Frequency of Price Adjustment and Pass-through

Gita Gopinath
Harvard and NBER

Oleg Itskhoki
Harvard

CEFIR/NES
March 11, 2009
Motivation

- Micro-level studies document significant heterogeneity in the frequency of price adjustment

- Primitive determinants of frequency are difficult to measure:
  - Menu Costs
  - Volatility of Shocks
  - Curvature of the Profit Function

- International data provides an observable cost shock — exchange rate shock

- Pass-through of cost shocks are shaped by some of the same primitives that determine frequency

- Study the link between frequency and pass-through to:
  1. Sources of variation in frequency / transmission of shocks
  2. Evidence of real rigidities
  3. Test theories of price setting
Motivation

• Micro-level studies document significant heterogeneity in the frequency of price adjustment

• Primitive determinants of frequency are difficult to measure
  — Menu Costs
  — Volatility of Shocks
  — Curvature of the Profit Function

• International data provides an observable cost shock — exchange rate shock

• Pass-through of cost shocks are shaped by some of the same primitives that determine frequency

• Study the link between frequency and pass-through to:
  1. Sources of variation in frequency / transmission of shocks
  2. Evidence of real rigidities
  3. Test theories of price setting
Motivation

• Micro-level studies document significant heterogeneity in the frequency of price adjustment

• Primitive determinants of frequency are difficult to measure
  — Menu Costs
  — Volatility of Shocks
  — Curvature of the Profit Function

• International data provides an observable cost shock — exchange rate shock

• Pass-through of cost shocks are shaped by some of the same primitives that determine frequency
Motivation

- Micro-level studies document significant heterogeneity in the frequency of price adjustment

- Primitive determinants of frequency are difficult to measure
  - Menu Costs
  - Volatility of Shocks
  - Curvature of the Profit Function

- International data provides an observable cost shock — exchange rate shock

- **Pass-through** of cost shocks are shaped by some of the same primitives that determine frequency

- Study the link between frequency and pass-through to:
  1. Sources of variation in frequency / transmission of shocks
  2. Evidence of real rigidities
  3. Test theories of price setting
What we do

- Document a positive relation between frequency and “long-run” pass-through (LRPT)

\[ LRPT^{HighFreq} \approx 2 \times LRPT^{LowFreq} \]

- LRPT increases from 15% to 75% from first to tenth frequency deciles
What we do

• Document a positive relation between frequency and “long-run” pass-through (LRPT)

\[ LRPT^{HighFreq} \approx 2 \times LRPT^{LowFreq} \]

— LRPT increases from 15% to 75% from first to tenth frequency deciles

• Theory: positive relation between LRPT and frequency
  — heterogeneity in mark-up variability
What we do

- Document a positive relation between frequency and “long-run” pass-through (LRPT)

\[ LRPT^{HighFreq} \approx 2 \times LRPT^{LowFreq} \]

- LRPT increases from 15% to 75% from first to tenth frequency deciles

- Theory: positive relation between LRPT and frequency
  - heterogeneity in mark-up variability

- Standard model with CES demand or exogenous frequency (e.g., Calvo) imply LRPT uncorrelated with frequency
What we do

- Document a positive relation between frequency and “long-run” pass-through (LRPT)

\[ LRPT^{HighFreq} \approx 2 \times LRPT^{LowFreq} \]

- LRPT increases from 15% to 75% from first to tenth frequency deciles

- Theory: positive relation between LRPT and frequency
  - heterogeneity in mark-up variability

- Standard model with CES demand or exogenous frequency (e.g., Calvo) imply LRPT uncorrelated with frequency

- Calibrate and simulate a dynamic menu cost model to show:
  - Variable mark-ups generate quantitatively large effects: 37% of the variation in frequency
Empirical Findings: Dataset

- BLS micro data on import prices at the dock for the U.S. (Gopinath and Rigobon, 2007)

- Monthly reported transaction prices for 55k imported items, period 1994-2004

- Data Sub-sample
  - Dollar priced goods (90% of all goods)
  - Manufactured Goods
  - Market Transactions
  - Crop Outliers
Long-Run Pass-through Estimates

- Life-long Micro-Regressions:

\[
\Delta p_{LR}^{i,c} = \alpha_c + \beta_{LR} \Delta RER_{LR}^{i,c} + \epsilon^{i,c}
\]  

\[\text{(1)}\]
Long-Run Pass-through Estimates

• Life-long Micro-Regressions:

\[ \Delta p_{LR}^{i,c} = \alpha_c + \beta_{LR} \Delta RER_{LR}^{i,c} + \epsilon^{i,c} \]  \hspace{1cm} (1)

• Aggregate Pass-through Regressions:

\[ \Delta P_{c,t} = \alpha_c + \sum_{j=0}^{n} \beta_{1,j} \Delta RER_{c,t-j} + \epsilon^{c,t} \]  \hspace{1cm} (2)

— Includes country fixed effect, SE clustered by country and 4 digit sector code.
# Life-Long Micro-Regressions

## All Countries

<table>
<thead>
<tr>
<th></th>
<th>Median Freq.</th>
<th>$\beta_{LR}$</th>
<th>$\sigma(\beta_{LR})$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.20</td>
<td>0.03</td>
<td>5111</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.39</td>
<td>0.40</td>
<td>0.05</td>
<td>5078</td>
</tr>
<tr>
<td><strong>Differentiated</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.19</td>
<td>0.04</td>
<td>2655</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.29</td>
<td>0.40</td>
<td>0.06</td>
<td>2573</td>
</tr>
</tbody>
</table>
### Life-Long Micro-Regressions

**High-Income OECD Subsample**

<table>
<thead>
<tr>
<th>Median Freq.</th>
<th>$\beta_{LR}$</th>
<th>$\sigma(\beta_{LR})$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.40</td>
<td>0.58</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Differentiated</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.26</td>
<td>0.07</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.33</td>
<td>0.58</td>
<td>0.08</td>
</tr>
</tbody>
</table>
## Life-Long Micro-Regressions

### Regions

<table>
<thead>
<tr>
<th></th>
<th>Median Freq.</th>
<th>$\beta_{LR}$</th>
<th>$\sigma(\beta_{LR})$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Japan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.31</td>
<td>0.07</td>
<td>714</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.27</td>
<td>0.62</td>
<td>0.15</td>
<td>704</td>
</tr>
<tr>
<td><strong>Euro Area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.28</td>
<td>0.09</td>
<td>972</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.33</td>
<td>0.49</td>
<td>0.09</td>
<td>980</td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.10</td>
<td>0.36</td>
<td>0.12</td>
<td>621</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.87</td>
<td>0.74</td>
<td>0.23</td>
<td>529</td>
</tr>
<tr>
<td><strong>Non HIOECD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.07</td>
<td>0.12</td>
<td>0.04</td>
<td>2031</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.36</td>
<td>0.26</td>
<td>0.06</td>
<td>2291</td>
</tr>
</tbody>
</table>
## Table: Life-long pass-through, 3 and more price changes

<table>
<thead>
<tr>
<th></th>
<th>Median Freq.</th>
<th>$\beta_{LR}$</th>
<th>$\sigma(\beta_{LR})$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Countries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.13</td>
<td>0.22</td>
<td>0.04</td>
<td>2281</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.58</td>
<td>0.44</td>
<td>0.07</td>
<td>2299</td>
</tr>
<tr>
<td>Differentiated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.11</td>
<td>0.15</td>
<td>0.07</td>
<td>1035</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.42</td>
<td>0.51</td>
<td>0.09</td>
<td>1095</td>
</tr>
<tr>
<td><strong>High-Income OECD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.12</td>
<td>0.30</td>
<td>0.07</td>
<td>1436</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.60</td>
<td>0.73</td>
<td>0.08</td>
<td>1323</td>
</tr>
<tr>
<td>Differentiated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Low Frequency</td>
<td>0.11</td>
<td>0.23</td>
<td>0.12</td>
<td>657</td>
</tr>
<tr>
<td>– High Frequency</td>
<td>0.50</td>
<td>0.77</td>
<td>0.09</td>
<td>646</td>
</tr>
</tbody>
</table>
Life-long Pass-through
Frequency Deciles, Manufactured Goods

All Countries

High Income OECD
Aggregate Pass-through Regressions
Manufactured Goods

All Countries, Manufactured Goods

High Income OECD, Manufactured Goods
Aggregate Pass-through Regressions
Differentiated Goods

- All Countries, Differentiated Goods
- High Income OECD, Differentiated Goods
Aggregate Pass-through Regressions
High-Income OECD Subsample, Differentiated Goods

The chart illustrates the aggregate pass-through for different bins over a 24-month horizon. The x-axis represents the horizon in months, ranging from 1 to 24. The y-axis measures the aggregate pass-through, ranging from 0 to 0.6.

- **Bin 1 (most inflexible)**: The blue line shows a slow and steady increase in pass-through over the horizon, reflecting less flexibility in price adjustments.
- **Bin 2**: The green line indicates a moderate increase in pass-through compared to Bin 1, showing some degree of flexibility in price adjustments.
- **Bin 3**: The red line illustrates a significant increase in pass-through, indicating higher flexibility in price adjustments.
- **Bin 4**: The teal line shows the least increase in pass-through, indicating the most inflexible behavior among the bins.

The data suggests that as the horizon increases, the aggregate pass-through also tends to increase, with Bin 1 showing the least and Bin 4 showing the most increase.
Summary Slide

Relation between Frequency and Pass-through

![Graph showing the relationship between frequency and pass-through.](image-url)
No correlation between frequency and size
## Substitutions

**Table: Substitutions**

<table>
<thead>
<tr>
<th>Decile</th>
<th>Freq</th>
<th>Life 1</th>
<th>Life 2</th>
<th>Freq sub 1</th>
<th>Freq sub 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.03</td>
<td>59</td>
<td>42</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>50</td>
<td>34</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>3</td>
<td>0.07</td>
<td>52</td>
<td>32</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>0.10</td>
<td>55</td>
<td>36</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>5</td>
<td>0.13</td>
<td>52</td>
<td>33</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>6</td>
<td>0.18</td>
<td>49</td>
<td>32</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>7</td>
<td>0.29</td>
<td>50</td>
<td>26</td>
<td>0.30</td>
<td>0.31</td>
</tr>
<tr>
<td>8</td>
<td>0.44</td>
<td>51</td>
<td>34</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>9</td>
<td>0.67</td>
<td>52</td>
<td>33</td>
<td>0.67</td>
<td>0.68</td>
</tr>
<tr>
<td>10</td>
<td>1.00</td>
<td>43</td>
<td>30</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Frequency and Pass-through

### Primitive Parameters

- Mark-up Variability, $\varepsilon$
- MC Variability, $\eta$
- Cost Sensitivity to ER, $\phi$
- Menu Cost, $\kappa$
- Sizes of the Shocks, $\sigma_a$

Pass-through

Frequency
Frequency and Pass-through

Primitive Parameters

- Mark-up Variability, $\varepsilon$
- MC Variability, $\eta$
- Cost Sensitivity to ER, $\phi$
- Menu Cost, $\kappa$
- Sizes of the Shocks, $\sigma_a$

Sources of variable mark-ups:
- Curvature of demand (e.g., Kimball demand)
- Strategic Complementarities (Atkeson and Burstein, 2005)
Analytical Model

- Static (or two period) menu cost model
- Problem of the firm
- Variable elasticity of demand
  - Extensions: (i) variable marginal costs; (ii) demand shocks
Analytical Model

• Static (or two period) menu cost model

• Problem of the firm

• Variable elasticity of demand
  – Extensions: (i) variable marginal costs; (ii) demand shocks

• Previous Literature:
  – Barro (1972)
  – Rotemberg and Saloner (1987)
  – Romer (1989)
  – Ball and Mankiw (1994)
Demand

- Demand schedule:
  \[ q = \varphi(p|\sigma, \varepsilon), \quad \sigma > 1 \quad \text{and} \quad \varepsilon \geq 0 \]

- Price elasticity of demand:
  \[ \tilde{\sigma} \equiv \tilde{\sigma}(p|\sigma, \varepsilon) = -\frac{\partial \ln \varphi(p|\sigma, \varepsilon)}{\partial \ln p} \]

- Super-Elasticity of demand:
  \[ \tilde{\varepsilon} \equiv \tilde{\varepsilon}(p|\sigma, \varepsilon) = \frac{\partial \ln \tilde{\sigma}(p|\sigma, \varepsilon)}{\partial \ln p}. \]

- Normalization: \( \tilde{\sigma}(1) = \sigma, \quad \tilde{\varepsilon}(1) = \varepsilon, \quad \varphi(1) = 1 \)

- Example (Klenow-Willis):
  \[ \varphi(p) = A\left[1 - \varepsilon \ln p\right]^{\sigma/\varepsilon} \]
Costs and Profits

• Cost Function:

\[ C(q|a, e; \phi) = (1 - a)(1 + \phi e)cq, \]

- \(a\) is idiosyncratic productivity shock
- \(e\) is a real exchange rate shock
- \(\phi \in [0, 1]\) is sensitivity to exchange rate shock ("local costs")
- \(a\) and \(e\) are independent with \(\mathbb{E}a = \mathbb{E}e = 0\) and standard deviations \(\sigma_a\) and \(\sigma_e\).

• Normalization: \(c = (\sigma - 1)/\sigma\)
Price Setting

- Firm sets price before observing shocks, $\bar{p}_0$
- After shock, can choose to adjust price to

$$p(a, e) = \arg \max_p \Pi(p|a, e), \quad \Pi(a, e) \equiv \Pi(p(a, e)|a, e)$$
Price Setting

• Firm sets price before observing shocks, \( \bar{p}_0 \)

• After shock, can choose to adjust price to

\[
p(a, e) = \operatorname{arg\ max}_p \Pi(p|a, e), \quad \Pi(a, e) \equiv \Pi(p(a, e)|a, e)
\]

• Will adjust if

\[
L(a, e) \equiv \Pi(a, e) - \Pi(\bar{p}_0|a, e) > \kappa
\]

• Region of Non-Adjustment

\[
\Delta \equiv \Delta_\kappa = \left\{ (a, e) : L(a, e) \leq \kappa \right\}
\]
Price Setting

- Firm sets price before observing shocks, $\bar{p}_0$
- After shock, can choose to adjust price to
  \[ p(a, e) = \arg\max_p \Pi(p|a, e), \quad \Pi(a, e) \equiv \Pi(p(a, e)|a, e) \]

- Will adjust if
  \[ L(a, e) \equiv \Pi(a, e) - \Pi(\bar{p}_0|a, e) > \kappa \]

- Region of Non-Adjustment
  \[ \Delta \equiv \Delta_\kappa = \left\{ (a, e) : L(a, e) \leq \kappa \right\} \]

- Initial Price:
  \[ \bar{p}_0 = \arg\max_p \mathbb{E}_\Delta \Pi(p|a, e) \approx p(0, 0) = 1 \]
Exchange Rate Pass-through

- Log Desired price:

\[ \ln p(a, e) \approx \tilde{\mu}(p) - a + \phi e + \ln c \]
Exchange Rate Pass-through

• Log Desired price:

\[
\ln p(a, e) \approx \tilde{\mu}(p) - a + \phi e + \ln c
\]

• Taylor approximation:

\[
\frac{p(a, e) - \bar{p}_0}{\bar{p}_0} \approx \Psi \cdot (-a + \phi e), \quad \Psi \equiv \frac{1}{1 - \frac{\partial \tilde{\mu}(1)}{\partial p}} = \frac{1}{1 + \frac{\varepsilon}{\sigma - 1}}
\]
Exchange Rate Pass-through

- Log Desired price:
  \[ \ln p(a, e) \approx \tilde{\mu}(p) - a + \phi e + \ln c \]

- Taylor approximation:
  \[ \frac{p(a, e) - \bar{p}_0}{\bar{p}_0} \approx \Psi \cdot (-a + \phi e), \quad \Psi \equiv \frac{1}{1 - \frac{\partial \tilde{\mu}(1)}{\partial p}} = \frac{1}{1 + \frac{\varepsilon}{\sigma - 1}} \]

- Exchange rate pass-through:
  \[ \psi_e \equiv \frac{\partial \ln p(a, e)}{\partial e} \bigg|_{a=e=0} \approx \phi \Psi = \frac{\phi}{1 + \frac{\varepsilon}{\sigma - 1}} \]

- Pass-through decreases in \( \varepsilon \) and increases in \( \phi \)
- Pass-through depends uniquely on \{\varepsilon, \phi, \sigma\}
Frequency of Price Adjustment

• Definition: probability of price adjustment

\[ \Phi = \Pr \{ (a, e) : L(a, e) > \kappa \} \]
Frequency of Price Adjustment

- Definition: probability of price adjustment

\[ \Phi = \Pr \{ (a, e) : L(a, e) > \kappa \} \]

- Approximation to the profit loss function:

\[ L(a, e) \approx \frac{1}{2} \frac{\sigma - 1}{\psi} (p(a, e) - \bar{p}_0)^2, \]
Frequency of Price Adjustment

- Definition: probability of price adjustment

\[ \Phi = \Pr \{ (a, e) : L(a, e) > \kappa \} \]

- Approximation to the profit loss function:

\[ L(a, e) \approx \frac{1}{2} \frac{\sigma - 1}{\Psi} \left( p(a, e) - \bar{p}_0 \right)^2, \]

\[ \approx \Psi \cdot (-a + \phi e) \]
Frequency of Price Adjustment

• Definition: probability of price adjustment

\[ \Phi = \Pr \{(a, e) : L(a, e) > \kappa\} \]

• Approximation to the profit loss function:

\[ L(a, e) \approx \frac{1}{2} \frac{\sigma - 1}{\Psi} \left( p(a, e) - \bar{p}_0 \right)^2, \]

\[ \approx \Psi \cdot (-a + \phi e) \]

\[ = \frac{1}{2} (\sigma - 1) \Psi (-a + \phi e)^2, \]

– Recall that \( \Psi = 1/[1 + \frac{\varepsilon}{\sigma - 1}] \)
– An increase in \( \varepsilon \) flattens out profit function
– Two effects: curvature vs. pass-through
Summary: Frequency and Pass-through

• Exchange Rate Pass-through:

\[ \psi_e = \phi \psi = \frac{\phi}{1 + \frac{\varepsilon}{\sigma - 1}} \]

• Frequency:

\[ \Phi \approx \Pr \left\{ \left| X \right| > \sqrt{\frac{2 \kappa}{(\sigma - 1)\psi \Sigma}} \right\}, \quad \Sigma \equiv \sigma_a^2 + \phi^2 \sigma_e^2, \]

- \( X \equiv (-a + \phi e)/\sqrt{\Sigma} \) is a normalized RV, e.g. \( \mathcal{N}(0, 1) \)
- Frequency increases in \( \psi, \Sigma, \sigma \) and decreases in \( \kappa \)
Summary: Frequency and Pass-through

- Exchange Rate Pass-through:

\[ \Psi_e = \phi \Psi = \frac{\phi}{1 + \frac{\varepsilon}{\sigma - 1}} \]

- Frequency:

\[ \Phi \approx \Pr \left\{ |X| > \sqrt{\frac{2}{(\sigma - 1)\Psi} \frac{\kappa}{\Sigma}} \right\}, \quad \Sigma \equiv \sigma_a^2 + \phi^2 \sigma_e^2, \]

- \( X \equiv (-a + \phi e)/\sqrt{\Sigma} \) is a normalized RV, e.g. \( \mathcal{N}(0, 1) \)

- Frequency increases in \( \Psi, \Sigma, \sigma \) and decreases in \( \kappa \)

- Positive relationship between \( \Psi_e \) and \( \Phi \) can be induced by:
  - Variation in \( \varepsilon \)
  - Variation in \( \sigma \) if \( \varepsilon > 0 \)
  - Variation in \( \phi \): limited by \( \sigma_e^2/\sigma_a^2 \)
Dynamic Model

- Dynamic menu cost model with domestic and foreign firms
- Two sources of shocks:
  - idiosyncratic productivity shocks
  - exchange rate shocks (semi-aggregate)
- Wage-based real exchange rate: $E = W^*/W$
- Partial equilibrium: wage rate is given exogenously
Firms: Demand and Cost Function

- Demand: Kimball consumption aggregator in each sector

\[
\frac{1}{|\Omega|} \int_{\Omega} \psi \left( \frac{|\Omega| C_{js}}{C_s} \right) dj = 1, \quad |\Omega| = 1 + \omega
\]

- Marginal cost:

\[
MC_{jt} = \frac{W_t^{(1-\phi)} W_t^*}{A_{jt}},
\]

\(A_{jt}\) is the idiosyncratic productivity shock:

\[
a_{jt} = \rho_a a_{j,t-1} + \sigma_a u_{jt}, \quad u_{jt} \sim iid \mathcal{N}(0,1)
\]

- \(j \in \Omega, \quad |\Omega| = 1 + \omega\) firms:
  - \([0, 1]\) domestic firms with \(\phi = 0\)
  - \([1, 1 + \omega]\) foreign firms with \(\phi \in (0, 1]\)
Dynamic Price Setting

- State vector for firm $j$:
  
  $$S_{jt} = (P_{j,t-1}, A_{jt}; P_t, W_t, W^*_t)$$

- Bellman Equations for the Value of the Firm:
  
  $$V^N_j(S_t) = \Pi_{jt}(P_{j,t-1}) + E_{S_{t+1}|S_t} Q(S_{t+1}) V_j(S_{t+1})$$
  $$V^A_j(S_t) = \max_P \left\{ \Pi_{jt}(P) + E_{S_{t+1}|S_t} Q(S_{t+1}) V_j(S_{t+1}) \right\},$$
  $$V_j(S_t) = \max \left\{ V^N_j(S_t), V^A_j(S_t) - \kappa_{jt} \right\}$$

- Policy Function:
  
  $$\bar{P}_j(S_t) = \arg \max_P \left\{ \Pi_{jt}(P_{jt}) + E_{S_{t+1}|S_t} Q(S_{t+1}) V_j(S_t) \right\}$$
  $$P_{jt} = \begin{cases} 
  P_{j,t-1}, & V^N_j > V^A_j - \kappa_{jt}, \\
  \bar{P}_j, & \text{otherwise.}
  \end{cases}$$
Simulation Procedure

- Bellman Operator Iteration on a Grid:
  - Grids for $P_j$, $P$, $E$, $A$

- Simulation of Prices for $N = 12,000$ domestic and foreign firms for $T = 120$ months repeated 100 times
  - Firms have random lives in the sample with an average number of price adjustments equal to 3.5

- Two fixed point problems:
  - Price level:
    \[
    \ln P_t(E_t) = \int_{j=0}^{N} \ln P_{jt}(P_t, A_{jt}, E_t)\,dj
    \]
  - Forecasting Rule:
    \[
    \mathbb{E}_t \ln P_{t+1} = \gamma_0 + \gamma_1 \ln P_t + \gamma_2 \mathbb{E}_t \ln E_{t+1}
    \]
Baseline Calibration

Klenow and Willis (2006) specification:

\[ \psi(x) \equiv \psi'^{-1}(x) = \left[ 1 - \varepsilon \ln x \right]^{\sigma/\varepsilon}, \quad x \equiv P_{jt}/P_t \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>( \delta )</td>
<td>0.96(^{1/12} )</td>
</tr>
<tr>
<td>Menu Cost</td>
<td>( \kappa )</td>
<td>2.5%</td>
</tr>
<tr>
<td>Exchange Rate Shock</td>
<td>( \Delta e )</td>
<td>2.5%</td>
</tr>
<tr>
<td>Idiosyncratic Shock</td>
<td>( \sigma_a )</td>
<td>8.5%</td>
</tr>
<tr>
<td></td>
<td>( \rho_a )</td>
<td>0.95</td>
</tr>
<tr>
<td>Fraction of Imports</td>
<td>( \omega/(1 + \omega) )</td>
<td>16.7%</td>
</tr>
<tr>
<td>Cost Sensitivity to ( W^* )</td>
<td>( \phi )</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Frequency and Pass-through

Variation in $\varepsilon \in [0, 40]$
Frequency and Pass-through
Import Prices vs. Consumer Prices

![Graph showing frequency and pass-through for different groups: Importers, All Firms, Domestic. The x-axis represents frequency, and the y-axis represents pass-through. The graph illustrates the relationship between frequency and pass-through for various firm categories.](image-url)
Aggregate Pass-through Regressions

Varying $\varepsilon$

![Graph showing aggregate pass-through varying $\varepsilon$]
Frequency and Pass-through

Effect of $\phi \in [0, 1]$ and $\kappa \in [0.5\%, 7.5\%]$, $\varepsilon = 4$
Calvo

$\sigma = 5, \varepsilon = 0$

Aggregate Pass-through

High Freq: 0.28
Low Freq: 0.07

LL PT: 0.70
LL PT: 0.61

Horizon, months

0 6 12 18 24 30 36

0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

Aggregate Pass-through

Horizon, months
Calvo

\( \sigma = 5, \ \varepsilon = 4 \)
Model vs Data

Frequency and Pass-through

\[ \kappa = 5\% \]
\[ \kappa = 1\% \]
\[ \kappa = 2.5\% \]

Data

Life-long Pass-through

Frequency
Model vs Data
Frequency and Pass-through

![Graph showing Model vs Data comparison](image)
Model vs Data

Frequency and Size

Only $\epsilon$

Only $\kappa$

$\epsilon$ and $\kappa$

Data

Frequency

Size
### Model vs Data

#### Summary

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Variation in $\varepsilon$</th>
<th>Variation in $\kappa$</th>
<th>Variation in $\varepsilon$ and $\kappa$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope(Freq., LRPT)</td>
<td>0.56</td>
<td>1.86</td>
<td>0.03</td>
<td>0.55</td>
</tr>
<tr>
<td>Min LRPT</td>
<td>0.06</td>
<td>0.13</td>
<td>0.44</td>
<td>0.22</td>
</tr>
<tr>
<td>Max LRPT</td>
<td>0.72</td>
<td>0.76</td>
<td>0.46</td>
<td>0.57</td>
</tr>
<tr>
<td>Slope(Freq., size)</td>
<td>-0.01</td>
<td>0.23</td>
<td>-0.15</td>
<td>-0.05</td>
</tr>
<tr>
<td>Min size</td>
<td>5.4%</td>
<td>3.8%</td>
<td>4.8%</td>
<td>5.8%</td>
</tr>
<tr>
<td>Max size</td>
<td>7.4%</td>
<td>11.8%</td>
<td>12.2%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Std. dev. of Freq.</td>
<td>0.30</td>
<td>0.11</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>Min freq.</td>
<td>0.03</td>
<td>0.07</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Max freq.</td>
<td>1.00</td>
<td>0.44</td>
<td>0.59</td>
<td>0.61</td>
</tr>
</tbody>
</table>
Conclusion

• Exploit the open economy context to understand frequency and dynamic response to cost shocks

• Document a positive relationship between LRPT and frequency:
  – As frequency increases from 0.03 to 1, pass-through increases from 0.15 to 0.75

• Models with incomplete pass-through and endogenous frequency choice are consistent with this pattern, while standard CES-Calvo framework is not

• Variable mark-ups generate quantitatively large variation in frequency
Pass-through and Currency Choice

![Graph showing pass-through over time for non-dollar, aggregate, and dollar currencies](image-url)