Asymmetric Price Adjustments in Airlines

Diego Escobari

Department of Economics & Finance
The University of Texas-Pan American

University of Alabama
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Outline

1 Introduction
   - Motivation
   - Dynamic pricing in airlines
   - Contribution

2 Data
   - Construction
   - Realized demand

3 Empirical strategy
   - Decomposition of $\text{Price}_t$
   - Transitory component $\text{Price}_t^T$
   - Markov-switching with FTP and TVTP
   - Asymmetries specifications: $\text{SIGN}_t$, $\text{SIZE}_t$, $\text{WKNDD}_t$, and $\text{SUMM}_t$

4 Results
   - Significance of the regime-switch
   - Maximum Likelihood Estimation
   - Transitory component of price: $\text{Price}_t^T$
   - State dependent Impulse Response Functions
   - Transition probabilities

5 Conclusions
Motivation

• Large price dispersion in airlines. Borenstein and Rose (JPE 1994), Gerardi and Shapiro (JPE 2009).

• Positive demand shifts drive prices up:
  • Basic prediction of economic theory.
  • Common view among travelers and the media:

  “The inevitable outcome of limited seats and stronger demand will be higher fares.”


• Do prices fall as a response to negative demand shifts?
Potential explanations for the asymmetric response:

- Simple convex supply curve.
- Models with costly capacity and demand uncertainty: Prescott (JPE 1976), Eden (JPE 1990), Dana (Rand 1999)
- Menu costs. Mankiw (QJE 1985), Ball and Mankiw (1994)
- ‘Asymmetric pricing.’ (changes in costs) Peltzman (JPE 2000)
- Collusion / Market power.
- Uninformed consumers. Tappata (Rand 2009)
- Inventories. Borenstein and Shepard (Rand 2002)
Motivation: Dynamic pricing in airlines

- Key characteristics:
  - Fixed capacity.
  - Perishable good.
  - Aggregate demand uncertainty.
  - Advance sales.

- Carriers exploit ‘fences’ such as:
  - Saturday-night-stayover.
  - Advance purchase discounts.
  - Minimum- and maximum-stay.
  - Refundable tickets.
  - Frequent flier miles.
  - Blackouts.
  - Volume discounts.
  - Fare classes (e.g. coach, first class)

- Airlines have the most sophisticated pricing systems in the world.
Contribution of the current paper

- First to explain price variation over different departure dates.
- Finds strong evidence of an asymmetric response.
- Combines different sources of asymmetries.
- Positive cost shifts have a positive effect, but negative demand shifts have no effect on prices.
- Cost shifts have larger effect on prices during summer travel.
- Less evidence that the shifts are related to the size of the demand shift or weekend and holiday travel.
- Importance of capacity constraints as a source of asymmetric pricing.
- Importance of asymmetric pricing to stabilize demand fluctuations.
Construction of the Data

- Minimum available non-refundable fare from expedia.com.
  - Controls for more expensive refundable fares.
- 126 days (18 weeks) for 48 flights departing between Tuesday June 9 and Monday October 12, 2009. Keeping the same flight-number.
  - Controls for time-invariant specific characteristics.
- One-way, non-stop, economy-class.
  - Connecting passengers / sophisticated itineraries / legs.
  - Uncertainty in the return portion of the ticket.
  - Saturday-night-stayover / min- and max-stay.
  - Fare classes (e.g. coach, first class).
- American, Alaska, Continental, Delta, United and US Airways.
Data

**Figure:** Realized demand. Shaded areas: Weekends and holidays
Decomposition of $\text{PRICE}_t$

Decompose $\text{PRICE}_t$ into:

$$\text{PRICE}_t = \text{PRICE}^P_t + \text{PRICE}^T_t.$$  

Permanent component as a random walk with time-varying drift:

$$\text{PRICE}^P_t = \mu + \text{PRICE}^P_{t-1} + \nu_t,$$

$\nu_t$ is a normally distributed i.i.d. r.v.
Transitory component $\text{PRICE}_t^T$

Transitory component as an autoregressive process:

$$\phi(L) \cdot \text{PRICE}_t^T = \gamma_0(L) \cdot \text{COST}_t + \gamma_1(L) \cdot \text{COST}_t \cdot S_t + \varepsilon_t,$$

$$\phi(L) = \sum_{k=0}^{K} \phi_k \cdot L^k; \quad \phi_0 = 1; \quad \gamma_i(L) = \sum_{j=0}^{J} \gamma_{j,i} \cdot L^j.$$  

$S_t$ indicator variable equal to 0 or 1 to capture the regime switches in the response.

$\varepsilon_t$ normally distributed i.i.d. r.v.

Lo and Piger (2005)
Fixed transition probabilities (FTP)

First-order Markov-switching fixed transitions probabilities:

\[
\begin{align*}
P(S_t = 0|S_{t-1} = 0) &= \frac{\exp(c_0)}{1 + \exp(c_0)} \\
P(S_t = 1|S_{t-1} = 0) &= 1 - P(S_t = 0|S_{t-1} = 0) \\
P(S_t = 1|S_{t-1} = 1) &= \frac{\exp(c_1)}{1 + \exp(c_1)} \\
P(S_t = 0|S_{t-1} = 1) &= 1 - P(S_t = 1|S_{t-1} = 1)
\end{align*}
\]
Time-varying transition probabilities (TVTP)

First-order Markov-switching time-varying transitions probabilities:

\[
P(S_t = 0|S_{t-1} = 0) = \frac{\exp(c_0 + z_t' \cdot a_0)}{1 + \exp(c_0 + z_t' \cdot a_0)}
\]
\[
P(S_t = 1|S_{t-1} = 1) = \frac{\exp(c_1 + z_t' \cdot a_1)}{1 + \exp(c_1 + z_t' \cdot a_1)}
\]

Four specifications for the vector \( z_t \):

- \( z_t = (z_{1t}, z_{2t}, ..., z_{qt})' \): Vector of state variables.
- \( a_0 = (a_{01}, a_{02}, ..., a_{0q})' \): Vector of coefficients. (‘low’ response)
- \( a_1 = (a_{11}, a_{12}, ..., a_{1q})' \): Vector of coefficients. (‘high’ response)
Asymmetries specifications

Four specifications for the vector $z_t$:

- $\text{SIGN}_t = 1$, if the demand shift is positive.
- $\text{SIZE}_t = 1$, if the demand shift is more than one standard deviation away from its mean.
- $\text{WKND}_t = 1$, if the departure date is during a weekend or holiday.
- $\text{SUMM}_t = 1$, if the departure date is during the summer.
Significance of the regime-switch

- Markov-switching state-space representation:
- Significance of the regime-switch.
  - Hansen (1992): $H_0: \gamma_{j,0} = \gamma_{j,1}$ for all $j$
  - p-value of 0.01.

**Table: Model Selection**

<table>
<thead>
<tr>
<th>Elements of $z_t$</th>
<th>SIC</th>
<th>AIC</th>
<th>Log likelihood</th>
<th>LR test$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>-2.5543</td>
<td>-2.8374</td>
<td>155.7086</td>
<td></td>
</tr>
<tr>
<td>TVTP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIGN</td>
<td>-2.5205</td>
<td>-2.8551</td>
<td>158.6084</td>
<td>0.0550</td>
</tr>
<tr>
<td>SIZE</td>
<td>-2.4816</td>
<td>-2.8161</td>
<td>156.6226</td>
<td>0.4009</td>
</tr>
<tr>
<td>WKND</td>
<td>-2.4947</td>
<td>-2.8293</td>
<td>157.2945</td>
<td>0.2048</td>
</tr>
<tr>
<td>SUMM</td>
<td>-2.5256</td>
<td>-2.8601</td>
<td>158.8659</td>
<td>0.0425</td>
</tr>
</tbody>
</table>

Note: $^a$ p-value for a test of the null of the FTP.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>FTP</th>
<th>Sign</th>
<th>Size</th>
<th>Wknd</th>
<th>Summ</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_\nu$</td>
<td>0.0039</td>
<td>0.0061</td>
<td>0.0046</td>
<td>0.0008</td>
<td>0.0051</td>
</tr>
<tr>
<td></td>
<td>(0.0005)</td>
<td>(0.0037)</td>
<td>(0.0064)</td>
<td>(0.0038)</td>
<td>(0.0049)</td>
</tr>
<tr>
<td>$\sigma_\epsilon$</td>
<td>0.0472</td>
<td>0.0462</td>
<td>0.0460</td>
<td>0.0478</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>(0.0041)</td>
<td>(0.0039)</td>
<td>(0.0039)</td>
<td>(0.0039)</td>
<td>(0.0037)</td>
</tr>
<tr>
<td>$\phi_1$</td>
<td>0.1995</td>
<td>0.1235</td>
<td>0.1911</td>
<td>0.2190</td>
<td>0.1856</td>
</tr>
<tr>
<td></td>
<td>(0.1173)</td>
<td>(0.0935)</td>
<td>(0.1228)</td>
<td>(0.0137)</td>
<td>(0.0858)</td>
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<tr>
<td>$\phi_2$</td>
<td>-0.0100</td>
<td>-0.0038</td>
<td>-0.0091</td>
<td>-0.0120</td>
<td>-0.0086</td>
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<tr>
<td></td>
<td>(0.0117)</td>
<td>(0.0058)</td>
<td>(0.0117)</td>
<td>(0.0598)</td>
<td>(0.0080)</td>
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<tr>
<td>$\gamma_{0,0}$</td>
<td>0.0995</td>
<td>0.1518</td>
<td>0.0908</td>
<td>0.0861</td>
<td>0.0862</td>
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<tr>
<td></td>
<td>(0.1150)</td>
<td>(0.0966)</td>
<td>(0.1073)</td>
<td>(0.0882)</td>
<td>(0.0971)</td>
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<tr>
<td>$\gamma_{1,0}$</td>
<td>-0.1122</td>
<td>-0.1390</td>
<td>-0.1288</td>
<td>-0.1098</td>
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<tr>
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<td>(0.0954)</td>
<td>(0.0879)</td>
<td>(0.0948)</td>
<td>(0.0929)</td>
<td>(0.0913)</td>
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<tr>
<td>$\gamma_{0,1}$</td>
<td>2.4106</td>
<td>2.0317</td>
<td>2.3063</td>
<td>2.5431</td>
<td>2.2110</td>
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<tr>
<td></td>
<td>(0.5238)</td>
<td>(0.5869)</td>
<td>(0.6688)</td>
<td>(0.4653)</td>
<td>(0.5563)</td>
</tr>
<tr>
<td>$\gamma_{1,1}$</td>
<td>0.8779</td>
<td>1.5148</td>
<td>0.9326</td>
<td>0.7594</td>
<td>0.8841</td>
</tr>
<tr>
<td></td>
<td>(0.4517)</td>
<td>(0.6347)</td>
<td>(0.4614)</td>
<td>(0.4390)</td>
<td>(0.3893)</td>
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<tr>
<td>$c_0$</td>
<td>2.2963</td>
<td>21.3711</td>
<td>1.3803</td>
<td>1.7558</td>
<td>3.4565</td>
</tr>
<tr>
<td></td>
<td>(0.5620)</td>
<td>(—$^b$)</td>
<td>(0.8459)</td>
<td>(0.5647)</td>
<td>(1.0222)</td>
</tr>
<tr>
<td>$c_1$</td>
<td>0.0434</td>
<td>-0.3268</td>
<td>-0.0754</td>
<td>0.1339</td>
<td>0.8511</td>
</tr>
<tr>
<td></td>
<td>(0.4481)</td>
<td>(0.9417)</td>
<td>(1.9404)</td>
<td>(0.9612)</td>
<td>(0.7516)</td>
</tr>
<tr>
<td>$a_{01}$</td>
<td>-9.6909</td>
<td>1.0691</td>
<td>4.6457</td>
<td>-8.0797</td>
<td>—$^b$</td>
</tr>
<tr>
<td></td>
<td>(0.5538)</td>
<td>(1.2950)</td>
<td>(1.6140)</td>
<td>(1.2852)</td>
<td>—$^b$</td>
</tr>
<tr>
<td>$a_{02}$</td>
<td>-10.7071</td>
<td>1.0616</td>
<td>19.8223</td>
<td>5.2679</td>
<td>—$^b$</td>
</tr>
<tr>
<td></td>
<td>(—$^b$)</td>
<td>(1.2449)</td>
<td>(—$^b$)</td>
<td>(—$^b$)</td>
<td>—$^b$</td>
</tr>
</tbody>
</table>

Log likelihood  155.7086  158.6084  156.6226  157.2945  158.8659

Note: The ML estimate of $c_0$ appears on the boundary, violating regularity conditions. Hence, to calculate the standard errors, $c_0 = 0$ was imposed to calculate the second derivatives of the log likelihood.
Positively skewed $\text{PRICE}_t$

Figure: $\text{PRICE}_t$. Shaded areas: $\text{SIGN}_t = 1$
State dependent Impulse Response Functions

- Simulate the path of $\text{Price}_t^T$ as captured by: $\hat{\gamma}_{0,0}$, $\hat{\gamma}_{1,0}$, $\hat{\gamma}_{0,1}$, and $\hat{\gamma}_{1,1}$.
- $\text{Price}_{t-1}^T = \text{Price}_{t-2}^T = 0$, $\varepsilon_{t+j} = 0$, $\forall j$ and $\text{Cost}_{t-j} = 0$, $j \neq 0$.
- $\text{Cost}_t = 5.5\%$

Figure: State dependent IRF of $\text{Price}_t^T$. TVTP: SIGN
Transition Probabilities

- Determine the transition probabilities as captured by:
  \[ \hat{c}_0, \hat{c}_1, \hat{a}_{01} \text{ and } \hat{a}_{02} \]

- When \( \text{SIGN}_{t-1} = \text{SIGN}_t = 0 \):
  \[
P(S_t = 0 | S_{t-1} = 0) = \frac{\exp(\hat{c}_0)}{1 + \exp(\hat{c}_0)} = 1
  \]
  \[
P(S_t = 1 | S_{t-1} = 0) = 0
  \]

- When \( \text{SIGN}_{t-1} = \text{SIGN}_t = 1 \):
  \[
P(S_t = 0 | S_{t-1} = 0) = \frac{\exp(\hat{c}_0 + \hat{a}_{01} + \hat{a}_{02})}{1 + \exp(\hat{c}_0 + \hat{a}_{01} + \hat{a}_{02})}
  \]
  \[= 0.726 \]
  \[
P(S_t = 1 | S_{t-1} = 0) = 0.274
  \]

- Positive demand shifts are more likely to have a large effect on prices than negative demand shifts.
Filtered probability, $P(S_t = 1|t)$. TVTP: $\text{SIGN}$

**Figure:** Filtered probability, $P(S_t = 1|t)$. TVTP: $\text{SIGN}$. Shaded areas: $\text{SIGN}_t = 1$
Filtered probability, $P(S_t = 1|t)$. TVTP: $\text{SUMM}$

**Figure:** Filtered probability, $P(S_t = 1|t)$. TVTP: $\text{SUMM}$. Shaded areas: $\text{SUMM}_t = 1$
Combined Asymmetries

- Combined asymmetries.
- Robustness of the SUMM specification.
- Variation within the summer departure dates.

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<tr>
<td>SUMM, WKND</td>
</tr>
<tr>
<td>SUMM, SUMM×SIGN</td>
</tr>
<tr>
<td>SUMM, SUMM×SIZE</td>
</tr>
<tr>
<td>SUMM, SUMM×WKND</td>
</tr>
</tbody>
</table>

Note: $^a$ p-value for a test of the null of the FTP model. $^b$ p-value for a test of the null of the SUMM model.
State Dependent Impulse Response Functions

State dependent IRF.

Figure: State dependent IRF of $P_{RICE_t^T}$. TVTP: $SUMM, SIGN \times SUMM$
Filtered probability, $P(S_t = 1|t)$

**Figure**: Filtered probability, $P(S_t = 1|t)$. TVTP: \( \text{SUMM}, \text{SIGN} \times \text{SUMM} \). Shaded areas: \( \text{SIGN}_t \times \text{SUMM}_t = 1 \)
Conclusions

- Strong evidence of response asymmetries.
- Prices are more sensitive to demand fluctuations during summer.
- Positive demand shifts are more likely to have a positive effect.
- Importance of capacity constraints as a source of ‘asymmetric pricing.’
- Importance of pricing to stabilize demand fluctuations.
- Results are consistent with:
  - Simple convex supply curve.
  - Menu cost models. Ball and Mankiw (1994)