Estimating the Optimal Inflation Target from Micro Price Data[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

- Fresh look at micro price data underlying the construction of CPI

Normative inference: optimal inflation target (OIT)

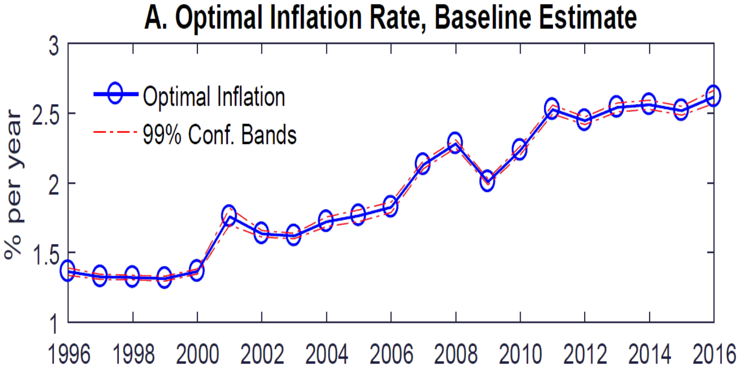
- Construct a rich sticky price model with a **product life-cycle**
- OIT in the model depends on features of product life-cycle
- Bring model to U.K. micro data: Office of National Statistics (ONS)

Introduction

Show how to estimate **optimal inflation target** from micro price data:

- to first-order accuracy: directly and in a parameter-free way
- fully nonlinear approach: requires additional parametric assumptions (demand elasticities, price stickiness, etc.)
- estimation works in a setting with sticky prices and historically sub-optimal monetary policy

Introduction



Mean estimate and +/- 2 std. dev. error bands

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  Minimizes welfare consequences of **relative price distortions**

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  Minimizes welfare consequences of **relative price distortions**

- Abstract from other factors affecting OITs:

  Higher optimal target:
  - Lower bound constraints on nominal rates
  (Adam (2006), Gorodnichenko et al. (2012))

  - Downward nominal wage rigidity, e.g., Benigno (2011)

  Lower optimal target:
  - Cash distortions, e.g., Kahn, King, Wolman (2003), Schmitt-Grohé, Uribe (2011)

  - Lack of commitment, e.g., Rogoff (1985)

Structure of the Presentation

1. Key Elements of the Price Setting Model
2. Optimal Inflation Target: Theory
3. The UK Micro Price Data
4. Optimal Inflation Target: Estimation Results

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Price Setting Model

- Representative consumer, growth-consistent preferences

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

Price Setting Model

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

- 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
  - **Product level:** constant entry and exit of products

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

Price Setting Model: Turnover

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  - Captures slow moving change in consumption basket:

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  - Empirical application: uses $(Z_t, \{\psi_{zt}\}_{z=1}^{Z_t})$ from ONS

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  - Empirical application: uses $(Z_t, \{\psi_{zt}\}_{z=1}^{Z_t})$ from ONS
  - Model-based interpretation of item turnover:
    changing consumer tastes (other interpretations possible...)

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  - Interpretation of product turnover: changing consumer tastes
  - Alternatively:
    - negative productivity shock to old producer
    - new product in quality-adjusted terms cheaper & perf. substitute

Price Setting Model: Product-Level Dynamics

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

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

Both dynamics are item specific: allowed to differ across z!

Price Setting Model: Quality Dynamics

Product quality dynamics (in item z):

- For product j entering in time t:

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

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  new qualities = new products

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- Idiosyncratic quality: $\varepsilon^{Q}_{jzt} \sim iiQ_z$ with $E\varepsilon^{Q}_{jzt} = 1$.

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- Idiosyncratic quality: $\varepsilon^{Q}_{jzt} \sim iiQ_z$ with $E\varepsilon^{Q}_{jzt} = 1$.
- The common time-trend evolves according to

$$Q_{zt} = q_{zt} Q_{zt-1} \text{ with } q_{zt} = q_z \epsilon^{q}_{zt},$$

  where $E\epsilon^{q}_{zt} = 1$ and

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

Price Setting Model: Productivity Dynamics

- Product output (in physical units):

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

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- General TFP:

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- General TFP:

$$A_{zt} = a_{zt} A_{zt-1}, \qquad with \ \ a_{zt} = a_z \epsilon^a_{zt},$$

- Product specific TFP:

- random draw at time of product entry $t : G_{jzt} \sim iiG_z$

- **experience accumulation over the product life:**

$$G_{jzt} = g_{zt} G_{jzt-1} \qquad with : g_{zt} = g_z \epsilon^g_{zt}$$

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

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 $\alpha_z \in [0, 1)$

Price Setting Model: Productivity Dynamics

- Can augment Calvo model with "temporary price" adjustments/sales (Kehoe and Midrigan (2015)):
  - Calvo price is the "list price" or "regular price"
  - Each period: prob. $\alpha_T \in (0,1)$ to set a temporary price for one period
  - Optimal temporary price: flex price
- Largely abstract from temporary 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!**

Price Setting Model: Optimal Reset Price

- Optimal (quality-adjusted) reset price $P^{\star}_{jzt}$:

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

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:

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

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Optimal Inflation Rate

- Derive closed-form results for the optimal steady-state inflation rate.
- Interpret optimal steady-state inflation $=$ optimal inflation target
- Aggregate shocks:

  cause only temporary deviation of opt. inflation from OIT
- Changing item structure $\Longrightarrow$ changes in OIT over time

Optimal Inflation Rate

Definition

A **steady state** is a situation with a fixed set of items $Z_t = Z$, constant item-weights $\psi_{zt} = \psi_z$, no item-level disturbances ($g_{zt} = g_z$, $q_{zt} = q_z$, $a_{zt} = a_z$), and a constant (potentially suboptimal) inflation rate Π.

The following *idiosyncratic shocks* continue to operate in a steady state:

- product entry and exit shocks

- shocks to price adjustment opportunities, and

- initial shocks to product quality & productivity, as implied by Q_z and G_z.

Theorem

Assume an efficient output subsidy $(\theta/((1-\tau)(\theta-1))=1)$ *and consider the limit* $\beta(\gamma)^{1-\sigma}\to 1$*, where* γ *is the growth trend of the aggregate economy. The inflation rate* Π^* *that maximizes steady state utility is*

$$\Pi^\star = \sum_{z=1}^{Z} \omega_z \left(\frac{g_z}{q_z} \frac{\gamma_z}{\gamma} \right), \tag{2}$$

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*

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

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

Optimal Inflation Rate

- Generalizes Adam and Weber (AER, forthcoming) to a setting with item and product-level heterogeneity
- Unlike in earlier work: optimal inflation rate ceases to implement efficient relative prices
- Each item $z \in Z$ has it own optimal inflation rate $\Pi_z^\star = g_z / q_z$
- Weights ω_z and rel. growth rates γ_z / γ determine how to optimally trade off between items
- Optimal weights ω_z not easy to interpret....

Optimal Inflation Rate

Corollary

To a first-order approximation, the optimal steady-state inflation rate is

$$\Pi^* = \sum_{z=1}^{Z} \psi_z \left(\frac{g_z \gamma_z}{q_z \gamma} \right), \tag{3}$$

where the approximation has been taken around a point, in which $\frac{g_z}{q_z} \frac{\gamma_z}{\gamma}$ *and* $\alpha_z (1 - \delta_z)(\gamma / \gamma_z)^{\theta - 1}$ *are constant across sectors* $z = 1, \ldots Z$.

- To first order: weights are simply ONS expenditure weights ψ_z!
- Inflation rates identify $\gamma_z / \gamma = \frac{P / P_{-1}}{P_z / P_{z,-1}}$
- Remains to identify g_z / q_z: can estimate from micro data

Optimal Inflation Rate

Proposition

Consider a steady state with (possibly suboptimal) inflation. In price adjustment periods, the optimal reset price $P^{\star}_{jzt}$ satisfies

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

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

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

- $g_z > 1$: experience accumulation in productivity -> optimal relative price falls over product lifetime
- $q_z > 1$: newer products higher quality, in constant-quality terms their prices are lower $\Rightarrow$ optimal relative price rises

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 price deviations due to price stickiness

(with aggregate shocks may also capture these)

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(with aggregate shocks may also capture these)

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

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

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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

Structure of the Presentation

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

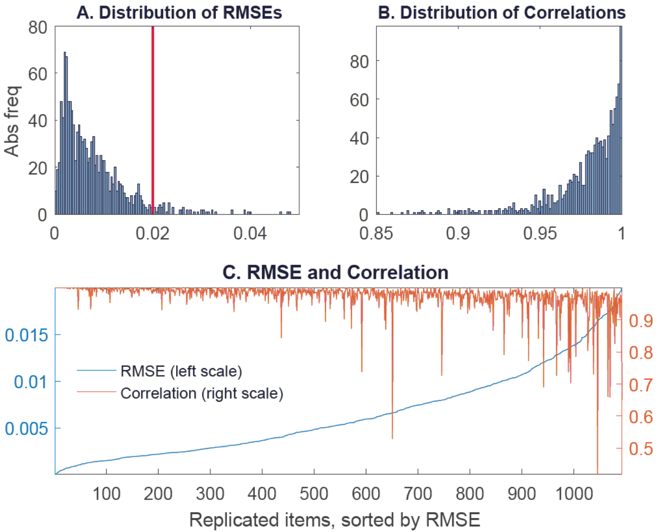
Table: Basic Data Statistics

# 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

U.K. Micro Price Data

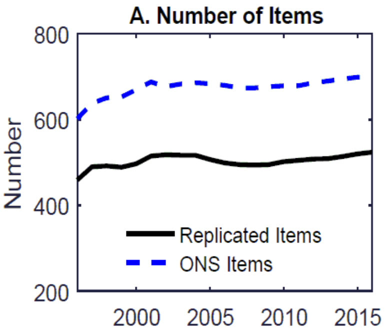


U.K. Micro Price Data

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



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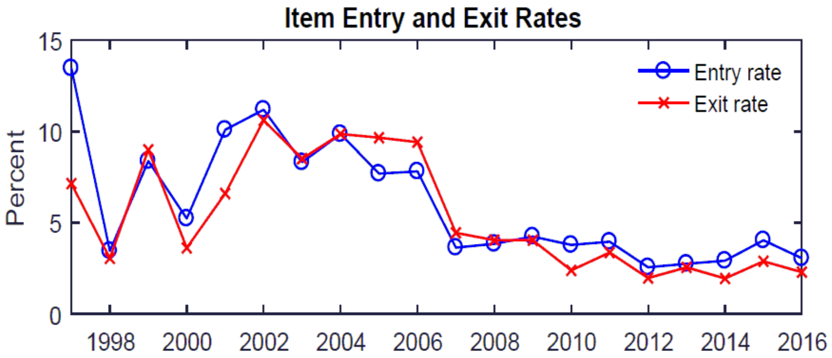

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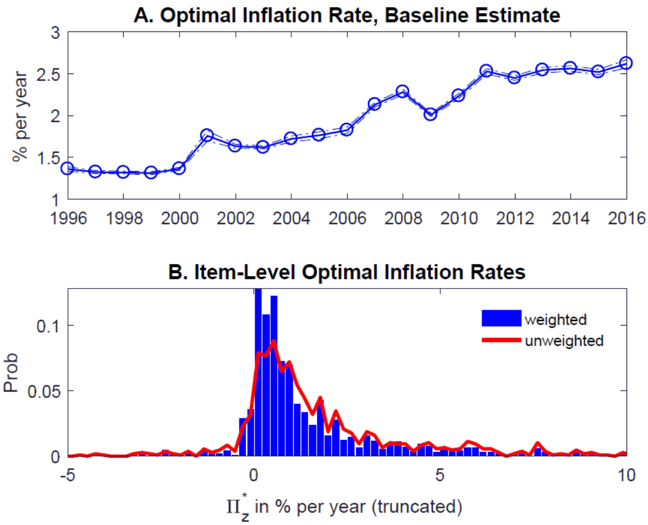
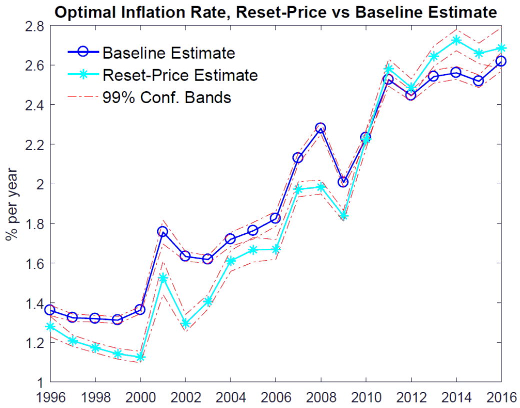
Benchmark Results - All Prices in Estimation

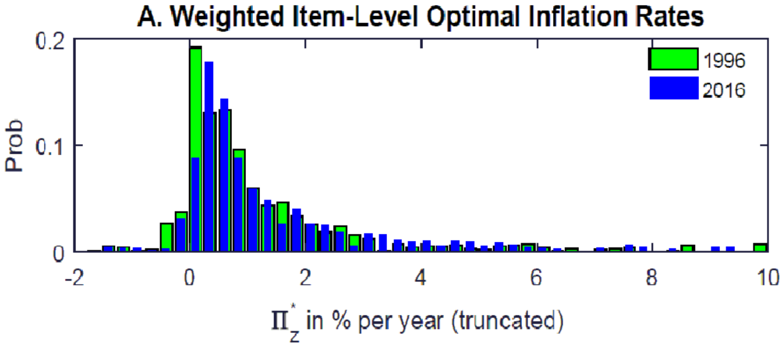


All Prices vs. Only Reset Prices in Estimation

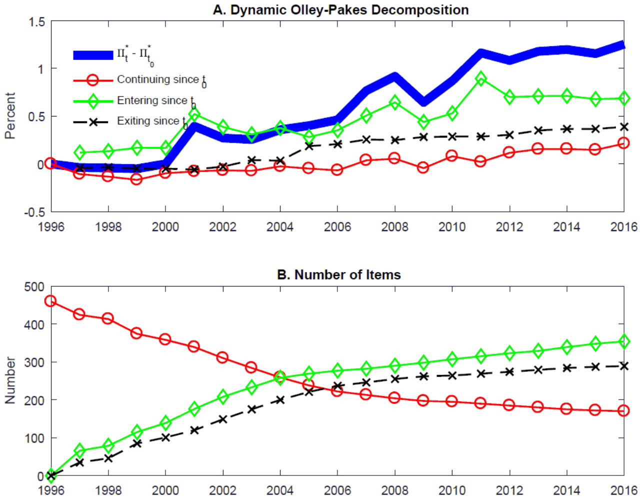


Source of the Upward Trend (All Prices)

Beginning versus end of sample distributions:

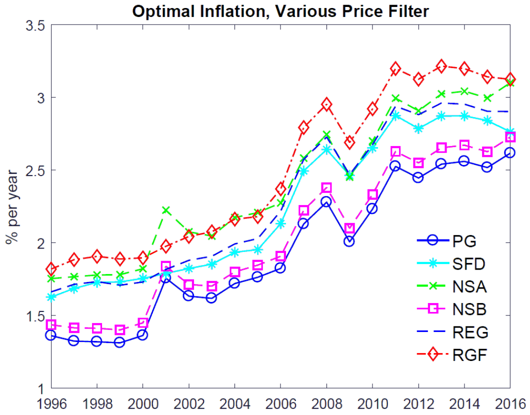


Source of the Upward Trend



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).

Actual vs. Optimal Inflation: Price Dispersion?

- Theory:

  Deviation of actual inflation Π_z from optimal inflation Π_z^*

  $\Rightarrow$ excess price dispersion

- Question: can we find this relationship in the U.K. price data?

- Nakamura, Steinsson, Sun, Villar (2018):

  Price dispersion effects elusive in U.S. data....

Deviations from Optimal Inflation: Price Dispersion?

- Theory implies (second-order approximation):

$$\ln\left(\frac{\Delta_z}{\Delta_z^e}\right) = c_z \cdot (\Pi_z - \Pi_z^\star)^2$$

where

$$\Delta_z/\Delta_z^e \geq 1: \quad \text{a measure of excess price dispersion}$$
$$c_z > 0: \quad \text{depends on } \alpha_z, \delta_z, ...$$

- Optimal inflation estimates $\Pi_z^\star$ for more than 1000 items z
- Can compute average inflation in each item $E[\Pi_{zt}]$
- Does $(\Pi_z^\star - E[\Pi_{zt}])^2$ predict excess price dispersion?

Deviations from Optimal Inflation: Price Dispersion?

- On the previous slide:

$$\frac{\Delta_z}{\Delta_z^e} = \int_0^1 \left(\frac{Q_{zt}}{G_{jzt} Q_{zt-s_{jt}}}\right) \left(\frac{P_{jzt}}{P_{zt}}\right)^{-\theta} dj \Big/ \left(\int_0^1 \left(\frac{Q_{zt}}{G_{jzt} Q_{zt-s_{jt}}}\right)^{1-\theta} \mathrm{dj}\right)^{\frac{1}{1-\theta}}$$

and

$$c_z = \frac{1}{2}\theta \left[\frac{\alpha^z (1-\delta^z)(\Pi_z^\star)^{\theta-1}}{(1-\alpha^z(1-\delta^z)(\Pi_z^\star)^{\theta-1})^2} \frac{1}{(\Pi_z^\star)^2}\right] > 0$$

Deviations from Optimal Inflation: Price Dispersion?

Measure of excess price deviation:

- For each product j in item z:
  compute std. dev. of deviations from estimated rel. price trend
- Take the median standard deviation σ_z^m in item z & estimate

$$\sigma_z^m = a + b\left(\Pi_z^* - E[\Pi_{z,t}]\right) + c\left(\Pi_z^* - E[\Pi_{z,t}]\right)^2$$

- Theory implies

$$b = 0 \text{ and } c > 0$$

(theory also implies $a = 0$, but not robust to measurement & estimation error)

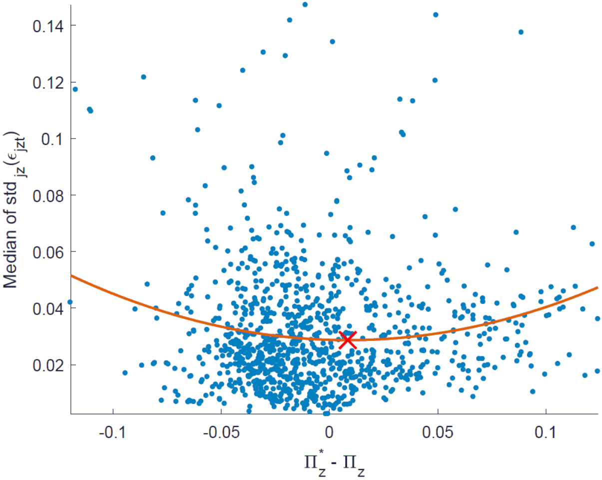
Deviations from Optimal Inflation: Price Dispersion?

Coefficient	Estimate	t-Statistic
a	0.0288	34.024
b	-0.0235	-1.3127
c	1.3979	4.7303
Minimum $\Pi_z^\star - \Pi_z$	0.84% per year	1.3862

Robustly get $c > 0$ and stat. significant, for

- sales filtered data
- measuring deviations from product-specific age trends
- mean instead of median std. dev.

Deviations from Optimal Inflation: Price Dispersion?



Conclusions

- Estimate optimal inflation target directly from micro price trends
- Relative price trends with flex prices =
  Relative price trends with sticky prices & sub-opt. inflation
- Relative price trends determine optimal inflation
- Optimal inflation:
  - minimizes relative price distortions by minimizing need for price adjustments
- Empirically, excess price dispersion moves in line with theory: increases as actual inflation deviates from opt. inflation
- Optimal U.K. inflation target slight upward trend:
  1996: 1.4%-1.8% $\Longrightarrow$ 2016: 2.6%-3.2%