Prescriptions for Monetary Policy when Inflation Is High

Aleš Maršál
(National Bank of Slovakia)

Based on: Undesired Consequences of Calvo Pricing in a Non-linear World

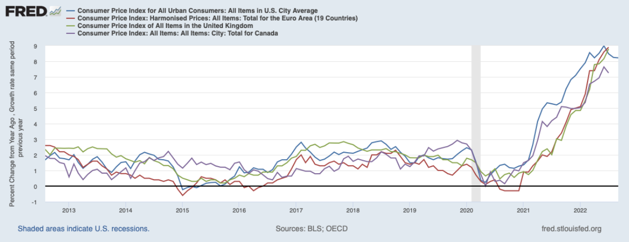
Marsal, Rabitsch, Kaszab

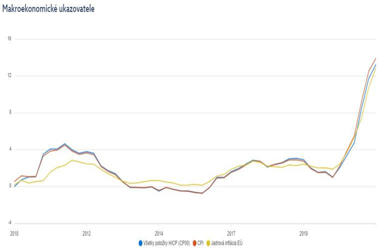
NBU Open Research Seminar

Contents

THE BURST OF HIGH INFLATION

- Inflation in most western advanced economies has been rising at a fast pace





Trend inflation matters for recent surge in prices

Inflation expectations

trend + cyclical component (permanent vs. transitory)

$$\pi = \pi^{trend} + \pi^{c} \tag{1}$$

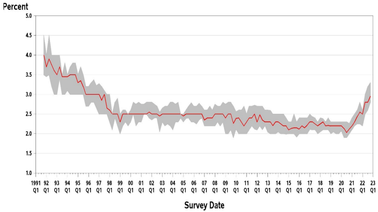
New Keynesian PC provides a way to think about it

$$\pi_t = \beta E_t \pi_{t+1} + \kappa(y_t - y_t^*) \tag{2}$$

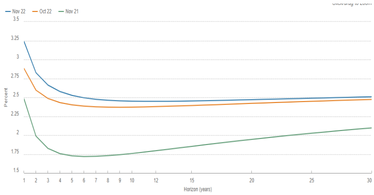
Long-run inflation expectation anchored to the trend component.
Inflation is heading where people expect inflation to go.

Trend inflation

10Y inflation expectations in US (markets)

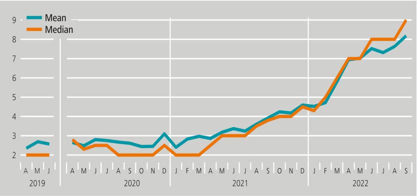


10Y inflation expectations from Swaps



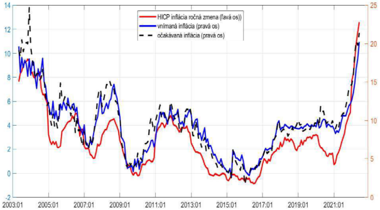
Source: Federal Reserve Bank of Cleveland calculations based on data from Blue Chip, Bloomberg, Bureau of Labor Statistics,Federal Reserve Bank of Philadelphia, Federal Reserve Board, Haver Analytics, and the model of Haubrich, Pennacchi, and Ritchken, 2012."Inflation Expectations, Real Rates, and Risk Premia: Evidence from Inflation Swaps." Review of Financial Studies, 25(5).

Inflation Expectations in EU



Source: Deutsche Bundesbank Online Panel Households (BOP-HH). * Question: What do you think the rate of inflation/deflation

Inflation Expectations Slovakia



Most of empirical and theoretical economics ...

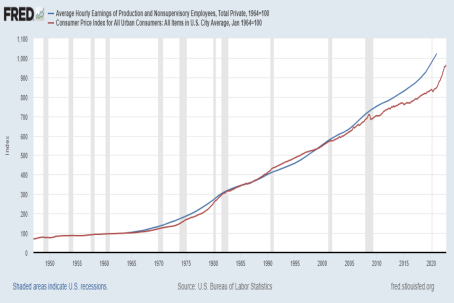
predicts that the costs of permanent inflation are small.

- money is neutral in the medium to long run
- The argument is that nominal income can adjust for anticipated inflation, leaving people almost as well off as they would have been in the absence of inflation
- McCandless and Weber (1995) find that inflation rates are not correlated with real output growth across countries.

Table 3
Correlation Coefficients for Money Growth and Real Output Growth*
Based on Data From 1960 to 1990

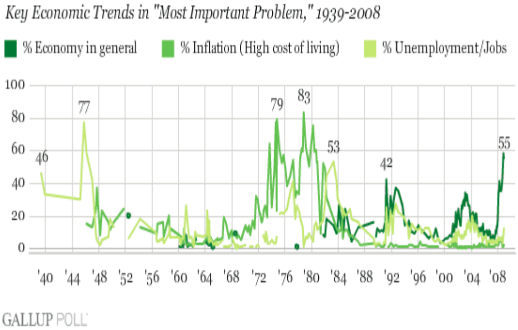
Sample	Coefficient for Each Definition of Money M0	M1	M2
All 110 Countries	−.027	−.050	−.014
Subsamples			
21 OECD Countries	.707	.511	.518
14 Latin American Countries	−.171	−.239	−.243

*Real output growth is calculated by subtracting changes in a measure of consumer prices from changes in nominal gross domestic product.
Source of basic data: International Monetary Fund



People hate inflation

Di Tella et.al., AER, 2001; **Shiller, Robert J.**, 1997



Inflace je rakovina, která rozleptá společnost

M. Mora, viceguvernér ČNB (Seznam Zprávy 4. 6. 2022, rubrika Očima byznysu)

A1. Do you think that controlling inflation should be a high priority for the US government and its agencies?

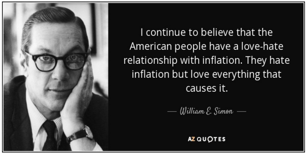
[Circle one number]

1. Yes, strongly agree	[59%]	[n=118]
2. Yes, agree somewhat	[33%]	
3. Neutral or no opinion	[1%]	
4. No, disagree somewhat	[4%]	
5. No, strongly disagree	[3%]	

A7. When you go to the store and see that prices are higher, do you sometimes feel a little angry at someone?

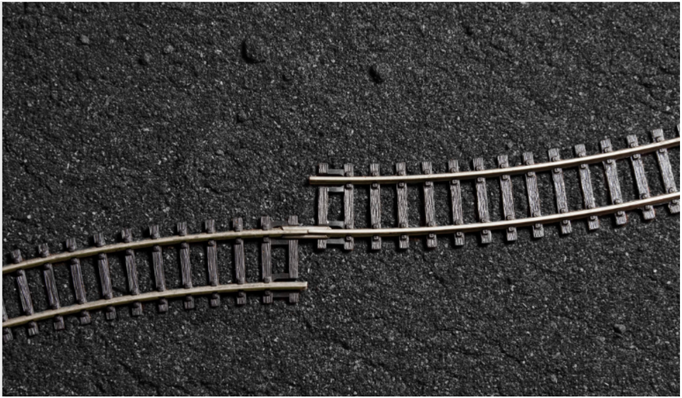
[Circle one number]

1. Yes, often	[38%]	[n=120]
2. Yes, sometimes	[48%]	
3. Never	[15%]	



Why, exactly, is higher inflation so bad?

Misalignment in relative prices



Story behind the mechanism

Example of firm adjusting to 10% inflation. Lvivske 5% up to keep market share, Obolon 15% up to minimize menu costs. Consequent catching up in relative prices starts inflation spiral.

Figure: CPI Jan 2022

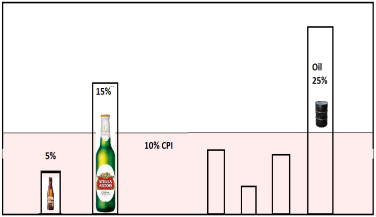
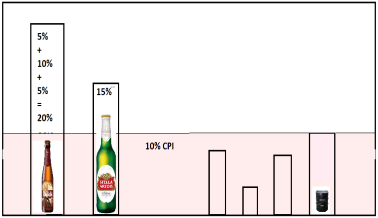


Figure: CPI Jan 2023



What the modern monetary theory tells us?

Taylor Principle, $\phi_\pi > 1$

... some well known stuff

$$i_t = \phi_\pi \pi_t \tag{3}$$

Generalized Taylor principle (Determinacy region)

$$i_t = \bar{\imath} + \phi_\pi(\pi_t - \pi^{trend}) + \phi_y\left(y_t - y_t^*\right) \tag{4}$$

What you should do in presence of price inflation spiral?

1. dispersion of prices across products can important source of inflation instability
   - trend inflation (2022 inflation outbreak)
   - real rigidities (break down of value chains - DRS)
2. to anchor inflation expectations in the presence of previously unnoticed price dispersion spiral: very aggressive response to inflation together with resignation on stabilizing real side of the economy

$\phi_\pi = \text{LARGE}; \ \phi_y = 0$

Empirical evidence for price dispersion

- No direct evidence but can be inferred from inflation expectations of price setters
- Bernanke, 2007: *Businesses are after all the price setters in the first instance*
- Coibion et.al. (2018) document remarkable agreement between firms' expectations of their future price changes and their subsequent price decisions.
- Albagli (2022) find that firms' inflation expectations are a critical factor shaping their pricing decisions.
  - firms operate as if they were located on different islands and learn from a subset of islands they have trade with (firms form their beliefs based on local conditions)
  - supply-chain inflation displays significant dispersion across firms
  - this is reflected in disagreement in inflation forecast
  - which is reflected in their pricing decisions (firm level PC)

Inflation spreads out distribution of prices

Candia et.al. (2021), US firms although distinct from HH feature similar pattern

Figure: U.S Household Survey Inflation Expectations

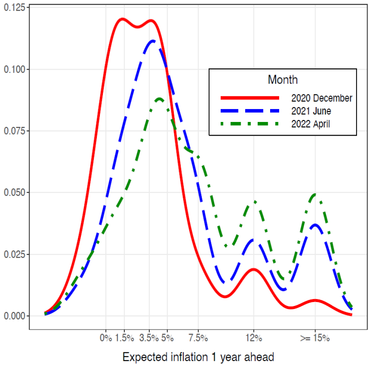
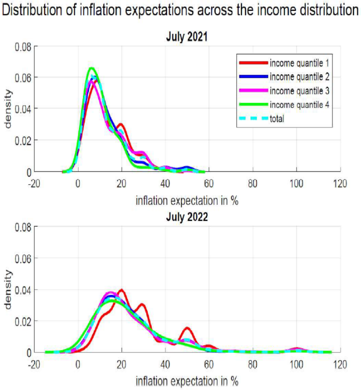


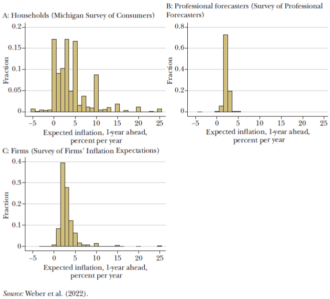
Figure: SK Household Survey Inflation Expectations



Inflation uncertainty impacts consumption saving decision

Figure: Treasury yield premium model

Figure: Cross-sectional Dispersion in Expectations



Mankiw, Reis, and Wolfers (2004), Weber et.al. (2022) report significant disagreement in expectations of HH's, firms and professional forecasters. Drenik and Perez (2014) show uncertainty increases price dispersion.

Where are we standing . . . ?

- Long-run inflation expectations are well above zero (price stability)
- Trend inflation (low frequency component of inflation) up
- Prices are more dispersed across products
- Uncertainty about future inflation increased - it is harder to predict

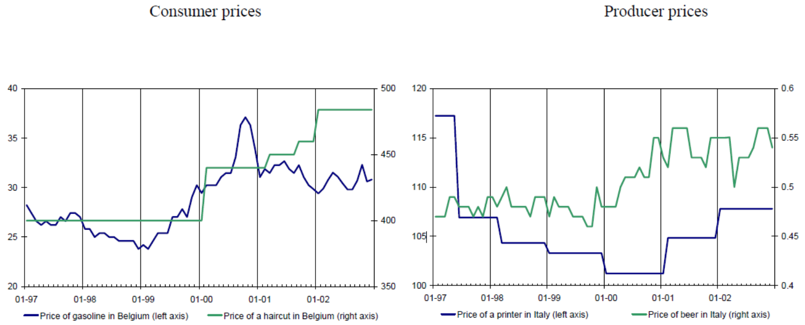
Where I am heading?

- how current situation changes the rules of the game for monetary policy
- NK DSGE model with Calvo pricing solved non-linearly

Contents

Prices are rigid

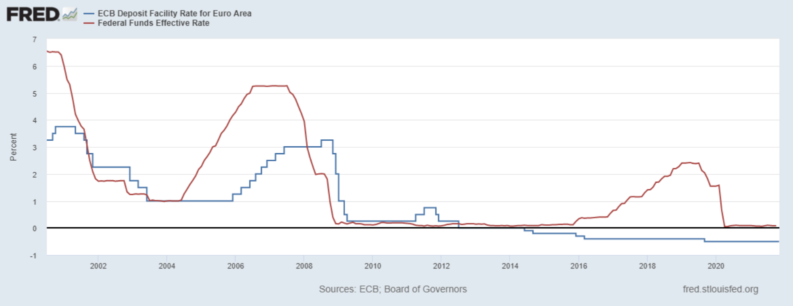
- Large amount of research has confirmed that prices adjust to the new economic environment in a sluggish way
  - *Klenow and Kryvtsov (2008), Eichenbaum, Jaimovich, Rebelo, and Smith (2014), Dhyne, Alvarez, Le Bihan, Veronese,Dias, Hoffmann, Jonker, Lunnemann, Rumler, and Vilmunen (2006) and Klenow and Malin (2010)*



Note : Actual examples of price trajectories, from the Belgian CPI and Italian PPI databases (See Aucremanne and Dhyne (2004) and Sabbatini (2005)). Prices are in Belgian Francs and Euro, respectively.

Central bank justification

- The fact that firms do not adjust their prices quickly enough in response to market changes leads to misallocation of resources and losses of aggregate output
- By regulating the price of money the monetary authority aims at internalizing the price externality caused by nominal rigidity



Why are prices sticky?

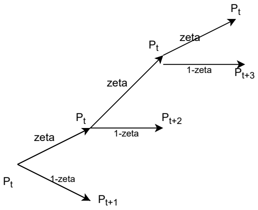
We do not really know...

- **Calvo pricing**
- **Taylor pricing**
- **Rotemberg pricing**
- Price fixed points, rational inattention, information frictions, money in the utility function

Calvo pricing

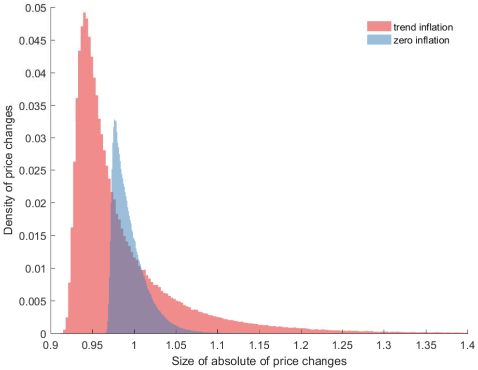
Calvo fairy

- Calvo fairy is in old fairytale from Kyiv. Each morning when Kyiv firms wake up, an exogenous fraction are visited by the Calvo fairy, a benevolent spirit who lives in Richard's castle. After the visit they have the privilege to change their price.



Non-linear solution

1. preserves distribution of prices across product varieties and break certainty equivalence
2. trend inflation



Departure: standard NK model

Households

$$U(C_t, N_t) = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\varphi}}{1-\varphi} + \chi_0 \frac{(1-N_t)^{1-\chi}}{1-\chi} \right], \qquad \varphi,\, \chi > 0, \tag{5}$$

subject to the flow budget constraint:

$$B_t + P_t C_t = W_t N_t + D_t + R_{t-1} B_{t-1} - \tau_t. \tag{6}$$

Departure: standard NK model

Firms

$$E_t \left\{ \sum_{k=0}^{\infty} \zeta^k Q_{t,t+k} \frac{P_t}{P_{t+k}} \left[P_t(i) Y_{t+k}(i) - P_{t+k} W_{t+k} N_{t+k}(i) \right] \right\}, \quad (7)$$

$$(p_t^*)^{1+\frac{\theta\epsilon}{1-\theta}} = \frac{\epsilon}{\epsilon - 1} \sum_{k=0}^{\infty} \Upsilon_{t+k} MC_{t+k}, \quad (8)$$

where $\Upsilon_{t+k} = \frac{\zeta^k E_t Q_{t,t+k} \Pi_{t+k}^{\frac{\epsilon}{1-\theta}} Y_{t+k}}{\sum_{k=0}^{\infty} \zeta^k E_t Q_{t,t+k} \Pi_{t+k}^{\epsilon-1} Y_{t+k}}$,

Monetary Policy

$$\log(i_t) = \log(\bar{\imath}) + \phi_\pi [\log(\Pi_t) - \log(\overline{\Pi})] + \phi_Y \log\left(\frac{Y_t}{\bar{Y}}\right), \quad (9)$$

Price dispersion

Where does it come from?

Firms produce goods,

$$Y_t(i) = A_t \bar{K}^{\theta} (N_t(i))^{1-\theta}, \tag{10}$$

To sell their output, firms face downward sloping demand curve for their goods,

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} Y_t. \tag{11}$$

Workers are all the same and the aggregation of hours worked is $N_t = \int_0^1 N_t(i) di$. Aggregation thus delivers,
$N_t = \left(\frac{Y_t}{A_t K^{\theta}} \right)^{\frac{1}{1-\theta}} \int_0^1 \left(\frac{P_t(i)}{P_t} \right)^{-\frac{\epsilon}{1-\theta}} di$
which can be re-written as

$$Y_t = S_t^{-1} A_t \bar{K}^{\theta} N_t^{1-\theta}, \tag{12}$$

where variable $S_t^{\frac{1}{1-\theta}} = \int_0^1 \left(\frac{P_t(i)}{P_t} \right)^{\frac{-\epsilon}{1-\theta}} di$ defines price dispersion.
S_t^{-1} measures the costs of misalignment in relative prices.

Price dispersion

Aggregation

We can use the Calvo (1993) result and rewrite $S_t^{\frac{1}{1-\theta}}$ recursively as

$$S_t^{\frac{1}{1-\theta}} \equiv \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{\frac{-\varepsilon}{1-\theta}} di, \qquad (13)$$

$$= (1-\zeta)(p_t^*)^{\frac{-\varepsilon}{1-\theta}} + \zeta(\Pi_t)^{\frac{\varepsilon}{1-\theta}} S_{t-1}^{\frac{1}{1-\theta}}.$$

Note that this can be done because of the assumption of the exogenous probability of price adjustments in Calvo.

$$S_t^{\frac{1}{1-\theta}} = (1-\zeta)\left[\frac{1-\zeta(\Pi_t)^{\epsilon-1}}{1-\zeta}\right]^{\frac{\epsilon}{(\epsilon-1)(1-\theta)}} + \zeta(\Pi_t)^{\frac{\epsilon}{1-\theta}} S_{t-1}^{\frac{1}{1-\theta}}. \qquad (14)$$

- upper and lower bound on inflation

Price dispersion spiral

Definition

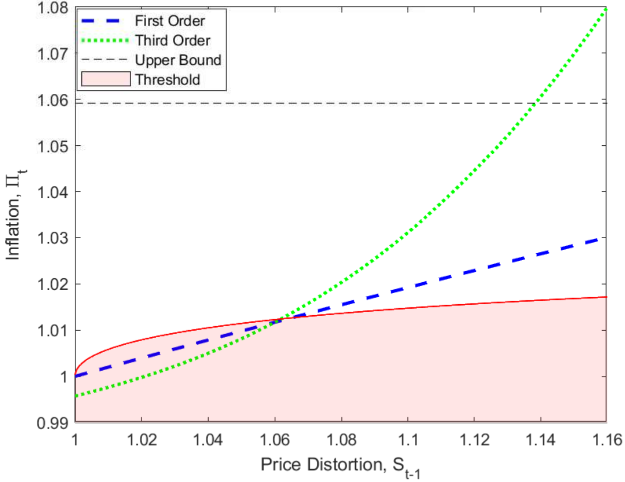
Inflation for which,

$$S_t > S_{t-1} \tag{15}$$

- if prices are widely dispersed in the economy the dispersion will become self-reinforcing
- the higher the steady state of inflation the higher is the probability that exogenous inflationary shocks will trigger this price-inflation spiral
- Trend inflation spreads out the distribution of prices as those firms which cannot change their low prices are left behind further and further from the optimal price as the price level grows. When these firms can finally change their price they create large inflation

What inflation triggers price dispersion spiral?

Inflation above 6%



The (red) line defines the inflation threshold, $\Pi^{threshold}$. Outside the (red-shaded) stability region, where $S_t < S_{t-1}$, price dispersion triggers a self-enforcing inflation spiral. Policy function from first (blue) and third (green) order perturbation solution illustrate that the unstable dynamics may arise already at mild inflation levels far below the inflation upper bound.

Contents

Model Solution Methods

- traditionally macroeconomic dynamics have been studied primarily in terms of (log-)linear approximations to the true model solution
  - no price dispersion: linear model approximate price distribution by a line
  - uncertainty about future enters the decision function of agents because of certainty equivalence
    - I might not buy a house today even if I am having good times because I am uncertain about future development

Model Solution Methods

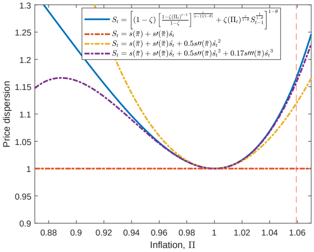


Figure: Approximation at $\pi = 0\%$.

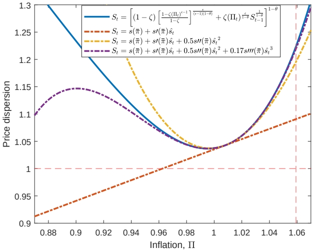


Figure: Approximation at $\pi = 4\%$.

Blue solid line, S_t, represents price dispersion as a function of Π_t, as given by equation (14), at point $S_{t-1} = \bar{S}$. Dash-dotted lines are first (red), second (yellow) and third (purple) order approximations of S_t at $\pi = 0\%$ and at $\pi = 4\%$. Light red Horizontal and vertical dashed lines represent the lower bound on S_t and upper bound on Π_t.

Contents

What should MP do to anchor inflation expectations?

...in the non-linear world with uncertainty and dispersion of prices...

Determinacy

- Bullard and Mitra (2002) and Blanchard and Kahn (1980) show that the economy outcome to have the only (stationary) equilibrium, $x_t = H(E_t x_{t+1})$, eigenvalues of matrix H should lie within the unit circle.
- The size of those eigenvalues now depends on the policy coefficients in $i_t = \bar{\imath} + \phi_\pi(\pi_t - \pi^{trend}) + \phi_y\,(y_t - y_t^*)$,

Stability

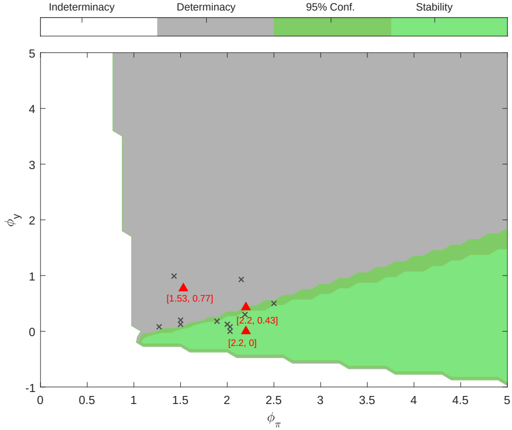
- $S_t < S_{t-1}$

$$H\left(\Pi | (S_{t-1} = S_t)\right) \geq \max\left(\hat{\mathbf{h}}(P_1(S, A), \gamma, \sigma), \ldots, \hat{\mathbf{h}}(P_{99}(S, A), \gamma, \sigma)\right) \tag{16}$$

Monetary Policy

Anchoring inflation expectations

$$i_t = \bar{\imath} + \phi_\pi(\pi_t - \pi^{trend}) + \phi_y(y_t - y_t^*)$$



Note: Simulated determinacy (gray) and stability (green) region. Gray 'x' marks correspond to other empirically found Taylor rule coefficients in the literature.

Anchored vs. de-anchored expectations

Global solution doesn't exists outside of the stability region

	$\phi_\pi = 2.5,\ \phi_Y = 0$			$\phi_\pi = 2.2,\ \phi_Y = 0.43$		$\phi_\pi = 1.53,\ \phi_Y = 0.77$	
	1st order	3rd order	global	1st order	3rd order	1st order	3rd order
Moments of macroeconomic variables							
std(C)	2.73	2.74	2.74	2.43	4.47	2.16	16.37
std(N)	0.93	0.94	0.94	1.21	2.20	1.47	11.89
std(i)	1.76	1.76	1.76	3.72	6.23	5.55	39.54
std(π)	0.70	0.70	0.70	2.89	5.01	4.94	36.12
Behavior of price dispersion and implied output loss, $\Delta_t = 100\left(1 - S^{-1}\right)$							
mean(Δ)	-0.00	0.05	0.05	-0.00	0.87	-0.00	1.85
std(Δ)	0.00	0.06	0.06	0.00	2.11	0.00	14.02
max(Δ)	0.00	0.42	0.43	0.00	16.85	0.00	67.47
min(Δ)	-0.00	0.00	0.00	-0.00	-7.76	-0.00	-143.34
$\pi_t > \pi^{upper}$	0.00	0.00	0.00	0.00	0.67	0.00	20.35
$S < 1$	0.00	0.00	0.00	0.00	12.63	0.00	44.98

No-existence of global solution

why no global solution...?

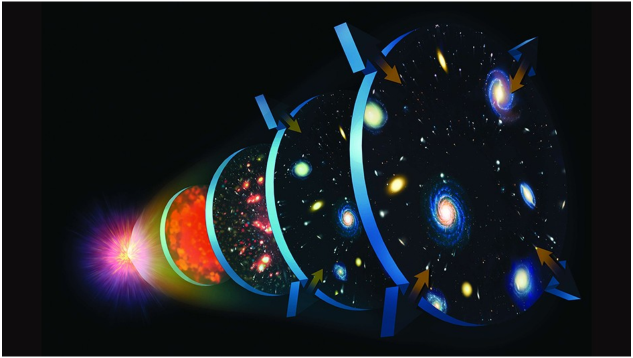
- we look for the (nonlinear) policy function $S_t = h(S_{t-1}, A_t)$ as the fixed point of the nonlinear system of difference equations implied by the DSGE model.
- problem: for some value of (low) A_t (that implies high Π_t), the relevant state space in the S_{t-1}-dimension becomes unbounded $<==>$ no specified S_{t-1} grid is large enough, S_t always falls outside of that grid (because $S_t > S_{t-1}$ when in the instability region $\Pi_t > \Pi^{threshold}$)
- enlarging the S_{t-1}-grid further is of no help; the new S_t will again fall outside the enlarged S_{t-1}-grid

No-existence of global solution

More intuition

The state variable S_t increases the solution space at faster rate

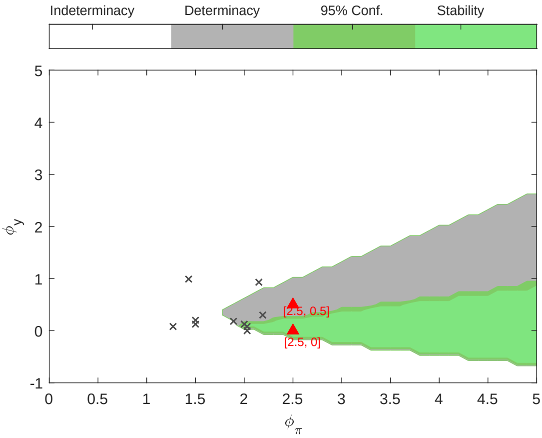
$$S_t^{\frac{1}{1-\theta}} = (1-\zeta)\left[\frac{1-\zeta(\Pi_t)^{\epsilon-1}}{1-\zeta}\right]^{\frac{\epsilon}{(\epsilon-1)(1-\theta)}} + \zeta(\Pi_t)^{\frac{\epsilon}{1-\theta}} S_{t-1}^{\frac{1}{1-\theta}}$$



Note: Expanding universe.

Trend inflation

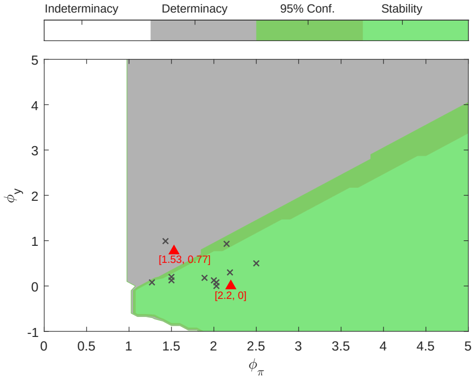
How to anchor inflation expectations in the high inflation periods like we face now?



Note: Simulated determinacy (gray) and stability (green) region. Gray 'x' marks correspond to other empirically found Taylor rule coefficients in the literature.

Real rigidity

Calvo not enough to capture effect of price stickiness on quantities. Real rigidities are the mechanism which lowers firms incentive to increase prices in the face of a rise in nominal demand.



Anchored vs. de-anchored expectations

	trend inflation					no DRS	
	$\phi_\pi = 2.5,\ \phi_Y = 0.$			$\phi_\pi = 2.5,\ \phi_Y = 0.5$		$\phi_\pi = 1.53,\ \phi_Y = 0.77$	
	1st order	3rd order	global	1st order	3rd order	1st order	3rd order
Moments of macroeconomic variables							
std(C)	3.11	3.13	3.13	5.12	104.67	2.13	10.52
std(N)	1.05	1.06	1.06	2.21	47.91	1.00	5.54
std(i)	1.80	1.79	1.79	6.11	108.81	9.02	42.60
std(π)	0.72	0.72	0.72	5.01	93.33	8.60	41.12
Behavior of price dispersion and implied output loss, $\Delta_t = 100\left(1 - S^{-1}\right)$							
mean(Δ)	0.94	1.01	0.54	0.97	-27.33	-0.00	1.72
std(Δ)	0.35	0.37	0.37	2.44	223.17	0.00	9.01
max(Δ)	1.94	2.72	2.23	7.86	99.95	0.00	52.27
min(Δ)	0.01	0.48	0.01	-5.61	-3999.1	-0.00	-71.58
$\pi_t > \pi^{upper}$	0.00	0.00	0.00	0.00	26.25	0.50	23.38
$S < 1$	0.00	0.00	0.00	35.57	38.42	0.00	42.56

Contents

Economic Channels

Marginal Cost Channel

$$Y_t^* = A_t \bar{K}^{\theta} N_t^{*(1-\theta)}$$

$$MC_t^* = \phi_{mc,t} MC_t \qquad \text{where} \qquad \phi_{mc,t} = \frac{\left(\frac{P_t^*}{P_t}\right)^{-\frac{\theta\epsilon}{1-\theta}}}{\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{\frac{-\epsilon}{1-\theta}} di}$$

Trend-Inflation Markup Channel

PV of Marginal Revenues = PV of Marginal Costs

$$\sum_{k=0}^{\infty} \zeta^k E_t Q_{t,t+k} \Pi_{t+k}^{\epsilon-1} Y_{t+k} \left(\frac{P_t^*}{P_t}\right)^{1+\frac{\epsilon\theta}{1-\theta}} = \frac{\epsilon}{\epsilon-1} \sum_{k=0}^{\infty} \zeta^k E_t Q_{t,t+k} \Pi_{t+k}^{\frac{\epsilon}{1-\theta}} Y_{t+k} MC_{t+k}(i)$$

Contents

Globaly solved models

- There are several papers in the (optimal) monetary policy literature using the framework we describe solved by projection methods (i.e. Anderson (2010), Leith (2014) and Miao and Ngo (2019)).
- None of these papers report issues with stability.

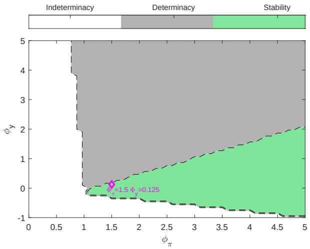


Figure: Approximation at $\pi = 0\%$.

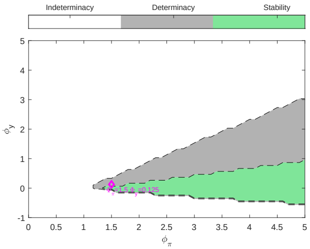


Figure: Approximation at $\pi = 4\%$.

Macro-finance Model

- price-dispersion spiral is relevant and quantitatively pronounced in widely used modeling framework of term structure of interest rates
- Rudebush and Swanson (2012)

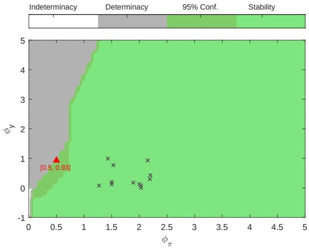


Figure: Approximation at $\pi = 0\%$.

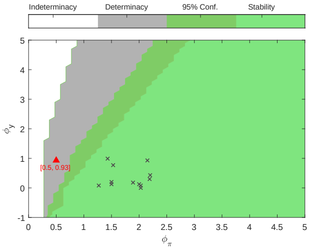


Figure: Approximation at $\pi = 4\%$.

Macro-finance Model

Unconditional Moment	US data 1961-2007	RS replication $\bar{\pi}=0$	RS with trend inflation $\bar{\pi}>0$	RS with linear $N_t(i)$ in PF $\bar{\pi}>0$	RS with $2\times\phi_\pi$ on π_t $\bar{\pi}>0$	RS indexation $\bar{\pi}>0$	RS Rotemberg pricing $\bar{\pi}>0$	RS Taylor pricing $\bar{\pi}>0$
Moments of macroeconomic variables								
std(C)	0.83	0.88	10.59	0.54	1.20	0.89	0.50	0.70
std(N)	1.71	2.51	30.01	1.42	2.91	2.50	1.50	1.82
std(i)	2.71	3.41	38.69	2.49	2.97	3.43	2.13	3.07
std(π)	2.52	3.01	32.92	2.35	1.98	2.98	2.14	2.78
Moments of finance variables								
std($i^{(40)}$)	2.41	3.94	4.79	5.42	4.16	5.24	4.03	4.34
mean($NTP^{(40)}$))	1.06	0.91	3.68	0.65	1.66	1.08	0.84	1.47
std($NTP^{(40)}$)	0.54	0.42	7.04	0.11	0.98	0.55	0.36	0.13
Behavior of price dispersion and implied output loss, $\Delta_t = 100\left(1 - S^{-1}\right)$								
violation of $\pi_t \leq \pi^{upper}$	-	0.05	7.46	0.00	0.06	0.11	0.00	0.00
violation of $S \geq 1$	-	8.77	51.50	0.08	45.68	12.95	0.00	19.10
mean(Δ)	0.4	0.55	-1.24	0.29	0.45	0.52	0.76	0.10
std(Δ)	-	0.99	61.87	0.35	1.73	1.03	0.88	0.15
max(Δ)	-	17.45	98.55	4.94	26.14	41.00	0.00	4.25
min(Δ)	-	-7.48	-6227.45	-0.42	-14.80	-7.17	0.00	-0.12

Contents

Empirical validation of price dispersion spiral

- Calvo pricing mechanism is a shortcut to modeling of nominal rigidities without having solid microeconomic fundation (Nakamura and Steinsson (2018), Alvarez et.al. (2018) and many others put Calvo at test).
- As long as the model delivers realistic predictions (matches moments and impulse response functions) about the economy under scrutiny it can be used to explain observable data; only in a linear setting
- It remains to be determined if Calvo pricing is an ideal tool to model nominal rigidities in non-linear model.