Price Trends over the Product Life Cycle and the Optimal Inflation Target

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1 The opinions expressed in this presentation are those of the authors and do not necessarily reflect the views of the Deutsche Bundesbank or the Eurosystem.
Introduction

Micro data from modern economies show high rates of product turnover

- Nakamura & Steinsson 2008: Micro data underlying U.S. CPI
- Broda & Weinstein 2010: Product data at barcode level

Work on endogenous growth emphasizes role of product turnover & life cycles in the *real economy* since long (e.g., Aghion & Howitt 1992)

This paper analyzes role of product life cycles in the *monetary economy*

1. provides new facts on trends in relative prices over product life cycle
2. shows how ”relative price trends” determine optimal inflation target $\Pi^*$
1. Product prices decline with product age, relative to average price in narrow expenditure category
   - *In relative terms*, newly entering products tend to be expensive, but become cheaper once they age

2. Substantial heterogeneity in age trends across expenditure categories
   - E.g., strongly negative age trends in items with "news value" (fashion)

3. Downward trend in relative prices accelerated over past two decades
Proposition: Estimated age trend in relative price $P_{jt}/P_t$ is efficient

- Holds in sticky price model with suboptimal inflation and shocks
- Price stickiness distorts level, but not age trend, of relative price

$\infty$ many ways to arrive at estimated age trend in $P_{jt}/P_t$

- Declining $P_{jt}$, increasing $P_t$, or any combination thereof

Optimal way to implement estimated age trend is positive $\Pi^*$

- Changes in $P_{jt}$ distortive $\implies$ $P_{jt}$ constant
  $\implies$ $P_t$ should increase at inverse rate of age trend
$P_t$ increases as newly entering products charge high relative prices...
Monetary policy tradeoff underlying choice of $\Pi^*$

- Estimated age trend in rel prices varies across expenditure categories
  $$\implies$$ optimal inflation $\Pi_z^*$ varies across categories

- In sticky price model with prod life cycle, tradeoff optimally resolved as
  $$\Pi^* \approx \text{expenditure-weighted average of } \Pi_z^*'s$$

Estimate $\Pi^*$ using U.K. micro price data

- $\Pi^*$ estimate ranges from 2.6% to 3.2% in 2016
- $\Pi^*$ estimate increases by around 1.2% between 1996 and 2016
1. U.K. Evidence on Age Trends in Relative Product Prices
2. Sticky Price Model with Product Life Cycles
3. Estimation Results for Optimal Inflation Target
Estimating Age Trends in Relative Product Prices

Employ U.K. micro price data underlying official U.K. CPI

Each product $j$ classified into one of $\approx 1100$ item (expenditure) categories

For each item category $z$, estimate linear panel regression

$$\ln \frac{\tilde{P}_{jzt}}{P_{zt}} = f_{jz} + \ln (b_z) \cdot s_{jzt} + u_{jzt}$$  \hspace{1cm} (1)

- $\tilde{P}_{jzt} =$ nominal price of product $j$ in item $z$
- $P_{zt} =$ *quality adjusted* price index for item $z$
- $s_{jzt} =$ in-sample product age (zero at entry date)
- $b_z =$ common age trend (w/o product turnover, must have $b_z = 1$)
Kryvtsov & Vincent 2017; Blanco 2018; Marencak & Hahn 2019

Monthly sample from Feb 1996 - Dec 2016, 29 million price quotes

Drop ”invalid” & ”duplicate” (not uniquely identified) quotes

Replicate official item indices (q adj, weights) excl duplicates

Follow same product over time to estimate age trends

Split price trajectory of uniquely identified product at (i) substitution flags and (ii) observation gaps larger than one month

Baseline sample: $Z = 1093$ items, 21.2 million price quotes
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Products per Item</strong></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>925</td>
</tr>
<tr>
<td>Mean</td>
<td>1523.5</td>
</tr>
<tr>
<td><strong>Number of Price Quotes per Item</strong></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>14846</td>
</tr>
<tr>
<td>Mean</td>
<td>18739</td>
</tr>
<tr>
<td><strong>Length of Price Spell per Product (Months)</strong></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>9</td>
</tr>
<tr>
<td>Mean</td>
<td>14.5</td>
</tr>
<tr>
<td>Item Description</td>
<td>Relative Price Change (in % per year)</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td><strong>Relative Price Increase</strong></td>
<td></td>
</tr>
<tr>
<td>HIFI - 2007</td>
<td>3.28</td>
</tr>
<tr>
<td>WIDESCREEN TV - 2005</td>
<td>2.55</td>
</tr>
<tr>
<td>CAMCORDER-8MM OR VHS-C</td>
<td>2.34</td>
</tr>
<tr>
<td>WASHING MACHINE - 2008</td>
<td>1.82</td>
</tr>
<tr>
<td>WASHING MACH NO DRYER MAX 1800</td>
<td>1.48</td>
</tr>
<tr>
<td>LEISURE CENTRE ANNUAL MSHIP</td>
<td>1.34</td>
</tr>
<tr>
<td>COOKED HAM PREPACKED/SLICED</td>
<td>0.84</td>
</tr>
<tr>
<td><strong>Relative Price Decline</strong></td>
<td></td>
</tr>
<tr>
<td>MENS SHOES TRAINERS</td>
<td>-7.84</td>
</tr>
<tr>
<td>PRE-RECORDED DVD TOP 20</td>
<td>-8.14</td>
</tr>
<tr>
<td>WOMENS SUIT</td>
<td>-8.95</td>
</tr>
<tr>
<td>LADYS SCARF</td>
<td>-20.19</td>
</tr>
<tr>
<td>COMPUTER GAME TOP 20 CHART</td>
<td>-21.69</td>
</tr>
<tr>
<td>WOMENS DRESS-CASUAL 1</td>
<td>-25.55</td>
</tr>
<tr>
<td>PRE-RECORDED DVD (FILM)</td>
<td>-35.03</td>
</tr>
</tbody>
</table>
A. Monthly Product Turnover Rate

B. Monthly Frequency of Price Changes

C. Stdev of Product-Fixed Effects

D. Expenditure Weight
Augmented version of one-sector model in Adam & Weber 2019

- Many expenditure items $z = 1, \ldots, Z_t$, exogenous item turnover
- Item-specific product life cycles driven by quality & productivity
  - **Product quality ”frontier”** $Q_{zt}$ evolves stochastically over time
  - **Product quality** $Q_{jzt}$ set at entry and constant thereafter
  - **Productivity** $G_{jzt}$ evolves dynamically over product life
- Idiosyn entry / exit shock yields **stochastic product life time**
Relative Price Trends over Product Life Cycle

Calvo-type pricing frictions

- At time of product entry, firm can freely choose product price
- Subsequently, firm faces item-specific price stickiness

Quality adj **optimal reset price** $P^*_{jzt} \equiv \tilde{P}^*_{jzt} / Q_{jzt}$ has two components:

$$\frac{P^*_{jzt}}{P_{zt}} = \left( \frac{Q_{jzt} G_{jzt}}{Q_{zt}} \right)^{-1} \times \left( \frac{\theta}{\theta - 1} \frac{1}{1 + \tau} \right) \frac{n_{zt}}{d_{zt} \rho_{zt}}$$

- Life cycle dynamics
- Stationary forward-looking comp

- Price stickiness only distorts fwd-looking comp $\implies$ level of $P^*_{jzt} / P_{zt}$
- $n_{zt}, d_{zt}$ are stationary exp disc marginal costs & revenues
Life Cycle Dynamics in Productivity

- Output *quantity* of product $j$ in item $z$

$$\tilde{Y}_{jzt} = A_{zt} G_{jzt} \left( K_{zjt}^{1-\frac{1}{\phi}} L_{zjt}^{\frac{1}{\phi}} \right)$$

- Product-specific TFP ("experience"):  

$$G_{jzt} = \overline{G}_{jzt} \cdot \epsilon^G_{jzt}, \quad \epsilon^G_{jzt} \sim \Xi^G_z \text{ drawn at entry, then constant}$$

$$\overline{G}_{jzt} = \begin{cases} 1 \\ g_{zt} \cdot \overline{G}_{jz,t-1} \end{cases} \text{ for age } s_{jzt} = 0,$$

$$g_{zt} = g_z \cdot \epsilon^g_{zt}, \quad \epsilon^g_{zt} := \text{stationary with } E \ln \epsilon^g_{zt} = 0$$

- Asspts Quality
Consider a stochastic economy with potentially suboptimal inflation $\Pi_t$. In price adjustment periods, the **optimal reset price** satisfies

$$\ln \frac{P_{jzt}^*}{P_{zt}} = f_{jz}^* - \ln \left( \frac{g_z}{q_z} \right) \cdot s_{jzt} + u_{jzt}^*, \quad (2)$$

where $s_{jzt}$ is product age and $u_{jzt}^*$ a stationary residual with $E[u_{jzt}^*] = 0$.

- Despite sticky prices, age trend only due to life cycle in productivity $g_z$ and quality $q_z$:
  - Sticky-price firm has profit incentive to track **flex-price trend**

- Eqn (2) resembles previous regression (but: reset vs all prices, q adj):
  - **Estimated age trends** in U.K. data are estimates of $g_z / q_z$!
Corollary

The optimal inflation rate that maximizes steady-state welfare is equal to

\[ \Pi^* = \sum_{z=1}^{Z} \psi_z \left( \frac{g_z}{q_z} \gamma_z \gamma \right) + \mathcal{O}(2), \]

where \( \psi_z \) is spending share and \( \gamma_z / \gamma \) relative growth of item \( z \).

1. **Optimality**: \( P_{zt} = \) inverse age trend \( \implies \Pi^*_z = g_z / q_z \)

2. **New policy tradeoff**: One instrument \( \Pi^* \) but many different \( \Pi^*_z \)'s
   - Wolman 2011 studies related tradeoff in model with \( g_z / q_z = 1 \)

3. **Estimation**: Age trends in relative prices in U.K. data inform \( \Pi^* \)
   - Allow for item turnover \( Z_t \implies \) gradual time variation in \( \Pi^* \)
Baseline Results - $\Pi^\star$ Estimate Using All Prices

A. Optimal U.K. Inflation Target

B. Item-Level Optimal Inflation Rates

$\Pi^\star_z = g_z/q_z$ in % per year (truncated)
\( \Pi^* \) Estimate Using All Prices (Baseline) vs Reset Prices

![Graph showing baseline estimate and reset-price estimate over time.](image-url)
A. Dynamic Olley-Pakes Decomposition

- $\Pi_t^* - \Pi_{1996}^*$
- Blue line: Continuing since 1996
- Red line: Entering since 1996
- Black line: Exiting since 1996

B. Number of Items

- Red line: Number of continuing items
- Green line: Number of entering items
- Black line: Number of exiting items
Conclusions

Provided new evidence from U.K. micro price data that

- relative product prices decline with product age
- age trends differ widely across expenditure categories

Showed that age trends determine optimal inflation target \( \Pi^* \):

- New monetary policy tradeoff underlying choice of \( \Pi^* \)
- For U.K. data, \( \Pi^* \) estimates in 2016 range from 2.6% to 3.2%
- \( \Pi^* \) estimate increased by 1.2% between 1996 and 2016
Relevance of Weighting Scheme for Estimated $\Pi^*$
### Table: Number of Price Quotes and ONS Product Identifiers

<table>
<thead>
<tr>
<th>Description</th>
<th>Price Quotes</th>
<th>ONS Product Identifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price quotes in raw data</td>
<td>28,995,064</td>
<td>736,078</td>
</tr>
<tr>
<td>Price quotes excluding duplicate quotes</td>
<td>24,525,632</td>
<td>687,212</td>
</tr>
<tr>
<td>Price quotes excluding duplicate &amp; invalid quotes</td>
<td>22,825,052</td>
<td>682,747</td>
</tr>
<tr>
<td>Price quotes w/o duplicate &amp; invalid quote for replicated items</td>
<td>21,215,430</td>
<td>613,031</td>
</tr>
</tbody>
</table>
**Table: Substitution & Turnover Rates: Products and Product Identifiers**

<table>
<thead>
<tr>
<th>Substitution within ONS Product Identifiers</th>
<th>Monthly Rate in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparable substitutions</td>
<td>5.74</td>
</tr>
<tr>
<td>Non-comparable substitutions</td>
<td>0.31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Turnover for ONS Product Identifiers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry rate</td>
<td>2.44</td>
</tr>
<tr>
<td>Exit rate</td>
<td>2.44</td>
</tr>
</tbody>
</table>
Mean increases by 2.3% reflecting aggr inflation (2% in sample)

Melser & Syed 2016: Mixed evidence for nominal product prices
<table>
<thead>
<tr>
<th>Division Description</th>
<th>Relative Price Trend (in % per year)</th>
<th>Exp. Weight in 2016 (in %)</th>
<th>Number of Items (full smpl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food &amp; Non-Alcoholic Beverages</td>
<td>-1.00</td>
<td>18.07</td>
<td>282</td>
</tr>
<tr>
<td>Alcoholic Beverages &amp; Tobacco</td>
<td>-0.41</td>
<td>8.03</td>
<td>66</td>
</tr>
<tr>
<td>Clothing &amp; Footwear</td>
<td>-9.36</td>
<td>11.92</td>
<td>149</td>
</tr>
<tr>
<td>Housing, Water, Electricity &amp; Gas</td>
<td>-0.83</td>
<td>0.75</td>
<td>38</td>
</tr>
<tr>
<td>Furniture, Equip. &amp; Maintenance</td>
<td>-1.67</td>
<td>9.98</td>
<td>146</td>
</tr>
<tr>
<td>Health</td>
<td>-0.73</td>
<td>3.82</td>
<td>26</td>
</tr>
<tr>
<td>Transport</td>
<td>-0.79</td>
<td>6.99</td>
<td>41</td>
</tr>
<tr>
<td>Communications</td>
<td>-6.97</td>
<td>0.11</td>
<td>7</td>
</tr>
<tr>
<td>Recreation &amp; Culture</td>
<td>-3.98</td>
<td>9.44</td>
<td>157</td>
</tr>
<tr>
<td>Restaurants &amp; Hotels</td>
<td>-0.36</td>
<td>18.82</td>
<td>79</td>
</tr>
<tr>
<td>Miscellaneous Goods &amp; Services</td>
<td>-1.68</td>
<td>12.54</td>
<td>90</td>
</tr>
</tbody>
</table>
Optimal Quality-Adjusted Reset Price

\[
\frac{P^*_{jzt}}{P_{zt}} = \left( \frac{Q_{jzt} G_{jzt}}{Q_{zt}} \right)^{-1} \left( \frac{\theta}{\theta - 1} \frac{1}{1 + \tau} \right) \frac{N_{zt}}{D_{zt}} \frac{P_t}{P_{zt}}
\]

\[
N_{zt} = \frac{MC_t}{P_t A_{zt} Q_{zt}} + \alpha_z (1 - \delta_z) E_t [\Omega_{t, t+1} \Pi_{z, t+1}^{\theta-1} \Pi_{t+1} \left( \frac{Y_{t+1}}{Y_t} \right) \left( \frac{q_{z, t+1}}{g_{z, t+1}} \right) N_{z, t+1}]
\]

\[
D_{zt} = 1 + \alpha_z (1 - \delta_z) E_t [\Omega_{t, t+1} \Pi_{z, t+1}^{\theta-1} \left( \frac{Y_{t+1}}{Y_t} \right) D_{zt+1}]
\]

with marginal costs $MC_t$; discount factor $\Omega_{t, t+1}$; output subsidy $\tau$
Life Cycle Dynamics in Product Quality

$$C_{zt} = \left( \int_{0}^{1} \left( Q_{jzt} \tilde{C}_{jzt} \right)^{\frac{\theta-1}{\theta}} \, dj \right)^{\frac{\theta}{\theta-1}}$$

- Quality of a new product \( j \) entering in time \( t \) is

\[ Q_{jzt} = Q_{zt} \cdot \epsilon_{jzt}^{Q}, \quad \epsilon_{jzt}^{Q} \sim \Xi_{z}^{Q} \] drawn at entry, then constant

- Quality of product \( j \) stays constant over product life,

\[ Q_{jzt} = Q_{jz,t-s_{jzt}} \quad \text{with} \quad s_{jzt} := \text{product age} \]

- Quality "frontier" evolves as

\[ Q_{zt} = q_{zt} Q_{zt-1} \quad \text{with} \quad q_{zt} = q_{z} \epsilon_{zt}^{q} \]

\( q_{z} := \text{mean quality growth}; \epsilon_{zt}^{q} := \text{stationary with} \ E \ln \epsilon_{zt}^{q} = 0 \)
Theorem

Assume $-1 < \tau \leq 1/(\theta - 1)$ and consider the limit $\beta(\gamma)^{1-\sigma} \to 1$. Then, the welfare maximizing steady-state inflation rate is given by

$$\Pi^* = \sum_{z=1}^{Z} \omega_z \left( \frac{g_z \gamma_z}{q_z \gamma} \right),$$

(3)

where $\gamma_z / \gamma = a_z q_z / \prod_{z=1}^{Z} (a_z q_z)^{\psi_z}$ and weights $\omega_z \geq 0$ are given by

$$\omega_z = \frac{\tilde{\omega}_z}{\sum_{z=1}^{Z} \tilde{\omega}_z}, \text{ where}$$

$$\tilde{\omega}_z = \theta \psi_z \alpha_z (1 - \delta_z) \left( \frac{\gamma}{\gamma_z} \Pi^* \right)^{\theta} \left( \frac{g_z}{q_z} \right)^{-1} \left[ 1 - \alpha_z (1 - \delta_z) \left( \frac{\gamma}{\gamma_z} \Pi^* \right)^{\theta-1} \right].$$
Define *not* quality adjusted item price level

\[
\tilde{P}_{zt} = \left( \int_0^1 (\tilde{P}_{jzt})^{1-\theta} dj \right)^{\frac{1}{1-\theta}}
\]

Show \( \tilde{\Pi}_z = q_z \Pi_z \implies \tilde{\Pi}_z \) too high w/o quality adj if \( q_z > 1 \)

Estimate *biased* age trend: \( \ln(\tilde{P}_{jzt}/\tilde{P}_{zt}) = \tilde{f}_{jz}^* - \ln(g_z) \cdot s_{jzt} \)

Set optimal target w/o quality adj: \( \ln \tilde{\Pi}^* = \sum_{z=1}^Z \psi_z \ln \left( g_z \frac{\gamma_z^e}{\gamma^e} \right) \)

This monetary policy achieves \( \ln \Pi = \ln \Pi^* \)