Price Setting Frequency and the Phillips Curve[1]

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May 2023

[1] Financial support from the Austrian National Bank (OeNB) grant no. 18611, Fundação para a Ciência e a Tecnologia grant no. UIDB/00315/2020 and from the European Union Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No. 721846, "Expectations and Social Influence Dynamics in Economics" is gratefully acknowledged.

Outline of the presentation

1. Motivation
2. An extended NK model
3. The asymmetric Phillips curve
4. Fitting micro and macro data with a small NK model
5. Conclusion

NK models and the shift in Phillips curve I

1. **Well established fact that NK models struggle to fit the shifts in the Phillips curve:**

$$\hat{\pi}_t = \beta(\chi)\mathbb{E}_t\hat{\pi}_{t+1} + \kappa(\theta, \chi, \cdot)\hat{y}_t + \chi\hat{\pi}_{t-1} + \varepsilon_t^s$$

2. Solving the missing deflation and inflation in NK models:
   - **higher Calvo => stickier prices / flatter NKPC** (Del Negro et al., 2015);
     - $\nearrow \theta \longrightarrow \searrow \kappa$
   - large autocorrelated **cost-push shocks** and **indexation** (Fratto and Uhlig, 2020; King and Watson, 2012);
     - $\nearrow \longrightarrow \searrow \beta$ and $\searrow \kappa$
3. We end up explaining inflation with shocks on inflation ....

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NK models and the shift in Phillips curve II

- Literature focuses on:
  - **non-linear** effects (Harding et al., 2022);
  - exogenous **shift in price stickiness** (Davig, 2016; Fernández-Villaverde and Rubio-Ramírez, 2007);
  - **change in price updating behaviour** (Del Negro et al., 2020; Costain et al., 2022).
- Point of departure, a combination of all of that:
  - **=> endogenous time-varying price-setting frequency θ_t.**

Motivation for time variation in the Calvo I

- The Calvo probability $0 < \theta < 1$ can be interpreted as the **exogenous share of unchanged prices** at one period.
  - It is assumed to be a structural parameter (Fernández-Villaverde and Rubio-Ramírez, 2007), yet the estimated value has moved from $\theta \simeq 0.75$ to $\theta \simeq 0.9$ with post 2008 samples?
- **Micro-data contradicts the static Calvo** assumption (Blinder et al., 1998; Klenow and Kryvtsov, 2008; Nakamura et al., 2018).
- Pure state dependent pricing models struggle with empirical money non-neutrality (Nakamura and Steinsson, 2010; Costain et al., 2022).

Motivation for time variation in the Calvo II

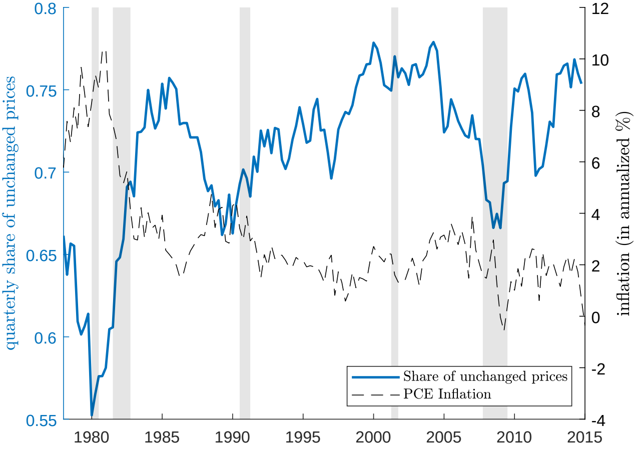

Figure 1: Seasonally adjusted share of unchanged prices, θ_t, in the US from price tags data changes weighted according to the 2000 household consumption basket based on Nakamura et al. (2018).

What we do

1. Implement a **time-varying price-setting frequency** in a NK model via the *Calvo law of motion*:
   - update or not $\mapsto$ **discrete choice process**;
   - decision is based on the **present values** of updating;
   - Time-dependent pricing with a flavour of state-dependence **=> highly tractable!**
2. Does this improve the NK model with regard to fitting the Phillips curve, macro and micro-data?

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Results

- Our extended model:
  1. generates an **asymmetric Phillips curve** which is:
     - steep during boom;
     - flat during bust;
  2. is consistent with **micro and macro**-data;
  3. can **explain the shifts in the Phillips Curve** without large cost-push shocks, high indexation or very sticky prices;

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=> How to approximate the resetting problem?

- Our **innovation:** discrete choice model à la Brock and Hommes (1997), McFadden (2001) or Matějka and McKay (2015):

$$\theta_t = \frac{\exp\left(\omega U_t^f\right)}{\exp\left(\omega U_t^f\right) + \exp\left(\omega\left(U_t^* - \tau + \varepsilon_t^\theta\right)\right)}, \qquad (1)$$

  - θ_t: Share of non resetting firms;
  - $*$ is the index for the optimal resetting price;
  - f is the index for the average old price;
  - U_t^f, U_t^*: Present values of the pricing decisions;
  - ω, τ: Intensity of choice and fixed cost of updating;
  - ε_t^θ : AR(1) shock explaining the residual variation.

⇒ Consistent with **state-dependent pricing models**.

Derivations (Rest of the model)

- Calvo aggregation:

$$P_t = \left(\theta_t P_{t-1}^{1-\epsilon} + (1-\theta_t) P_t^{*\,1-\epsilon}\right)^{\frac{1}{1-\epsilon}} \tag{2}$$

- Firm maximization problem (w/ linear production technology):

$$\max_{P_t^*} \ \mathbb{E}_t \sum_{j=0}^{\infty} \mathcal{D}_{t,t+j} \left(\prod_{k=0}^{j} \theta_{t+k}\right) \theta_t^{-1} \left[\frac{P_t^*}{P_{t+j}} - \frac{\Gamma'_{t+j}}{P_{t+j}}\right] Y_{i,t+j}$$

$$\text{s.t. } Y_{i,t+j} = \left(\frac{P_t^*}{P_{t+j}}\right)^{-\epsilon} Y_{t+j}$$

- Firm's FOC:

$$p_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\mathbb{E}_t \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \theta_{t+k}\right) \theta_t^{-1} \mathcal{D}_{t,t+j} \Pi_{t+1,t+j}^{\epsilon} Y_{t+j} w_{t+j}}{\mathbb{E}_t \sum_{j=0}^{\infty} \left(\prod_{k=0}^{j} \theta_{t+k}\right) \theta_t^{-1} \mathcal{D}_{t,t+j} \Pi_{t+1,t+j}^{\epsilon-1} Y_{t+j}} \tag{3}$$

Non-linear dynamics (Fair and Taylor, 1983)

Calibration Intuition

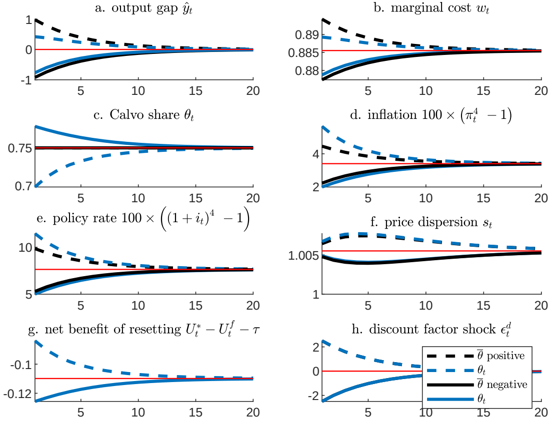
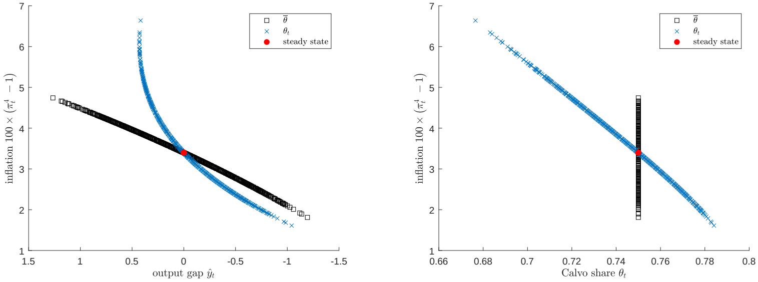


Figure 2: Asymmetric impulse responses to a positive or negative demand shock in the small-scale NK model. The shock is a ±2.5% shock at the discount factor.

The Non-linear NKPC (Fair and Taylor, 1983)



(a) Inflation and Output (b) Inflation and the Calvo

Figure 3: Simulated moments of the non-linear model under discount factor shocks.

Estimation results of the small NK model

Posteriors

- **Objective:** demonstrate the **quantitative** relevance of the mechanism.
- We estimate the model using data for the US (GDPC1, PCE, FEDFUNDS) from 1964 to 2019.
- Measurement equations are

$$
\begin{aligned}
y_t^{obs} &= \hat{y}_t \\
\pi_t^{obs} &= 100 \times \ln(\overline{\pi}) + \hat{\pi}_t, \qquad \text{where} \qquad \overline{\pi} = 1 + \gamma_\pi / 100 \\
r_t^{obs} &= 100 \times ((\overline{\pi}/\beta) - 1) + \hat{i}_t \\
\theta_t^{obs} &= \theta_t,
\end{aligned}
$$

- Key novelty: Nakamura et al. (2018) **micro**-data for the last equation.

A Demand Driven Inflation [Calvo share]

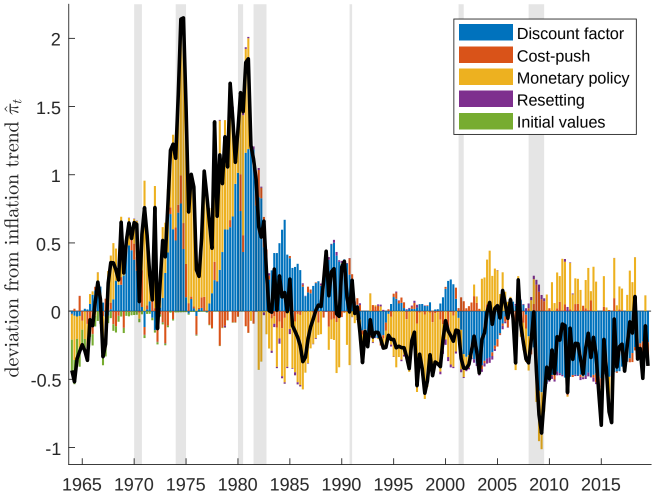


Figure 4: Historical decomposition, observed inflation, US data (1964-2019).

Relevance of the endogenous Calvo model

Detailed moments

(1964-2019 (full sample))		Filtered model	$\theta_t = \overline{\theta}\ \forall t$	$\epsilon_t^{\theta} = 0\ \forall t$
π_t	mean	3.3665	3.2370	3.3926
	median	2.6056	2.6782	2.6595
	variance	5.3527	3.8370	5.4351
	skewness	1.3271	0.8472	1.3343
$\text{corr}(\pi_t, \theta_t)$		-0.8443	0	-0.9844
$\text{corr}(\pi_t, \hat{y}_t)$		0.0839	0.1442	0.0734

Table 1: Inflation moments and related statistics, filtered non-linear model and counter-factuals.

Conclusion

1. Assuming a **static Calvo** share has **limitations**;
2. We provide a model that approximates well the **aggregate** variation in price resetting;
3. The model is consistent with **micro-data and macro-data** dynamic;
4. The endogenous price resetting variation drives the non-linearity in the Phillips Curve;
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Thank you for your attention.

Questions? Comments?

The present value of a pricing decision Back

- In a simple linear production NK economy we have :

$$U_t^x = \mathbb{E}_t \sum_{k=0}^{\infty} \mathcal{D}_{t,t+k} \left(\prod_{j=0}^{k} \theta_{t+j} \right) \theta_t^{-1}$$
$$\left[Y_{t+k} \left(\frac{p_t^x}{(\Pi_{t,t+k-1})\, \Pi_t^{-1}} \right)^{1-\epsilon} - Y_{t+k} w_{t+k} \left(\frac{p_t^x}{(\Pi_{t,t+k-1})\, \Pi_t^{-1}} \right)^{-\epsilon} \right]$$
$$= \left({p_t^x}^{1-\epsilon} \phi_t - {p_t^x}^{-\epsilon} \psi_t \right) Y_t^{\sigma},$$

  - θ_t: Share of non resetting firms;
  - p_t^x: Relative price ;
  - w_t: real wage;
  - Π_t: is the cumulated inflation;
  - ϵ: elasticity of substitution among goods;
  - ϕ_t and ψ_t: numerator and denominator of the FOC of the optimal price decision.

Calvo Law of Motion Back

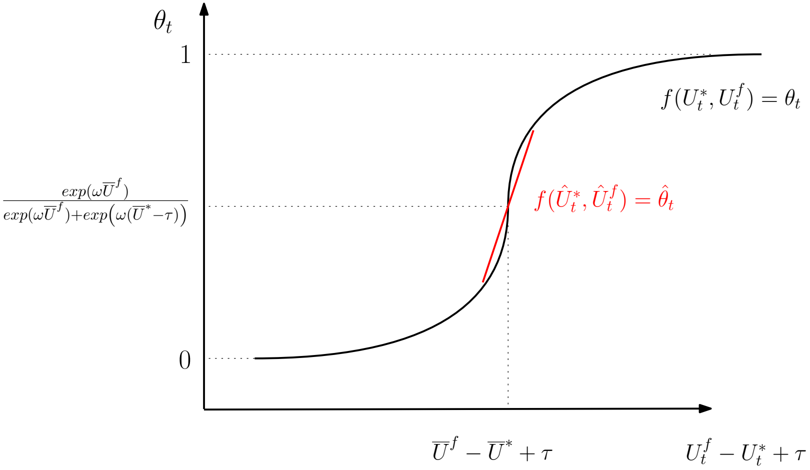

Figure 5: The Calvo law of motion (black). The y-axis is the level of θ and the x-axis is the difference between the expected profit of not updating and updating the price.

Asymmetry in the profit function Back

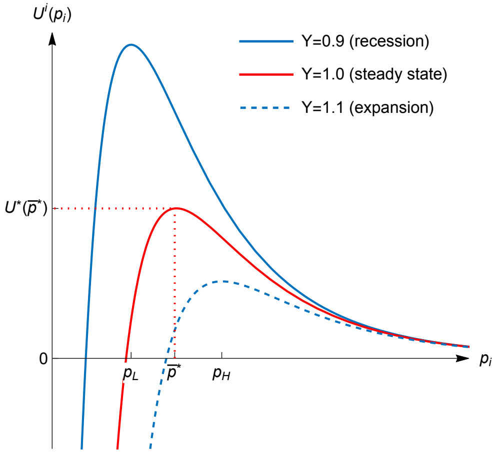

Figure 6: Comparative statics: present value of real profits as function of relative price at different levels of output.

An augmented linearised Phillips Curve

Back

The negative relation between inflation and realized/expected Calvo (non-price resetting) share:

$$\hat{\pi}_t = \alpha_1 \hat{y}_t + \alpha_2 \mathbb{E}_t \hat{\pi}_{t+1} + \alpha_3 \mathbb{E}_t \hat{\phi}_{t+1} + \alpha_4 \hat{\theta}_t + \alpha_5 \mathbb{E}_t \hat{\theta}_{t+1} + \varepsilon_t^s, \quad (4)$$

with $\alpha_1, \alpha_2, \alpha_3, \alpha_5 > 0 > \alpha_4$.

The Non-Linear Model Back I

Aggregate demand: $Y_t^{-\sigma}\exp(\epsilon_t^d) = \beta\mathbb{E}_t\left\{\frac{(1+i_t)}{\pi_{t+1}}Y_{t+1}^{-\sigma}\exp(\epsilon_{t+1}^d)\right\}$

Labor supply: $w_t = \exp(\epsilon_t^s)\chi N_t^{\varphi}Y_t^{\sigma},$

Price setting freq. : $\theta_t = \frac{\exp\left(\omega U_t^f\right)}{\exp\left(\omega U_t^f\right)+\exp\left(\omega\left(U_t^* - \tau + \epsilon_t^{\theta}\right)\right)},$

Value of firm: $U_t^x = \left({p_t^x}^{1-\epsilon}\phi_t - {p_t^x}^{-\epsilon}\psi_t\right)Y_t^{\sigma} \quad \text{for} \quad x \in \{*, f\}$

Opt. relative price: $p_t^* = \frac{\epsilon}{\epsilon-1}\frac{\psi_t}{\phi_t}$

$$\psi_t = w_t Y_t^{1-\sigma} + \mathbb{E}_t\beta\theta_{t+1}\pi_{t+1}^{\epsilon}\psi_{t+1}$$

$$\phi_t = Y_t^{1-\sigma} + \mathbb{E}_t\beta\theta_{t+1}\pi_{t+1}^{\epsilon-1}\phi_{t+1}$$

Av. relative old price: $p_t^f = 1/\pi_t$

Inflation: $1 = \left(\theta_t \pi_t^{\epsilon-1} + (1-\theta_t) p_t^{*\,1-\epsilon}\right)^{\frac{1}{1-\epsilon}}$

Price dispersion: $s_t = (1-\theta_t) p_t^{*\,-\epsilon} + \theta_t \pi_t^{\epsilon} s_{t-1}$

Aggregate output: $Y_t = N_t / s_t.$

Monetary policy:

$$\left(\frac{1+i_t}{1+\bar{\imath}}\right) = \left(\frac{1+i_{t-1}}{1+\bar{\imath}}\right)^{\rho} \left(\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi} \left(\frac{Y_t}{\overline{\overline{Y}}}\right)^{\phi_y}\right)^{(1-\rho)} \exp(\epsilon_t^r),$$

Cost-push shock: $\epsilon_t^s = \rho_s \epsilon_{t-1}^s - \mu_s u_{\epsilon^s,t-1} + u_{\epsilon^s,t}$

Other shocks: $\epsilon_t^j = \rho_j \epsilon_{t-1}^j + u_{\epsilon^j,t},$

where $j \in \{d, r, \theta\},$

with $0 \le \rho_j, \rho_s < 1$, $0 \le \mu_s < 1$ and $u_{\epsilon^j,t}, u_{\epsilon^s,t} \sim \text{iid } \mathcal{N}(0, \sigma_j^2)$.

Calibration Back

Price setting		Value	Source
ω	Intensity of choice	10	-
$\overline{\theta}$	Calvo share	0.75	Galí (2015)
Monetary authority			
ϕ_π	MP. stance, π_t	1.5	Galí (2015)
ϕ_y	MP. stance, Y_t	0.125	Galí (2015)
ρ	Interest-rate smoothing	0	-
$\overline{\pi}$	Gross inflation trend	1.008387	Average log growth of PCE implicit price deflator, 1964-2019
Preferences and technology			
β	Discount factor	0.99	Galí (2015)
σ	Relative risk aversion	1	Galí (2015)
φ	Inverse of Frisch elasticity	0	Ascari and Ropele (2009)
ϵ	Price elasticity of demand	9	Galí (2015)
Exogenous processes			
ρ_d	Discount factor shock, AR(1)	0.8	illustrative purpose
ρ_r	MP shock, AR(1)	0.8	illustrative purpose

Table 2: Calibrated parameters (Galí, 2015) for dynamic simulations (quarterly basis)

Priors and Posteriors

Back

Price setting		Shape	*Prior* Mean	STD	*Posterior* Mean	5%	95%
ω	Intensity of choice	$\mathcal{N}$	10	.5	8.3664	7.5543	9.1891
$\bar{\theta}$	Calvo share	$\mathcal{B}$	.5	.1	0.7105	0.6984	0.7231
Monetary authority							
ϕ_π	MP. stance, π_t	$\mathcal{N}$	1.5	.15	2.4311	2.2542	2.6162
ϕ_y	MP. stance, Y_t	$\mathcal{N}$	.12	.05	0.2499	0.1886	0.3101
ρ	Interest-rate smoothing	$\mathcal{B}$	.75	.1	0.1585	0.1006	0.2151
γ_π	Quarterly inflation trend	$\mathcal{G}$	.839	.1	0.7486	0.6610	0.8351
Preferences and technology							
$100((\bar{\pi}/\beta)-1)$	Natural interest rate	$\mathcal{G}$	1.292	.1	1.1861	1.0507	1.3224
σ	Relative risk aversion	$\mathcal{N}$	1.5	.25	1.6180	1.2940	1.9398
φ	Inverse of Frisch elasticity	$\mathcal{N}$	2	.37	1.9044	1.3785	2.4297
Exogenous processes							
σ_d	Discount factor shock, std.	$\mathcal{IG}$	.1	2	0.0255	0.0183	0.0320
σ_s	Cost-push shock, std.	$\mathcal{IG}$	.1	2	0.0322	0.0272	0.0371
σ_r	MP shock, std.	$\mathcal{IG}$	.1	2	0.0079	0.0072	0.0086
σ_θ	Resetting shock, std.	$\mathcal{IG}$	.1	2	0.0139	0.0121	0.0155
ρ_d	Discount factor shock, AR(1)	$\mathcal{B}$	.5	.1	0.9362	0.9173	0.9552
ρ_s	Cost-push shock, AR(1)	$\mathcal{B}$	.5	.1	0.9779	0.9676	0.9889
μ_s	Cost-push shock, MA(1)	$\mathcal{B}$	.5	.1	0.1732	0.1195	0.2265
ρ_r	MP shock, AR(1)	$\mathcal{B}$	.5	.1	0.5271	0.4789	0.5770
ρ_θ	Resetting shock, AR(1)	$\mathcal{B}$	.5	.1	0.7749	0.7071	0.8427
Log-likelihood						-74.6242	

Table 3: Estimated parameters of the augmented small-scale NK model (US: 1964-2019). $\mathcal{B}$, $\mathcal{G}$, $\mathcal{IG}$, $\mathcal{N}$ denote beta, gamma, inverse gamma and normal distributions, respectively.

An endogenous Calvo law of motion

Back

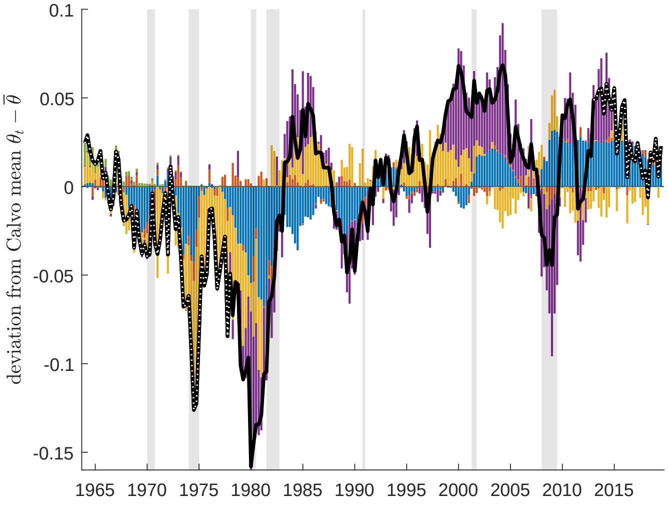

Figure 7: Historical decomposition, observed Calvo share, US data (1964-2019).

Relevance of the model (expanded)

Back

(a) 1964-2019 (full sample)		Filtered model	$\epsilon_t^\theta = 0\ \forall t$	$\epsilon_t^s = 0\ \forall t$	$\epsilon_t^s = \epsilon_t^\theta = 0\ \forall t$	$\epsilon_t^d = 0\ \forall t$	$\epsilon_t^r = 0\ \forall t$	$\epsilon_t^d = \epsilon_t^r = 0\ \forall t$
π_t	mean	3.3665	3.3926	3.3725	3.4013	3.3195	3.0151	2.9678
	median	2.6056	2.6595	2.7075	2.7123	2.9865	2.9039	2.9555
	variance	5.3527	5.4351	5.2963	5.3741	3.1133	1.9792	0.1025
	skewness	1.3271	1.3343	1.2980	1.3160	1.6055	0.8554	0.5939
$\text{corr}(\pi_t, \theta_t)$		-0.8443	-0.9844	-0.8359	-0.9836	-0.7522	-0.7249	-0.4065
$\text{corr}(\pi_t, \hat{y}_t)$		0.0839	0.0734	-0.0296	-0.0380	-0.0994	0.1762	-0.5882
(b) 1964-1984								
π_t	mean	5.3995	5.4256	5.3968	5.4270	4.4178	3.9173	2.9924
	median	5.1631	5.1602	4.9738	4.9894	4.0428	3.4877	2.9997
	variance	6.0894	6.2343	5.8975	6.0505	4.7642	2.0190	0.1814
	skewness	0.4630	0.4876	0.4977	0.5253	0.9690	1.0406	0.3136
$\text{corr}(\pi_t, \theta_t)$		-0.9327	-0.9951	-0.9288	-0.9953	-0.8757	-0.8319	-0.4095
$\text{corr}(\pi_t, \hat{y}_t)$		0.0905	0.0802	-0.0136	-0.0486	-0.0741	0.0891	-0.5886
(c) 1985-2003								
π_t	mean	2.3207	2.3314	2.3316	2.3405	2.1526	3.1477	2.9542
	median	2.2032	2.2279	2.1992	2.1889	2.0992	3.0875	2.9703
	variance	0.7802	0.7958	0.8222	0.8333	0.5783	0.7724	0.0441
	skewness	0.7364	0.7155	0.8576	0.8082	0.1354	-0.0328	0.0495
$\text{corr}(\pi_t, \theta_t)$		-0.6005	-0.9820	-0.6236	-0.9848	-0.2971	-0.7056	-0.2960
$\text{corr}(\pi_t, \hat{y}_t)$		0.3484	0.3390	0.1707	0.2207	-0.4339	0.5908	-0.6399
(d) 2004-2014								
π_t	mean	2.0393	2.1094	2.0240	2.1017	3.3201	1.7428	2.9709
	median	2.0967	2.0811	2.0509	2.1373	3.4543	1.4219	2.9350
	variance	0.9520	1.0373	1.1295	1.1798	0.7157	0.5455	0.0802
	skewness	-0.4800	-0.2448	-0.7384	-0.5228	-0.5588	0.6189	1.3824
$\text{corr}(\pi_t, \theta_t)$		0.2980	-0.9530	0.3193	-0.9351	0.1237	-0.2042	-0.5880
$\text{corr}(\pi_t, \hat{y}_t)$		0.5540	0.4577	0.4975	0.5322	-0.2105	0.7310	-0.5130
(e) 2015-2019								
π_t	mean	1.6207	1.6196	1.6882	1.6916	3.1784	1.3842	2.9028
	median	1.7169	1.7643	1.8971	1.9032	3.4464	1.3859	2.9042
	variance	0.9074	0.9890	0.8298	0.8996	0.7946	0.1362	0.0446
	skewness	-0.5074	-0.6060	-0.5028	-0.5992	-0.1402	-0.0915	0.6438
$\text{corr}(\pi_t, \theta_t)$		-0.7487	-0.9096	-0.7578	-0.9210	-0.8215	-0.7935	-0.4349
$\text{corr}(\pi_t, \hat{y}_t)$		0.1297	0.0907	0.8588	0.8924	-0.2886	0.3788	-0.6304

Table 4: Inflation moments and related statistics, filtered non-linear model and counter-factuals.

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