \in \mathcal{C} | \{i \ \ departs \ \ in \ \ l\}\right]$$

$$\eta_y(\mathcal{Y}, l) = E\left[y_i \in \mathcal{Y} | \{i \ \ departs \ \ in \ \ l\}\right]$$

where

$\mathcal{C} \in \{$S.Francisco-S.Mateo, Sta Clara, Alameda-C.Costa, Solano-Napa, Sonoma-Marin$\}$

$\mathcal{Y} \in \{<\$25k, \$25k\text{-}50k, \$50k\text{-}75k, \$75k\text{-}100k, \$100k\text{-}150k, \$150k\text{-}200k, >\$200k\}$

$$l \in \{\mathcal{L}, \mathcal{H}\}$$

- Sample analog of moments

$$\eta_c(\mathcal{C}, l) - \frac{\sum_{i=1}^{g} \sum_{\{jt | l_{jt} = l\}} s_{ijt}(\delta(\theta), \cdot; \theta) M_t \mathbb{1}\{L_i \in \mathcal{C}\}}{\sum_{i=1}^{g} \sum_{\{jt | l_{jt} = l\}} s_{ijt}(\delta(\theta), \cdot; \theta) M_t}$$

Similar for household income.

Estimation Procedure: GMM Discussion

Estimation

- Optimal 2-step GMM estimators

$$\hat{\vartheta} = arg \min_{\vartheta} \hat{G}(\vartheta)'\Phi^{-1}\hat{G}(\vartheta)$$

where

$$\vartheta = \left[\begin{array}{c} \theta \\ \gamma_m \end{array} \right]$$

- Algorithm (Nevo (2000))
    1. Solve the contraction mapping: given initial values for $\dot{\theta}$ and $\dot{\gamma}_m$, solve for $\delta(\dot{\theta})$.
    2. GMM optimization problem: given $\delta(\dot{\theta})$, solve for $\ddot{\theta}$ and $\ddot{\gamma}_m$).
    3. Iterate again until convergence is reached.

Estimation Procedure: *FCost* and β^d

- Combine Frequency F.O.C. and linear specification for undelayed flight cost equation.

$$
\begin{aligned}
&\frac{1}{92}\sum_{t\in T}\sum_{j\in\mathcal{J}_{ct}}\left[(p_{jt}-m_{jt})\frac{\partial s_{jt}}{\partial f_{l'r'c}}M_t+\frac{\partial p^*_{jt}}{\partial f_{l'r'c}}s_{jt}M_t\right]-fees\times weight_{l'r'c}-\rho_{l'}-\\
&-\frac{1}{92}\left[\sum_{r\in\Omega_c}\sum_{l\in\{L,H\}}\tilde{f}_{lrc}\left[\frac{\partial fees}{\partial f_{l'r'c}}weight_{lrc}+fees\frac{\partial weight_{lrc}}{\partial f_{l'r'c}}\right]-\frac{\partial RC_c}{\partial f_{l'r'c}}\right]=\\
&=w^f_{lrc}\gamma_f+\beta^d\left[D_l+\frac{1}{92}\sum_{r\in\Omega_c}\sum_{l\in\{\mathcal{L},\mathcal{H}\}}\tilde{f}_{lrc}\frac{\partial D_l}{\partial f_{l'r'c}}\right]+\omega^f_{lrc}
\end{aligned}
$$

- OLS estimation

return

Data and Statistics

Table : Spoke-Routes Statistics

	Off-Peak		**Peak**		**Both**	
	Mean	**Sd**	**Mean**	**Sd**	**Mean**	**Sd**
Frequency (f)	2.64	1.58	2.38	1.42	2.50	1.49
Weight(10^3 pounds)	124.86	79.66	137.94	81.81	132.07	80.87
Capacity (10^3 pounds)	290.38	250.18	336.78	311.34	315.97	285.64
Nb Spokes	49	-	56	-	58	-

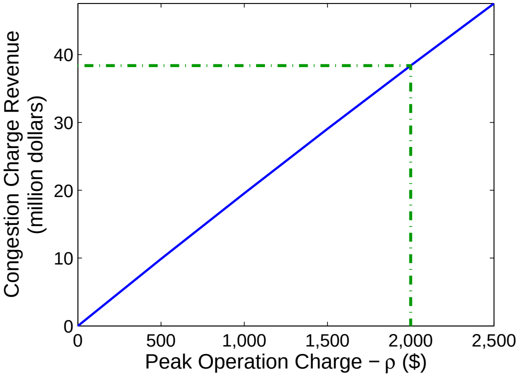
Table : Financial Information for year 2006

Weight-Based Landing Fee ($ per 10^3 pounds of MGLW)	3.213
Enplaned Passengers in 2006 (10^3)	16,574
Operating Revenues (OR) (\$$10^3$)	125,656
Groundside Revenues ($GRev$) (\$$10^3$)	57,686
$\psi_{terminal}$ **($ per passenger)**	7.580
ψ_{ground} **($ per passenger)**	3.476
Total Weight in 2006 ($TWeight$) (10^6 pounds)	20,095

return

Counterfactual: Two-Part Landing Fee

Figure : Congestion Charge Revenues (million dollars)

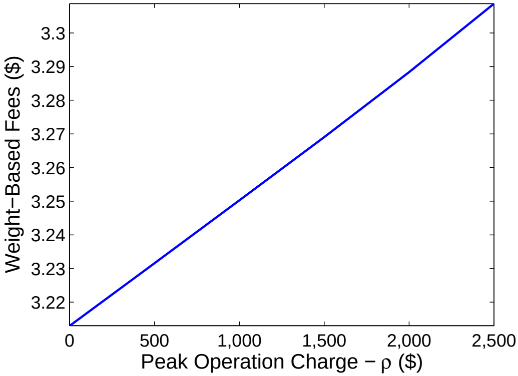


- National rebate programs (Daniel (2001)): Aircraft, miles flown, fuel taxes
- Next Generation Air Transportation System (NextGen)

return

Counterfactual: Two-Part Landing Fee

Figure : Weight-Based Fees ($)



return