Price Trends over the Product Life Cycle and the Optimal Inflation Target[1]

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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

- **Estimate optimal inflation target**
- Estimation approach: estimate optimal target from micro price data
- Micro price data U.K. Office of National Statistics (ONS) : 2.8%

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- Optimal inflation: minimizes relative price & mark-up distortions in SS
- **Why positive optimal inflation target?**

  Product turnover & price trends over product life

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- Modern economies: very high rate of product turnover....

  ...but monetary literature ignored product life cycle

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  Relative product prices decline with product age

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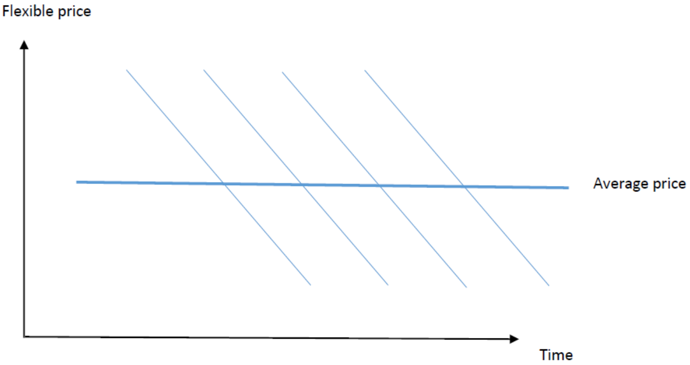
  Over the product life cycle:

  Relative product prices decline with product age

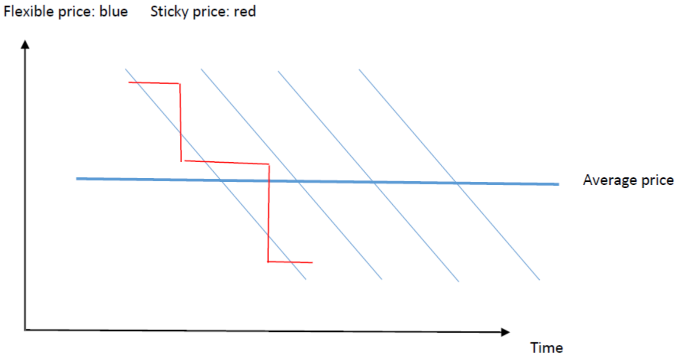
- This observation has important normative implications:

  Positive inflation target optimal!

Intuition: Fully Flexible Prices



Intuition: Sticky Prices



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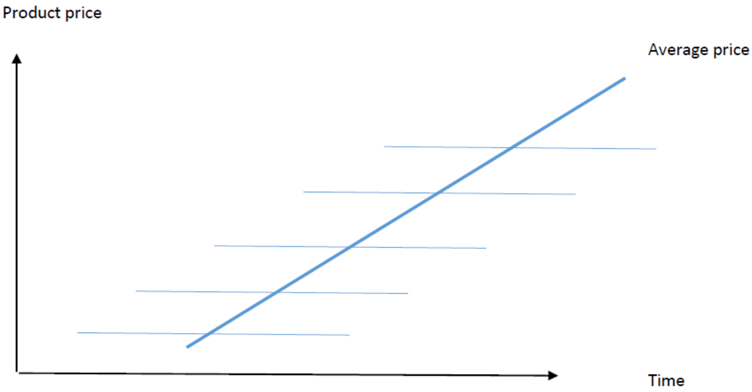

Optimal increase of average price:
inverse of the decrease in relative price on previous slides

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  Need a model to tell us how to optimally trade-off mark-up & relative price distortions across goods

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  Need a model to tell us how to optimally trade-off mark-up & relative price distortions across goods

- Construct sticky price model with a **product life-cycle**:

  - features rich amounts of heterogeneity

  - captures key features of micro price behavior

  - aggregation in closed-form & analytic expression for optimal target

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Modell tells us 2 important things:

- **Relative price trends in the data:**

  - identify rel. price trends under flex prices: a fundamental!

  - rel. price trends invariant to MP & price stickiness (generate only level istortions!)

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- **Optimal inflation rate:**

  - complicated nonlinear weighted av. of inverse relative price trends

  - to first order:

  expenditure-weighted average of inverse relative price trends

  $=>$ can be easily estimated from micro price data

Structure of the Presentation

1. New Stylized Fact
2. Key Elements of the Price Setting Model
3. Optimal Inflation Target: Theory
4. Optimal Inflation Target: Estimation Results

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

P_{zt} the average price in expenditure item z (>1000 items)

P_{jzt} price of individual product j

f_{jz} product specific intercept (unobserved quality, location, service components etc.)

s_{jzt} sample age of product j in item z at time t

b_z parameter of interest: age slope ($>$ 1000 estimates)

u_{jzt} residual

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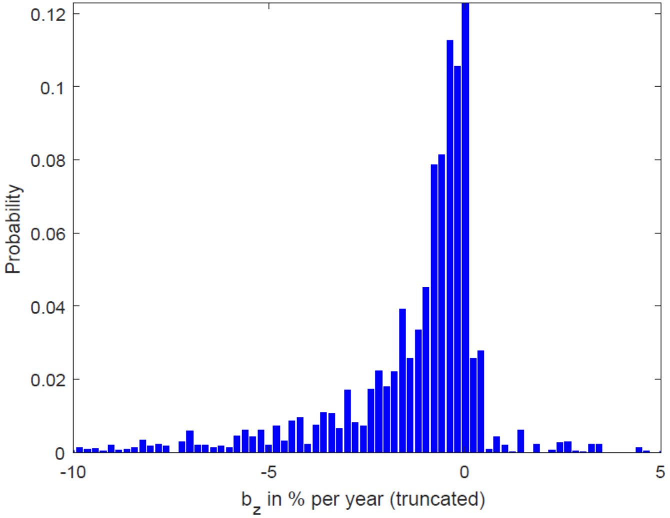
- Linear trends only

Stylized Facts: Relative Price Trends

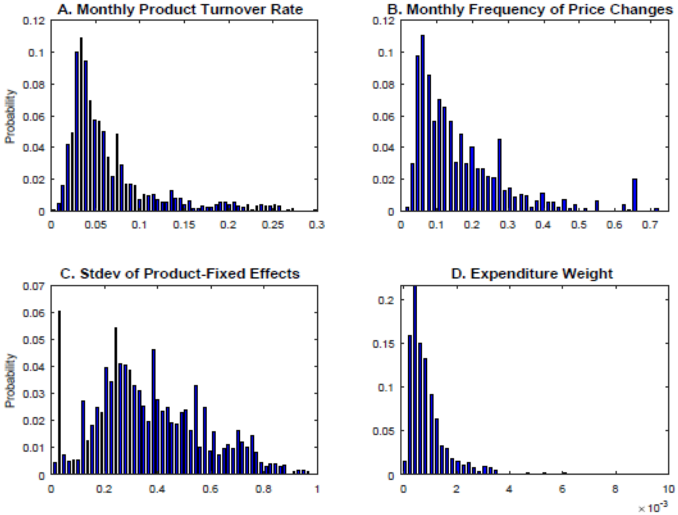


Stylized Facts: Relative Price Trends

Division Description	Relative Price Trend (in % per year)	Exp. Weight in 2016 (in %)	Number of Items (full sample)
Food & Non-Alcoholic Beverages	-1.00	18.07	282
Alcoholic Beverages & Tobacco	-0.41	8.03	66
Clothing & Footwear	-9.36	11.92	149
Housing, Water, Electricity & Gas	-0.83	0.75	38
Furniture, Equipment & Maintenance	-1.67	9.98	146
Health	-0.73	3.82	26
Transport	-0.79	6.99	41
Communications	-6.97	0.11	7
Recreation & Culture	-3.98	9.44	157
Restaurants & Hotels	-0.36	18.82	79
Miscellaneous Goods & Services	-1.68	12.54	90

Notes: The number of items does not sum to 1093 because not all items are assigned to a division.

Other Dimensions of Heterogeneity



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  - different product entry/exit rates
  - different degrees of price stickiness
  - different idiosyncratic quality/productivity dispersion

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- Monetary policy faces a trade-off (unlike in earlier work):

  impossible to implement efficient relative prices
  optimal policy trades off price & mark-up distortions across exp. items

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- Aggregation in closed form & analytic expressions for optimal inflation target

Price Setting Model

- Representative consumer, growth-consistent preferences

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\left[C_t V(L_t)\right]^{1-\sigma} - 1}{1-\sigma} \right),$$

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- Z_t expenditure items with expenditure weight ψ_{zt} :

$$C_t = \prod_{z=1}^{Z_t} (C_{zt})^{\psi_{zt}}, \quad \text{with} \sum_{z=1}^{Z_t} \psi_{zt} = 1$$

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- Expenditure items are a Dixit-Stiglitz aggregate of individual goods

$$C_{zt} = \left(\int_0^1 \left(Q_{jzt} \widetilde{C}_{jzt} \right)^{\frac{\theta-1}{\theta}} \mathrm{dj} \right)^{\frac{\theta}{\theta-1}},$$

Q_{jzt} : quality of product j in item z at time t.
$\widetilde{C}_{jzt}$: physical or not quality-adjusted units

Price Setting Model: Turnover

- Two levels at which turnover takes place in the economy
  - **Item level:** items exit/new items enter/expenditure weights change

    Example: CD-players drop out, get replaced by flash-drive devices

    Slow process: theory takes items as constant
  - **Product level:** constant entry and exit of products

    Example: particular flash-drive model exits, a new model enters

    Fast process: theory has exogenous product turnover

Price Setting Model: Product-Level Dynamics

Model features **2 types of flexible fundamental dynamics:**

- **Quality growth dynamics:** evolution of quality of new products
- **Productivity growth dynamics:** evolution of productivity over time

Quality & productivity dynamics item-specific :
generate item-specific relative price trends!

Price Setting Model: Quality Dynamics

Product quality dynamics (in item z):

- For product j entering in time t:

$$Q_{jzt} = \underbrace{Q_{zt}}_{common\, time\text{-}trend} \cdot \underbrace{\varepsilon^{Q}_{jzt}}_{idiosyncratic}$$

Price Setting Model: Quality Dynamics

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- Following entry: product quality constant over product lifetime
- The common time-trend evolves according to

$$Q_{zt} = q_z Q_{zt-1}$$

where

q_z : **mean quality growth for products in item z**

⇒ causes opt. rel. price to rise over prod. life

Price Setting Model: Productivity Dynamics

- Output of product j in item z (in physical units):

$$\widetilde{Y}_{jzt} = \underbrace{A_{zt}}_{General\ \ TFP} \cdot \underbrace{G_{jzt}}_{Product-specific\ \ TFP} \cdot (K_{zjt})^{1-\frac{1}{\phi}} (L_{zjt})^{\frac{1}{\phi}}$$

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- General TFP:

$$A_{zt} = a_z A_{zt-1}$$

- Product specific TFP:

  - at time of product entry: random draw $G_{jzt} \sim iiG_z$
  - **experience accumulation over the product life:**

$$G_{jzt} = g_z G_{jzt-1}$$

g_z : **mean experience prod. growth for products in item z**

$\Rightarrow$ **causes rel. prices to fall over prod. life**

Price Setting Model: Productivity Dynamics

- Model with Calvo-type price setting frictions at the product level
  - At time of product entry: firms can freely choose product price
  - Subsequently: *item-specific* stickiness $\alpha_z \in [0, 1)$
- Abstract from temporary/sales prices in presentation

Price Setting Model: Quality-Adjusted Prices

- Quality-adjusted product price

$$P_{jzt} = \frac{\widetilde{P}_{jzt}}{Q_{jzt}}$$

$\widetilde{P}_{jzt}$: price per physical unit

- In line with ONS, quality-adjusted price indices

$$\textit{Item Price Index} \quad : \quad P_{zt} = \left(\int_0^1 \left(\frac{\widetilde{P}_{jzt}}{Q_{jzt}} \right)^{1-\theta} \mathrm{dj} \right)^{\frac{1}{1-\theta}}$$

$$\textit{General Price Index} \quad : \quad P_t = \prod_{z=1}^{Z_t} \left(P_{zt} \right)^{\psi_{zt}}$$

- **Optimal inflation target is for the quality-adjusted price index!**

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Steady-State Aggregation

Aggregation 'almost' like in the plain-vanilla NK model:

$$
\begin{aligned}
y &= \left(\frac{\rho(\Pi)}{\Delta^e}\right)\left(k^{1-\frac{1}{\phi}} L^{\frac{1}{\phi}}\right) \\
c\left(-\frac{\partial V(L)/\partial L}{V(L)}\right) &= \frac{1}{\mu(\Pi)}\frac{1}{\Delta^e}\left(\frac{k}{L}\right)^{1-\frac{1}{\phi}}\left(\frac{1}{\phi}\right) \\
\frac{1}{\beta\left(\gamma^e\right)^{-\sigma}} - 1 + d &= \frac{1}{\mu(\Pi)}\frac{1}{\Delta^e}\left(\frac{k}{L}\right)^{-\frac{1}{\phi}}\left(1-\frac{1}{\phi}\right) \\
y &= c + (\gamma^e - 1 + d)k.
\end{aligned}
$$

$\rho(\Pi) \leq 1$: aggregate relative price distortion
$\mu(\Pi)$: aggregate mark-up distortion

Only place where heterogeneity & inflation enter: $\rho(\Pi)$ & $\mu(\Pi)$

Steady-State Aggregation

Aggregate mark-up distortion:

$$\mu(\Pi) = \prod_{z=1}^{Z} \mu_z(\Pi)^{\psi_z},$$

where

$$\begin{aligned}\mu_z(\Pi) \equiv & \left(\frac{1}{1+\tau}\frac{\theta}{\theta-1}\right) M_z \\ & \cdot \left(\frac{1-\alpha_z(1-\delta_z)\beta(\gamma^e)^{1-\sigma}[(\gamma^e/\gamma_z^e)\,\Pi]^{\theta-1}}{1-\alpha_z(1-\delta_z)\beta(\gamma^e)^{1-\sigma}[(\gamma^e/\gamma_z^e)\,\Pi]^{\theta}(g_z/q_z)^{-1}}\right),\end{aligned}$$

for all $z = 1, \ldots Z$, with

$$M_z \equiv \left(\frac{1-\alpha_z(1-\delta_z)[(\gamma^e/\gamma_z^e)\,\Pi]^{\theta-1}}{1-\alpha_z(1-\delta_z)(g_z/q_z)^{\theta-1}}\right)^{\frac{1}{\theta-1}}.$$

Steady-State Aggregation

Aggregate relative price distortion:

$$(\rho(\Pi)\mu(\Pi))^{-1} = \sum_{z=1}^{Z} \psi_z (\mu_z(\Pi)\rho_z(\Pi))^{-1},$$

where for all $z = 1, \ldots Z$ the item-level relative price distortions $\rho_z(\Pi)$ are given by

$$\rho_z(\Pi)^{-1} = M_z^{\theta} \left(\frac{1 - \alpha_z(1-\delta_z)(g_z/q_z)^{\theta-1}}{1 - \alpha_z(1-\delta_z)[(\gamma^e/\gamma_z^e)\,\Pi]^{\theta}(g_z/q_z)^{-1}} \right).$$

Theorem

Consider the limit $\beta(\gamma)^{1-\sigma} \to 1$. The welfare maximizing steady state inflation rate is

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

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

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

$$\tilde{\omega}_z = \frac{\psi_z \theta \alpha_z (1-\delta_z)(\gamma/\gamma_z \Pi^\star)^\theta (q_z/g_z)}{\left[1 - \alpha_z(1-\delta_z)(\frac{\gamma}{\gamma_z}\Pi^\star)^\theta (\frac{q_z}{g_z})\right] \left[1 - \alpha_z(1-\delta_z)(\frac{\gamma}{\gamma_z}\Pi^\star)^{\theta-1}\right]}.$$

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

- g_z / q_z: rate at which rel. prices fall over product life with flexible prices!

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

- g_z / q_z: rate at which rel. prices fall over product life with flexible prices!
- How to identify g_z / q_z? How to get at weights ω_z?

Optimal Inflation Rate

Corollary

To a first-order approximation, we have

$$\Pi^* = \sum_{z=1}^{Z} \psi_z \left(\frac{g_z \gamma_z}{q_z \gamma} \right). \tag{2}$$

- To first order:

  Can use ONS expenditure weights ψ_z!

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- To first order:

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- Remains to identify g_z / q_z

Optimal Inflation Rate

Proposition

Consider a stochastic equilibrium with a (possibly suboptimal but) stationary inflation rate. In price adjustment periods, the optimal reset price $P^{\star}_{jzt}$ *satisfies*

$$\ln \frac{P^{\star}_{jzt}}{P_{zt}} = c_{jz} - \ln\left(\frac{g_z}{q_z}\right) \cdot s_{jzt} + e_{jzt}$$

s_{jzt} : *age of product j in item z*

c_{jz} : *product-item-specific intercept*

Optimal Inflation Rate

Economic insight:

- trend in relative reset prices (g_z / q_z) is the trend under flexible prices!
- sticky prices lead only to *temporary deviations* from the relative price trend under flexible prices
- Not special to the Calvo setup & equally true for menu-cost models:

  sS-bands limit price deviation from flex-price trend

Optimal Inflation Rate

- Can estimate the relative price trend using

$$\ln \frac{P_{jzt}}{P_{zt}} = c_{jz} - \ln \frac{g_z}{q_z} \cdot s_{jzt} + \varepsilon_{jzt}$$

ε_{jzt} : idiosyncratic effects of price stickiness & aggr. shocks

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- Estimate one trend $\frac{g_z}{q_z}$ for each item z, then aggregate according to

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- Use ONS item composition & weights at any time t

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- Use ONS item composition & weights at any time t
- Get (slowly) time-varying inflation target Π^*as items (slowly) change

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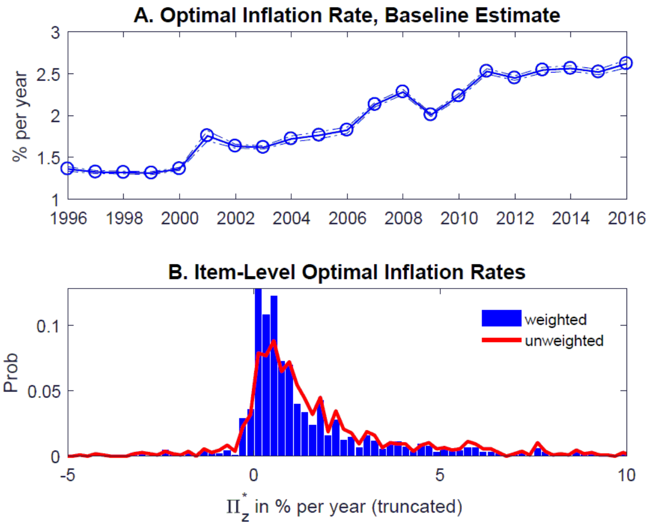
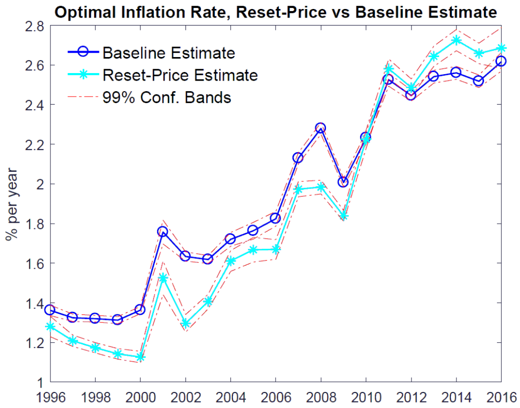
Benchmark Results - All Prices in Estimation

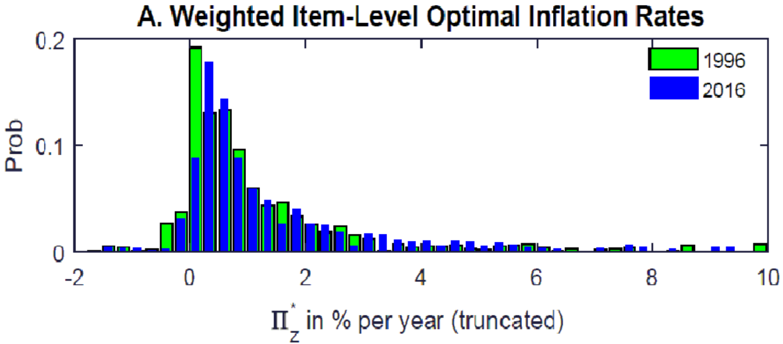


All Prices vs. Only Reset Prices in Estimation



Source of the Upward Trend (All Prices)

Beginning versus end of sample distributions:



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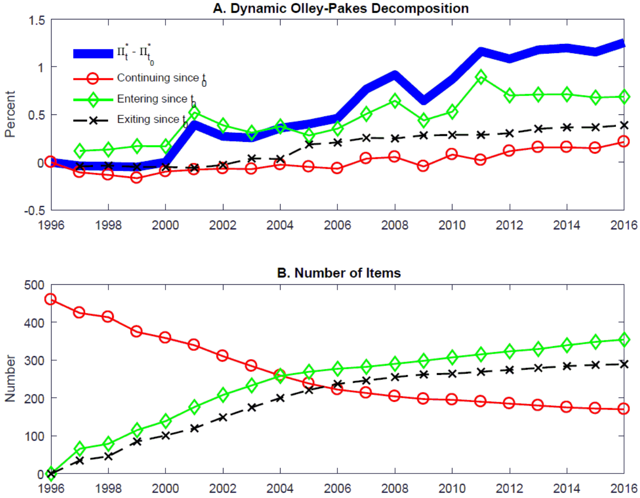
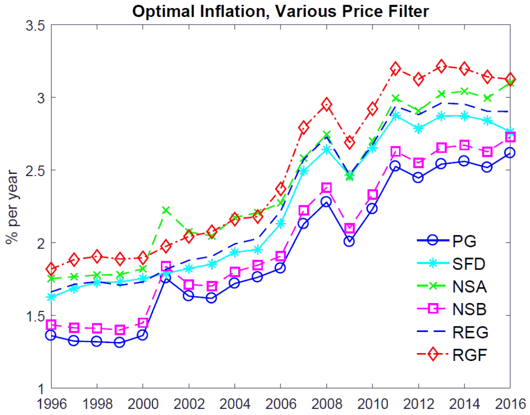


Dynamic Olley-Pakes Decomp. according to Melitz and Polanec (RAND, 2015)

Optimal Inflation: AlternativeTreatment of Sales Prices



PG: Baseline - no filter; SFD: Prices with ONS sales flag deleted; NSA/NSB: Nakamura-Steinsson (2008) sales filter version A/B; REG: Kehoe and Midrigan (2015) regular prices ; RGF: regular prices with only sales prices filtered, following Kryvstov and Vincent (2017).

Conclusions

- Construct sticky price model with product life-cycle & lots of heterogeneity
- Analytically solve for the optimal inflation target
- Estimate optimal inflation target directly from micro price trends
- Key insight: relative price trends at the product level determine optimal inflation
- U.K.: optimal target **1996: 1.4%** $\Longrightarrow$ **2016: 2.6%**

U.K. Micro Price Data

- Further details on the micro price data & price setting frictions

U.K. Micro Price Data

- 20 years of ONS micro price data: Feb. 1996 - Dec. 2016
- Monthly data with approx. 29m price observations
- Not all products uniquely identified: ONS does *not* disclose complete location information
- Eliminate not uniquely identified price quotes: leaves 24.5m prices
- Some price quotes considered "invalid" by ONS for other reasons: leaves 22.8 million observations
- Split product price series at ONS substitutions flags or at observation gaps to insure we follow the same product over time

U.K. Micro Price Data

Table: Basic Data Statistics

# price quotes in raw data	28.995.064
# items	1233
# regions	13
# shop codes	2770
# product identifiers	736078
# price quotes excluding duplicate quotes	24.525.632
# product identifiers	687212
# price quotes excluding invalid quotes	22.825.052
# product identifiers	682747
# price quotes in replicated items	21.215.430
# product identifiers	613031

U.K. Micro Price Data

- **Replication check:**
  - aggregate individual prices to item indices using ONS methodology
  - compare our item indices to ONS indices
- Correlations with ONS index generally high:
  $>$0.95 for vast majority of items
- Omission of "duplicate prices" sometimes drives a wedge
- Use only items for which RMSE between our index and ONS index is below 0.02: $\approx$ 93% of valid price quotes
- Work with 21.2m price observations as our base sample

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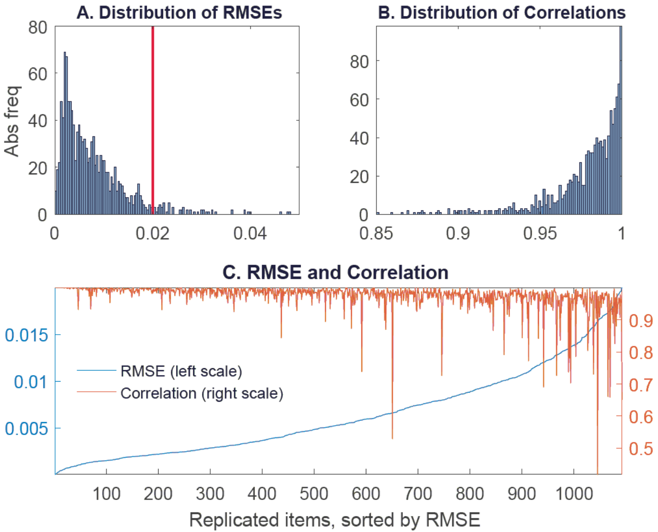
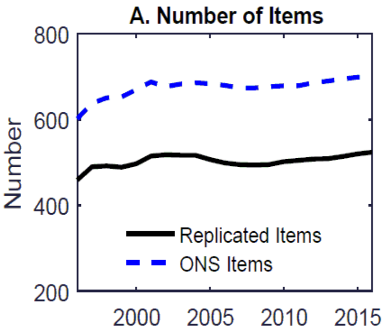


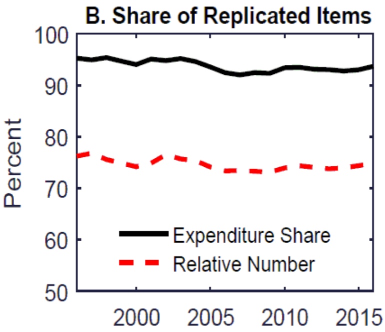
U.K. Micro Price Data

Table: Descriptive Statistics For Replicated Items

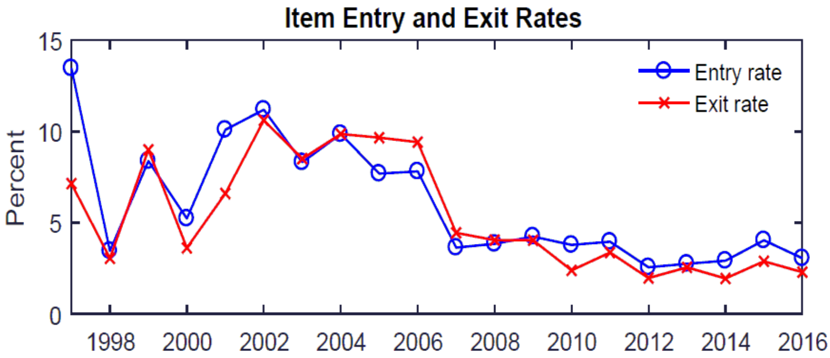
Number of items	1093
Number of Price Quotes	
Minimum across items	253
Median across items	15458
Mean across item	19410.3
Maximum across items	81840
Number of Products	
Minimum across items	32
Median across items	470
Mean across item	560.9
Maximum across items	2080

U.K. Micro Price Data





U.K. Micro Price Data



Price Setting Model: Optimal Reset Price

- Calvo price stickiness: ajdustment fequency $\alpha_z \in (0,1)$ for item z
- Optimal (quality-adjusted) reset price $P^{\star}_{jzt}$:

$$\frac{P^{\star}_{jzt}}{P_{zt}} \left(\frac{Q_{jzt-s_{jt}} G_{jzt}}{Q_{zt}} \right) = \left(\frac{\theta}{\theta - 1} \frac{1}{1+\tau} \right) \frac{N_{zt}}{D_{zt}} \frac{P_t}{P_{zt}}, \quad (3)$$

N_{zt}, D_{zt} are discounted expected marginal revenues and costs.

Price Setting Model: Optimal Reset Price

- We have

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

$$D_{zt} = 1 + \alpha_z (1-\delta_z) E_t \frac{\Omega_{t,t+1} Y_{zt+1}}{Y_{zt}} \frac{P_t}{P_{t+1}} \left(\frac{P_{zt+1}}{P_{zt}}\right)^{\theta} D_{zt+1}.$$

MC_t : nominal marginal costs of production
$\Omega_{t,t+1}$: stochastic discount factor
Y_{zt} : item-level output (in constant quality units), defined as:

$$Y_{zt} = \left(\int_0^1 \left(Q_{jzt} \widetilde{Y}_{jzt}\right)^{\frac{\theta-1}{\theta}} \mathrm{dj}\right)^{\frac{\theta}{\theta-1}}$$