Rationing Under Sticky Prices

Tom Holden

Deutsche Bundesbank

Slides available at https://www.tholden.org/. EXTREMELY PRELIMINARY!

Sticky prices lead to rationing

- If a firm cannot adjust its nominal price, then its real price will decline over time at the rate of inflation.
- A lower real price implies higher demand for its good. Higher demand means higher marginal costs.
- Eventually, its marginal costs (rising) will be greater than its price (falling) if it continues to meet all demand.

- No firm wants to sell at a price below marginal cost. Instead, it should stop producing, rationing demand.
- Yet essentially all the prior sticky price literature (Calvo or menu cost) assumes that firms always meet all demand.

- This paper: What are the macroeconomic implications of allowing firms to ration?
- Findings: Rationing generates a convex Phillips curve. Rationing massively reduces the welfare costs of inflation.

Does rationing matter in practice?

"Mark-ups are 10%, inflation is 2%, prices are updated at least once per year, real prices will not hit marginal cost."

- But: firm demand: $y \propto \left(\frac{p}{P}\right)^{-\epsilon}$ ($\epsilon \approx 10$) and marginal costs: $mc \propto y^{\frac{\alpha}{1-\alpha}}$ ($\alpha \approx \frac{5}{9}$), so $mc \propto \left(\frac{p}{P}\right)^{-\epsilon\frac{\alpha}{1-\alpha}} \approx \left(\frac{p}{P}\right)^{-12.5}$.
  - In the short run, some labour and intermediate inputs are fixed ($\approx \frac{1}{3}$ at annual freq. (Abraham et al. 2024)) $\Rightarrow \alpha \approx \frac{5}{9}$.
- So: A 2% fall in real prices increases marginal costs by 25%. Good-bye mark-ups! Hello rationing!
- Additionally:
  - Firms face high frequency demand fluctuations. Mark-ups are much lower at times of high demand.
  - Inflation can be much higher than 2%. It was near 10% post-Covid!
  - Marginal costs are also rising over time if not all capital depreciation can be fixed quickly.
  - Demand is growing over time due to aggregate income growth. A 2% increase in aggregate demand increases MC by 2.5%.

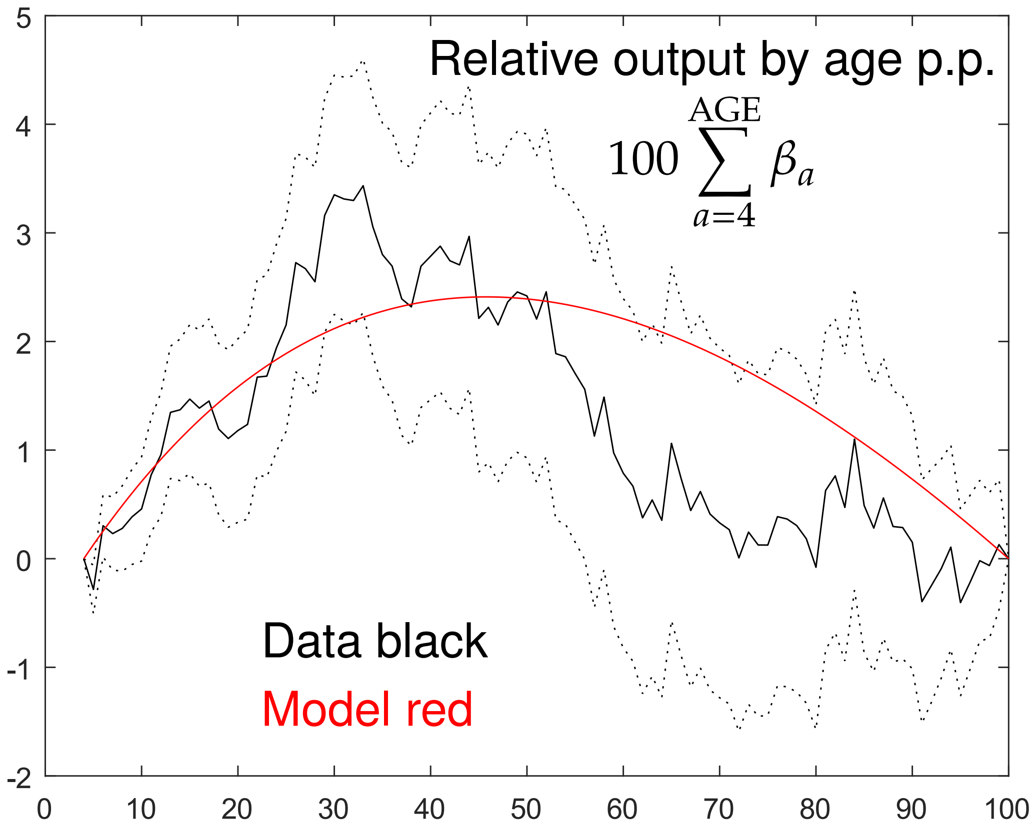
Empirical evidence for rationing

- Cavallo & Kryvtsov (2023) find that around 11% of all consumer goods were out of stock (=rationing) in 2019.
- In 2022 (Jan-Aug), this number went up to around 23%. In line with my story: high inflation ⇒ high rationing.
  - Cavallo & Kryvtsov (2023) stress causality in the opposite direction. (Stockouts lead to inflation.)

- I'll show: Quantities sold are concave in price age, in line with goods with old prices being rationed.
- I'll show: Rationing helps match the immediate response of output to cleanly identified monetary policy shocks.
  - "Clean" monetary shock papers: Miranda-Agrippino & Ricco (2021), Bauer & Swanson (2023).
- I'll also show: Rationing helps match the estimated convexity of the Phillips curve (Forbes, Gagnon & Collins 2022).

- Almost all evidence supporting your favourite sticky price model will also support that model with rationing added.
  - This paper is not about a new model. It is about removing one approximation (no rationing) used in solving old models.

Average output growth over the life of a price



Price age in weeks

Effect is identified up to a linear trend.

99% confidence band.

Data: Dominick's Finer Foods (1989-1994)

21,474,126 observations after dropping ∀ products, stores:

First/last price, any price ≠ cumulative max price, one week after each price change/missing, one obs. due to Δ, any price older than four years.

Specification (estimated via FGLS):

$$\frac{y_{i,j,t} - y_{i,j,t-1}}{\bar{y}_{i,j}} = \beta_{A(i,j,t)} + \gamma_{i,t} + \sigma^{(1)}_{i,A(i,j,t)} \sigma^{(2)}_{i,j} \sigma^{(3)}_{i,t} \varepsilon_{i,j,t}$$

i indexes narrow categories (92) × stores (93)

j indexes products × prices (947,660)

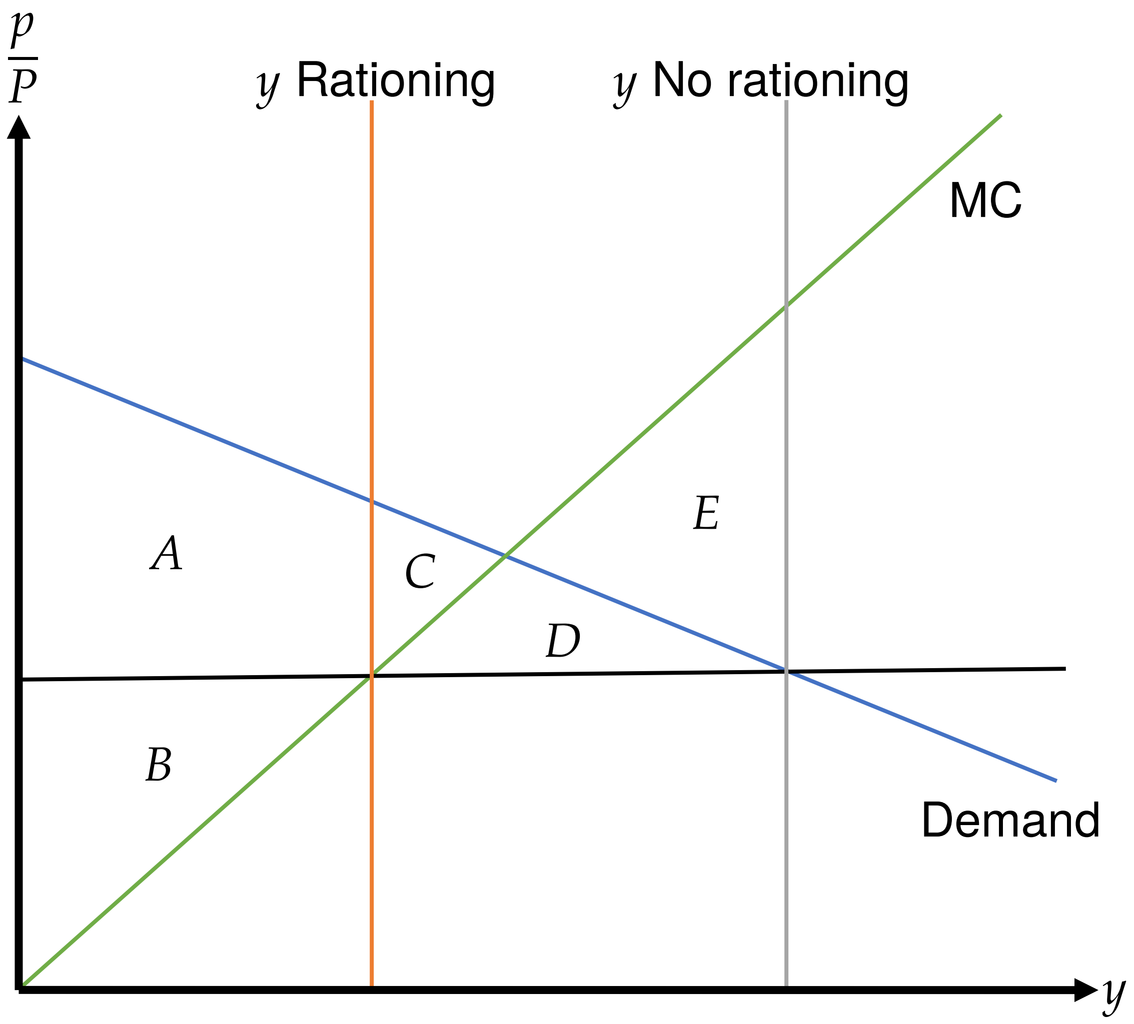
t indexes weeks (398)

$A(i,j,t)$ is the "age" of the i,j price at t

$\bar{y}_{i,j}$ is average output over the life of the price.

Standard errors 3-way clustered: $(i, A(i,j,t))$, (i,t) & (i,j).

The microeconomics of rationing vs excess production



- Without rationing: CS is $A + C + D$. PS is $B - D - E$.
- Without rationing: Welfare is $A + B + C - E$.
- With rationing: CS is A. PS is B. Welfare is $A + B$.
- Welfare is higher with rationing when $E > C$.
- Plausible as demand ($\propto y^{-\frac{1}{\epsilon}}$) is flatter than MC ($\propto y^{\frac{\alpha}{1-\alpha}}$).
- The economy with rationing should be less distorted!

The macroeconomics of rationing vs excess production

- If too much is produced by some firms (with old prices), other firms face higher marginal costs, so produce less.
- Demand is shifted from undistorted firms (with new prices) to distorted ones (with old prices).
- Bad!

- If demand is rationed for some goods (with old prices), other firms face lower marginal costs, so produce more.
- Demand is shifted from distorted firms (with old prices) to undistorted ones (with new prices).
- Good!

Rationing vs supply disruptions / constraints

- Ever Given / Covid / Ukraine drew attention to the importance of supply disruptions and supply constraints.

- Supply disruptions imply large increases in firm marginal costs.

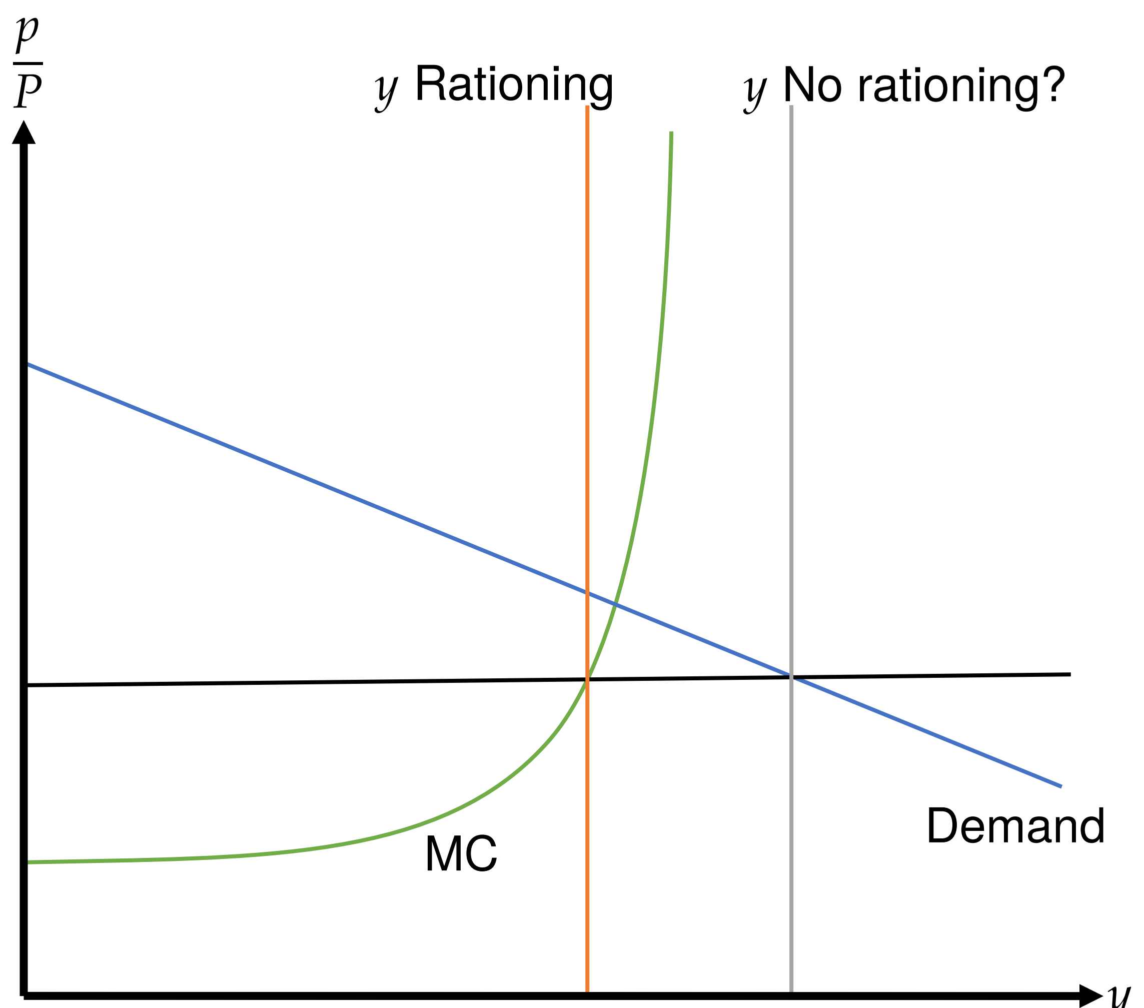
  - Still MC is never infinite. If you're prepared to pay an astronomical amount for a production input, you can always obtain it.

- With flexible prices, the price increases proportionally, and there are no stock outs.

- But during Covid we saw a lot of stock outs! And waiting times for some goods (e.g. cars) increased significantly.

- Best understood as rationing due to sticky prices. For some reason, toilet paper (etc.) prices couldn't increase.

Sticky prices with near vertical marginal costs



- Holding macro quantities fixed, there is no way to have equilibrium in this (micro) market without rationing.
- Total cost to produce "y No rationing" is infinite.
- So, what happens?
- As we climb the green line, an ever-increasing share of the economy's productive capacity goes to this market.
- $\Rightarrow$ Aggregate output falls.
- $\Rightarrow$ Lower demand for this good at any price.
- Macro quantities move to clear this micro market!
- Is this really plausible???
- Rationing seems more reasonable.

Strange properties of the Calvo model

- The Calvo model has some deeply strange properties (Holden, Marsal & Rabitsch 2024).
  - It implies a hard upper bound on steady-state inflation. With standard parameters, this is 5% to 10%.
  - Inflation above this level reduces the output *growth rate* not just the output level, due to ever growing price dispersion.
  - Under standard monetary rules, temporary high inflation can push the economy to this growing price dispersion path.

- These strange properties are tightly linked to the losses made by firms forced to sell at prices below marginal cost.

- When rationing is allowed, these strange properties disappear. Additional motivation for looking at it.

Answers to some potential doubts about rationing

- Why don't firms just change prices, rather than rationing?
  - By revealed preference, firms that can ration make higher profits than firms that cannot. Under rationing, profits always >0.
  - Since profits are higher when rationing is allowed, lower menu (etc.) costs are needed to justify the observed price stickiness.

- Doesn't rationing make output implausibly variable, or implausibly sensitive to conditions?
  - Rationing limits the increase in output following expansionary shocks, actually reducing output variability.
  - Firms can calculate their maximum production quantity before demand realised. Limits on overtime labour not implausible!

Prior literature

- Early:
  - Drèze (1975) Barro (1977), Svensson (1984), Corsetti & Pesenti (2005) (restrict shocks to ensure no rationing).
- Stockouts in inventory models:
  - Alessandria, Kaboski & Midrigan (2010), Kryvtsov & Midrigan (2013), Bils (2016).
  - In these papers, firms always meet demand if they have stock available, even if marginal value of that stock > price.
- Rationing under sticky wages: Huo & Ríos-Rull (2020), Gerke et al. (2023): Infinite dimensional state, numerical.
- Rationing under sticky prices: Hahn (2022): Only steady state results. No dynamics. No idiosyncratic shocks.
- Other related work:
  - Continuous time NK models: Posch, Rubio-Ramírez & Fernández-Villaverde (2011), (2018)
  - Endogenous price adjustment frequency: Blanco et al. (2024).

The model

Basics: Set-up, households, monetary policy

- The model is in continuous time, with no aggregate uncertainty, just MIT shocks.

- In period τ, households maximize: $\int_\tau^\infty e^{-\int_\tau^t \rho_v \, d_v} \left[\log Y_t - \Psi_t \frac{1}{1+\nu} L_t^{1+\nu}\right] dt$ where $\nu > 0$, $\Psi_t > 0$, $\rho_t > 0$.

- They face the budget constraint: $Y_t + \frac{\dot{B}_t^{(i)}}{P_t} + \dot{B}_t^{(r)} = W_t L_t + i_t \frac{B_t^{(i)}}{P_t} + r_t B_t^{(r)} + \mathrm{T}_t$.

  - $B_t^{(i)}$ nominal bonds. $B_t^{(r)}$ real bonds. Y_t output = consumption, at price P_t. W_t wage. L_t labour. T_t profits from owning firms.

- FOCs imply $\Psi_t L_t^\nu = \frac{W_t}{Y_t}$, $r_t = \rho_t + \frac{\dot{Y}_t}{Y_t}$, $i_t = r_t + \pi_t$, where $\pi_t = \frac{\dot{P}_t}{P_t}$.

- Monetary policy sets $i_t = r_t + \pi_t^* + \phi(\pi_t - \pi_t^*)$ with $\phi > 1$ and π_t^* an exogenous target (Holden 2024).

- From Fisher equation, $r_t + \pi_t = i_t = r_t + \pi_t^* + \phi(\pi_t - \pi_t^*)$, so $\pi_t = \pi_t^*$ for all t. Inflation is effectively exogenous.

Aggregators

- Assume firm price change opportunities arrive at rate $\lambda_t > 0$.
- The time t density of firms that last updated at τ is $\lambda_\tau e^{-\int_\tau^t \lambda_v \, dv}$. Note $\int_{-\infty}^t \lambda_\tau e^{-\int_\tau^t \lambda_v \, dv} \, d\tau = 1$.
- Index firms (and products) by the time they last updated their price, and by their demand shock ζ.
- The aggregate good is produced from intermediates by a perfectly competitive industry with technology:

$$Y_t = \left[\int_{-\infty}^t \lambda_\tau e^{-\int_\tau^t \lambda_v \, dv} \int_0^1 \zeta y_{\zeta,\tau,t}^{\frac{\epsilon-1}{\epsilon}} g(\zeta) \, d\zeta \, d\tau\right]^{\frac{\epsilon}{\epsilon-1}} \left[\int_0^1 \zeta g(\zeta) \, d\zeta\right]^{-\frac{\epsilon}{\epsilon-1}}$$

- $g(\zeta)$ is the PDF of the demand shock, which is independent across time and firms.
- For tractability, we assume $g(\zeta) = \theta \zeta^{\theta-1}$ where $\theta > 0$ (so $\zeta \sim \text{Beta}(\theta, 1)$). Mean ζ: $\frac{\theta}{\theta+1}$. Variance ζ: $\frac{\theta}{(\theta+1)^2(\theta+2)}$.
    - We will use an empirical moment not targeted by the prior literature to pin down θ.

Firm production (and rationing!) choices

- The FOC of the aggregators imply demand must satisfy: $y_{\zeta,\tau,t} \leq \left(\frac{\theta}{\theta+1}\frac{1}{\zeta}\frac{p_\tau}{P_t}\right)^{-\epsilon} Y_t$.

- Firms produce using the production technology: $y_{\zeta,\tau,t} = \left(A_t l_{\zeta,\tau,t}\right)^{1-\alpha}$. Real wage is W_t. Define $\widehat{W}_t := \frac{W_t}{A_t}$.

- Firm flow real production profits: $o_{\zeta,\tau,t} = \frac{p_\tau}{P_t}\left(A_t l_{\zeta,\tau,t}\right)^{1-\alpha} - W_t l_{\zeta,\tau,t}$. Guaranteed to be positive for small enough $l_{\zeta,\tau,t}$.

- Optimal production: There is a quantity $\bar{\zeta}_{\tau,t} := \frac{\theta}{\theta+1}\left(\frac{p_\tau}{P_t}\right)^{1+\frac{1-\alpha}{\epsilon\alpha}}\left(\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{1-\alpha}{\epsilon\alpha}} Y_t^{-\frac{1}{\epsilon}} > 0$ such that:

- If $\zeta < \bar{\zeta}_{\tau,t}$, there is no rationing, so: $y_{\zeta,\tau,t} = \left(\frac{\theta}{\theta+1}\frac{1}{\zeta}\frac{p_\tau}{P_t}\right)^{-\epsilon} Y_t$ and $A_t l_{\zeta,\tau,t} = \left[\left(\frac{\theta}{\theta+1}\frac{1}{\zeta}\frac{p_\tau}{P_t}\right)^{-\epsilon} Y_t\right]^{\frac{1}{1-\alpha}}$.

- If $\zeta > \bar{\zeta}_{\tau,t}$, there is rationing, so: $y_{\zeta,\tau,t} = \left(\frac{p_\tau}{P_t}\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{1-\alpha}{\alpha}}$ and $A_t l_{\zeta,\tau,t} = \left(\frac{p_\tau}{P_t}\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{1}{\alpha}}$.

The quasi flexible and fully flexible price cases

- The limit as $\lambda_t \to \infty$ is not fully flexible prices, as for any λ_t, firms face all possible ζ before changing price.
- Instead, the limit is quasi flexible prices, which maximize $o_{\tau,t} := \int_0^1 o_{\zeta,\tau,t} g(\zeta)\, d\zeta$.
- If $\frac{\epsilon}{\epsilon-1} \frac{\theta+\epsilon}{\theta+\frac{\epsilon}{1-\alpha}} \leq 1$ then even quasi-flex-price firms ration with positive probability (for all t), meaning $\bar{\zeta}_{\tau,t} < 1$.
  - This condition will hold in my calibration. It would be violated if α was very small, or θ was very large.

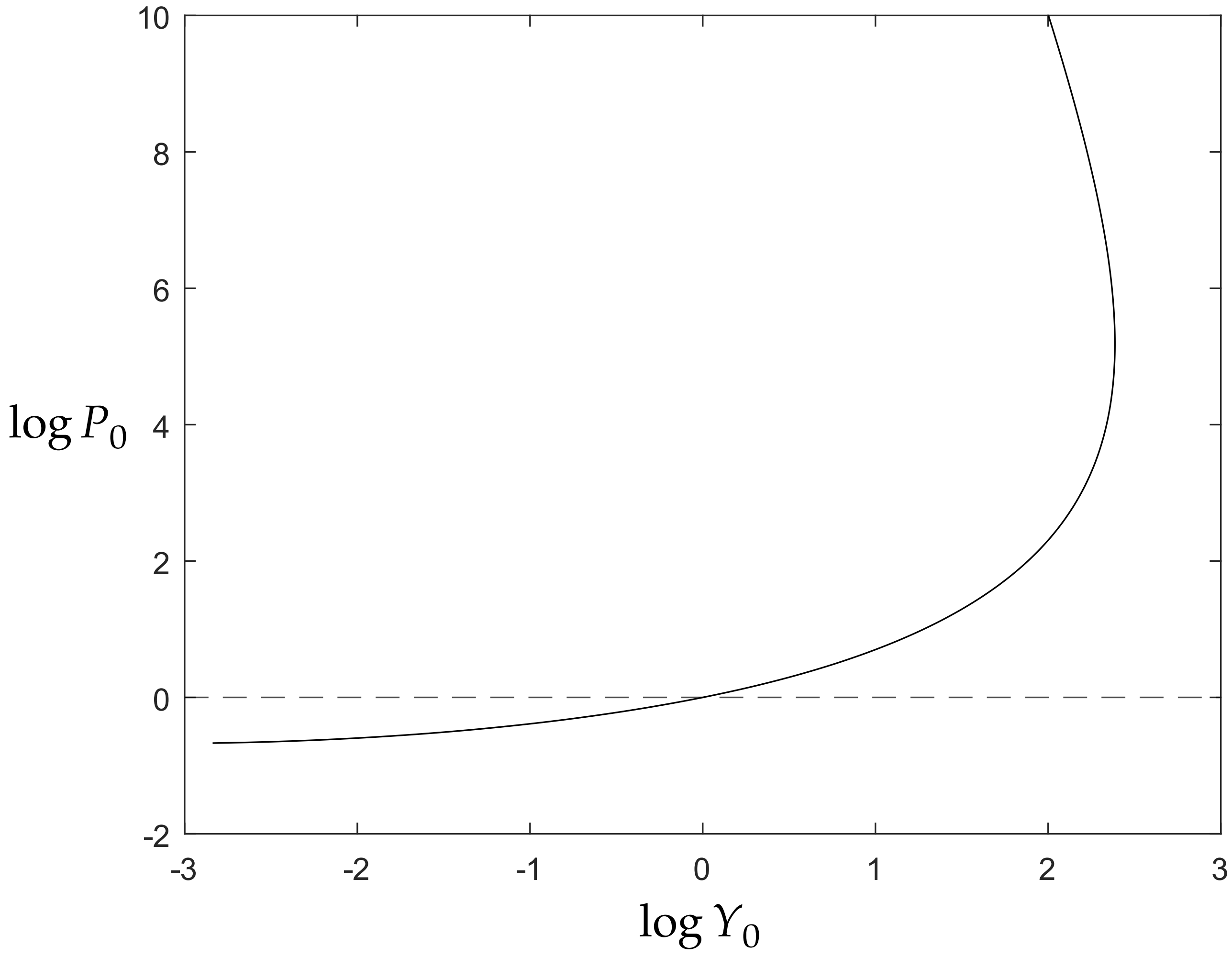
- A hypothetical fully flexible price firm would choose its price to maximize $o_{\zeta,\tau,t}$.
- Optimal choice is: $\left(\frac{p_{\zeta,\tau,t}}{P_t}\right)^{1+\epsilon\frac{\alpha}{1-\alpha}} = \frac{\epsilon}{\epsilon-1}\left(\zeta\,\frac{\theta+1}{\theta}\right)^{\epsilon\frac{\alpha}{1-\alpha}} \frac{\widehat{W}_t}{1-\alpha} Y_t^{\frac{\alpha}{1-\alpha}}$.
- Note that this is increasing in ζ, while the price of a sticky or quasi-flex-price firm is not increasing in ζ.
- Rationing reduces quantities for high ζ, like in the fully flex price case!

State variables and the short-run Phillips curve

- For $j \in \mathbb{N}$, define: $X_{j,t} := \int_{-\infty}^{t} \lambda_\tau e^{-\int_\tau^t \lambda_v \, dv} p_\tau^{\chi_j} \, d\tau$. So: $\dot{X}_{j,t} = \lambda_t \left[p_t^{\chi_j} - X_{j,t} \right]$.
- Allowing rationing, total labour demand $L_t := \int_{-\infty}^{t} \lambda_\tau e^{-\int_\tau^t \lambda_v \, dv} \int_0^1 l_{\zeta,\tau,t} g(\zeta) \, d\zeta \, d\tau$ satisfies:
  - $A_t L_t = -\frac{\epsilon}{(1-\alpha)\theta+\epsilon} \left(\frac{\theta}{\theta+1}\right)^{\theta} \left(\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{1}{\alpha}+\frac{\theta}{\epsilon}\frac{1-\alpha}{\alpha}} Y_t^{-\frac{\theta}{\epsilon}} P_t^{-\left(\theta+\frac{1}{\alpha}+\frac{\theta}{\epsilon}\frac{1-\alpha}{\alpha}\right)} X_{1,t} + \left(\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{1}{\alpha}} P_t^{-\frac{1}{\alpha}} X_{2,t}$, with $\chi_1 := \theta + \frac{1}{\alpha} + \frac{\theta}{\epsilon}\frac{1-\alpha}{\alpha}$, $\chi_2 := \frac{1}{\alpha}$.
- Additionally, from the definition of aggregate output, allowing rationing:
  - $1 = -\frac{\epsilon-1}{\theta+\epsilon} \left(\frac{\theta}{\theta+1}\right)^{\theta+1} \left(\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{\theta+\epsilon}{\epsilon}\frac{1-\alpha}{\alpha}} Y_t^{-\frac{\theta+\epsilon}{\epsilon}} P_t^{-\left(\frac{1}{\alpha}+\theta+\frac{\theta}{\epsilon}\frac{1-\alpha}{\alpha}\right)} X_{1,t} + \left(\frac{1-\alpha}{\widehat{W}_t}\right)^{\frac{\epsilon-1}{\epsilon}\frac{1-\alpha}{\alpha}} Y_t^{-\frac{\epsilon-1}{\epsilon}} P_t^{-\frac{\epsilon-1}{\epsilon}\frac{1-\alpha}{\alpha}} X_{3,t}$, with $\chi_{3,1} := \frac{\epsilon-1}{\epsilon}\frac{1-\alpha}{\alpha}$.
- Combined with the household labour FOC, these two equations give a short-run Phillips curve, holding states fixed.

- If rationing is not allowed, the equivalent two equations are:
  - $A_t L_t = \frac{\theta}{\theta+\frac{\epsilon}{1-\alpha}} \left(\frac{\theta+1}{\theta}\right)^{\frac{\epsilon}{1-\alpha}} P_t^{\frac{\epsilon}{1-\alpha}} Y_t^{\frac{1}{1-\alpha}} X_{4,t}$ with $\chi_4 := -\frac{\epsilon}{1-\alpha}$. $1 = \left(\frac{\theta+1}{\theta+\epsilon}\right)\left(\frac{\theta+1}{\theta}\right)^{\epsilon-1} P_t^{\epsilon-1} X_{0,t}$, with $\chi_0 := -(\epsilon-1)$.
  - With $X_{0,t}$ fixed, P_t is fixed. The short-run Phillips curve is horizontal in the NK model without rationing!

Plotting the short-run Phillips curve



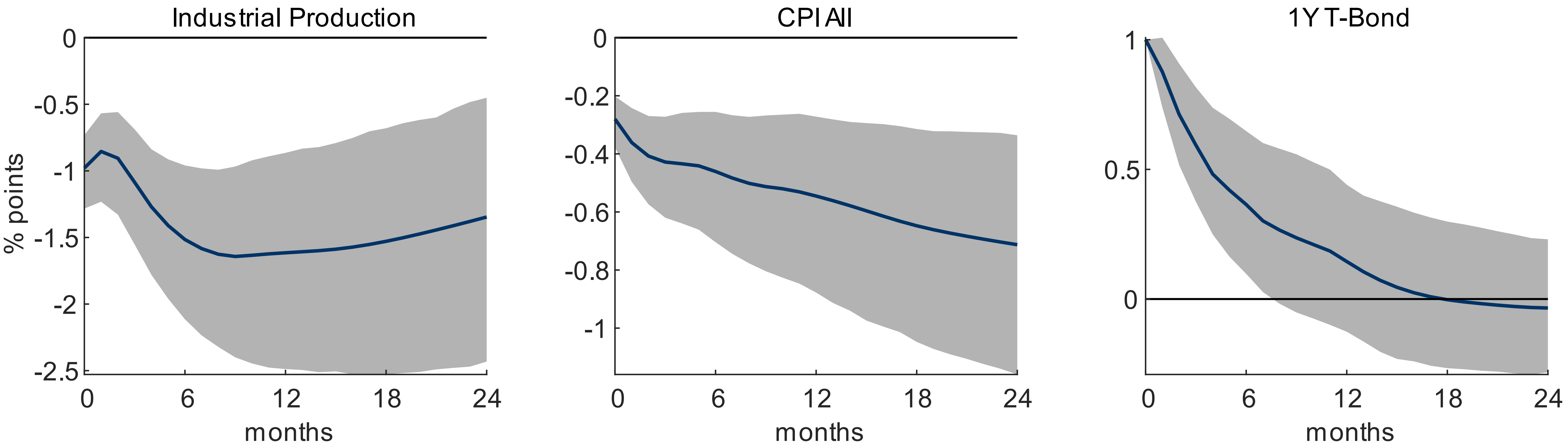
- Assume: $P_t = \exp(\pi t)$ for $t < 0$.
- And: $P_t = P_0 \exp(\pi t)$ for $t \geq 0$.
- So, prices jump at time 0.
- Graphs plot possible (Y_0, P_0).

- Solid line is short-run PC allowing rationing.
- Dashed line is short-run PC without rationing.

- Independent of price setting!

- Full calibration will be given shortly.

The short-run Phillips curve in the data



Taken from Figure 3 of Miranda-Agrippino & Ricco (2021).

Note the immediate jump down of both output (IP) and the price level (CPI)!

Mapping IP to Brave-Butters-Kelley GDP (via relative SDs) this corresponds to a PC slope of 0.508.

Instability without rationing

- We stationarize $X_{j,t}$ by defining $\widehat{X}_{j,t} := \frac{X_{j,t}}{P_t^{\chi_{j,1}}}$. And we define: $\hat{p}_t := \frac{p_t}{P_t}$. Then: $\dot{\widehat{X}}_{j,t} = \lambda_t \hat{p}_t^{\chi_j} - \left(\lambda_t + \chi_j \pi_t\right) \widehat{X}_{j,t}$.

- So: $\lambda_t + \chi_j \pi_t$ determines the stability of $\widehat{X}_{j,t}$. It is stable if and only if $\lambda_t + \chi_j \pi_t > 0$.

- For the model with rationing, we had $\chi_1 = \theta + \frac{1}{\alpha} + \frac{\theta}{\epsilon}\frac{1-\alpha}{\alpha} > 0$, $\chi_2 = \frac{1}{\alpha} > 0$ and $\chi_{3,1} = \frac{\epsilon-1}{\epsilon}\frac{1-\alpha}{\alpha} > 0$. Stability guaranteed!

- For the model without rationing, we had $\chi_4 = -\frac{\epsilon}{1-\alpha} < 0$ and $\chi_0 = -(\epsilon - 1) < 0$.

- If ϵ, α or π_t are large enough, then $\lambda_t + \chi_4 \pi_t < 0$ or $\lambda_t + \chi_0 \pi_t < 0$. Potential instability!

New prices

- For $j \in \mathbb{N}$, define: $z_{j,\tau} := \int_\tau^\infty e^{-\int_\tau^t \lambda_v \, dv - \int_\tau^t r_v \, d_v} \widehat{W}_t^{\omega_{j,2}} Y_t^{\omega_{j,3}} P_t^{\omega_{j,4}} \, dt$, so $\dot{z}_{j,\tau} = -\widehat{W}_t^{\omega_{j,2}} Y_\tau^{\omega_{j,3}} P_\tau^{\omega_{j,4}} + (\lambda_\tau + r_\tau) z_{j,\tau}$.

- Allowing rationing, updating firms optimally set: $p_\tau^{\theta + \frac{\theta}{\epsilon}\frac{1-\alpha}{\alpha}} \propto \frac{z_{2,\tau}}{z_{1,\tau}}$.
  - Where: $\omega_{1,2} := -\frac{\theta+\epsilon}{\epsilon}\frac{1-\alpha}{\alpha}$, $\omega_{1,3} := -\frac{\theta}{\epsilon}$, $\omega_{1,4} := -\chi_1$, $\omega_{2,2} := -\frac{1-\alpha}{\alpha}$, $\omega_{2,3} := 0$, $\omega_{2,4} := -\chi_2$.
- Without rationing, updating firms optimally set: $p_\tau^{1+\epsilon\frac{\alpha}{1-\alpha}} \propto \frac{z_{6,\tau}}{z_{5,\tau}}$.
  - Where: $\omega_{5,2} := 0$, $\omega_{5,3} := 1$, $\omega_{5,4} := \epsilon - 1$, $\omega_{6,2} := 1$, $\omega_{6,3} := \frac{1}{1-\alpha}$, $\omega_{6,4} := \frac{\epsilon}{1-\alpha}$.
- We stationarize by defining: $\hat{z}_{j,t} := \frac{z_{j,t}}{P_t^{\omega_{j,4}}}$.

Price change opportunity arrival rate choice

- If long-run inflation is higher, then plausibly prices would be changed more frequently.
  - At least aggregate state dependence is necessary for reasonable comparative static results.
  - I broadly follow Blanco et al. (2024) in modelling an endogenous rate of price change opportunities.

- Suppose all firms are owned by conglomerates. Each conglomerate owns countably many firms.
- Each conglomerate chooses the price adjustment rate λ_t for the firms it owns (the same rate for all firms).
  - The conglomerate maximizes its firms' total profit, minus a cost of $\frac{1}{2}\kappa\lambda_t^2$ labour units. New labour FOC $\Psi_t\left(L_t + \frac{1}{2}\kappa\lambda_t^2\right)^\nu = \frac{A_t \widehat{W}_t}{Y_t}$.
- The conglomerate cannot control which particular firms update at any point in time, only the total quantity.
  - Surprisingly consistent with price micro data, which finds hazard rates are flat in price age (Klenow & Malin 2010).
- Optimal: $\lambda_t = \frac{1}{\kappa}\frac{o_t - Q_t^*}{W_t}$, where $o_\tau := \int_\tau^\infty e^{-\int_\tau^t \lambda_v\,dv - \int_\tau^t r_v\,d_v} o_{\tau,t}\,dt$, $Q_s^* := \int_{-\infty}^s \lambda_\tau e^{-\int_\tau^s \lambda_v\,dv} \int_s^\infty e^{-\int_s^t \lambda_v\,dv - \int_s^t r_v\,d_v} o_{\tau,t}\,dt\,d\tau$.

Parameterization / calibration

- $\alpha := \frac{5}{9}$, $\rho = 2\%$. $\pi = \pi^* = 2\%$ unless otherwise stated. Standard.
- $\epsilon := 10$, $\nu := 2$. Smets & Wouters (2007).
- $\lambda := -4\log(1 - 0.297)$. Blanco et al. (2024).
- $\theta = 32.9$. Matching local short-run Phillips curve slope of 0.508 derived from Miranda-Agrippino & Ricco (2021).
    - Implies ζ's mean is 0.97 and ζ's standard deviation is 0.03.

- With an endogenous λ_t, κ is chosen to match the steady-state level of λ above when $\pi = 2\%$.
    - With rationing allowed, 0.6% of all labour is used for price adjustment (in line with Blanco et al. (2024)).
    - Without rationing, this number is 4.8%. Rationing reduces the price adjustment frictions needed to match the data!
- $A := 1$. $\Psi := 1$ when λ_t is exogenous. Units.
    - When λ_t is endogenous, Ψ is chosen to match production labour between the endogenous & exogenous models when $\pi = 2\%$.

Results

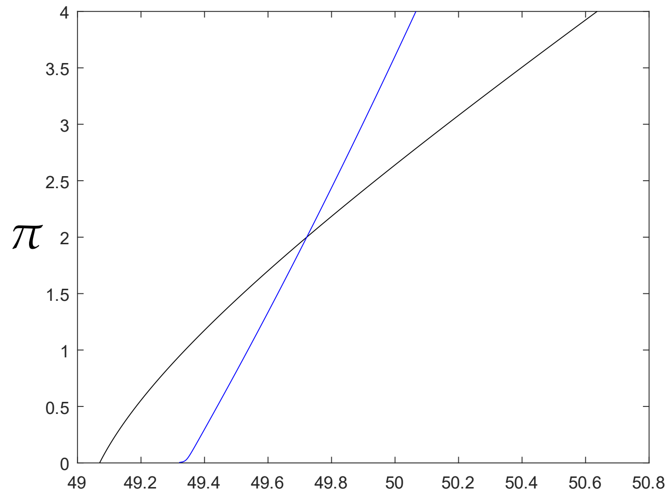
Comparative statics results

- How does the economy change as the long-run inflation rate is varied?

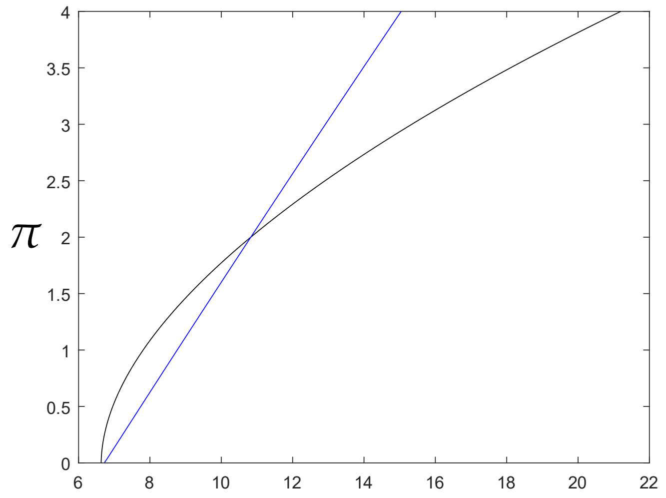
- In most of the following plots:
  - Black solid lines are the model with rationing, without endogenous λ_t.
  - Black dashed lines are the model without rationing, without endogenous λ_t.
  - Blue solid lines are the model with rationing, with endogenous λ_t.
  - Blue dashed lines are the model without rationing, with endogenous λ_t.

- Unless otherwise stated, units are percent or percentage points.

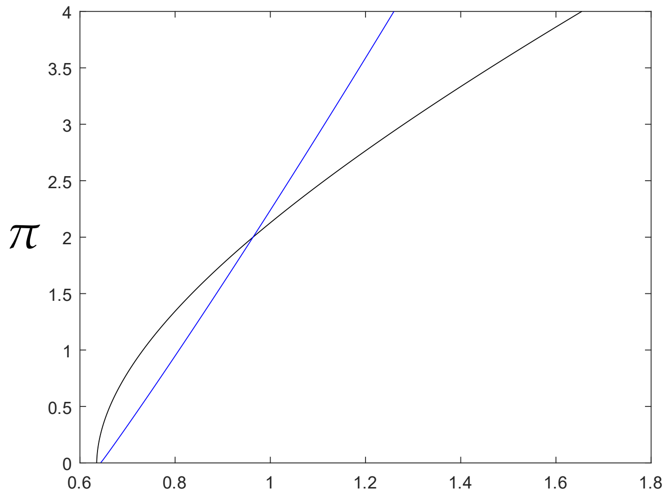
Rationing as a function of inflation



Average probability of rationing



Excess demand

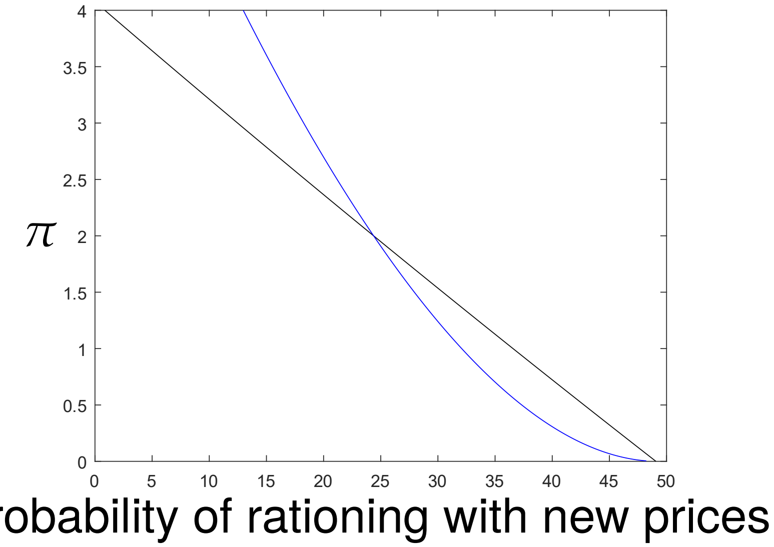


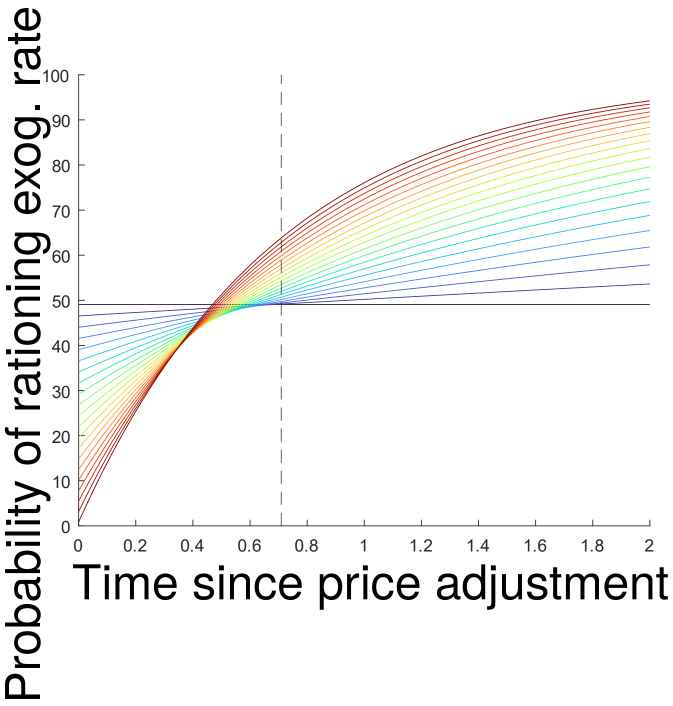
Aggregator profit share of output

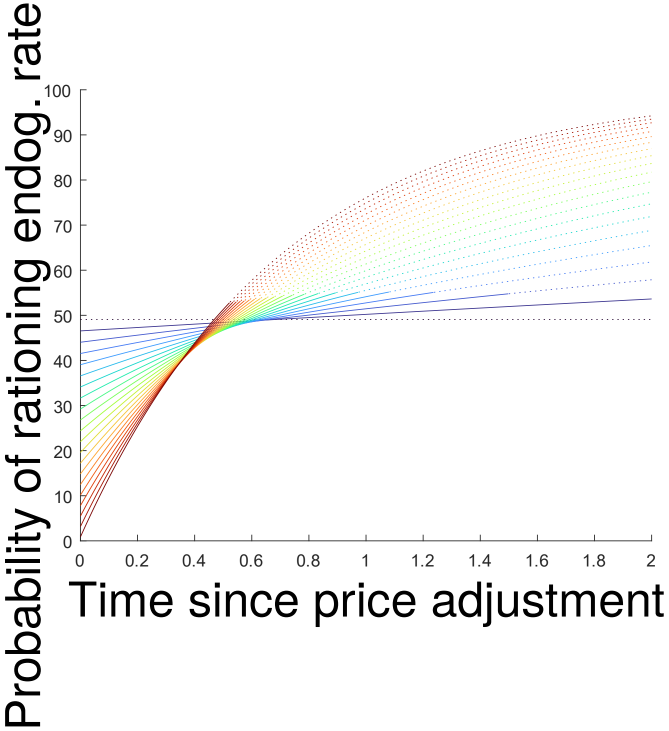
When inflation is high rationing (and related quantities) are high. High inflation quickly erodes mark-ups.

With 2% inflation, excess demand is around 11% in line with evidence of Cavallo & Kryvtsov (2023) (untargeted).

Which firms ration?



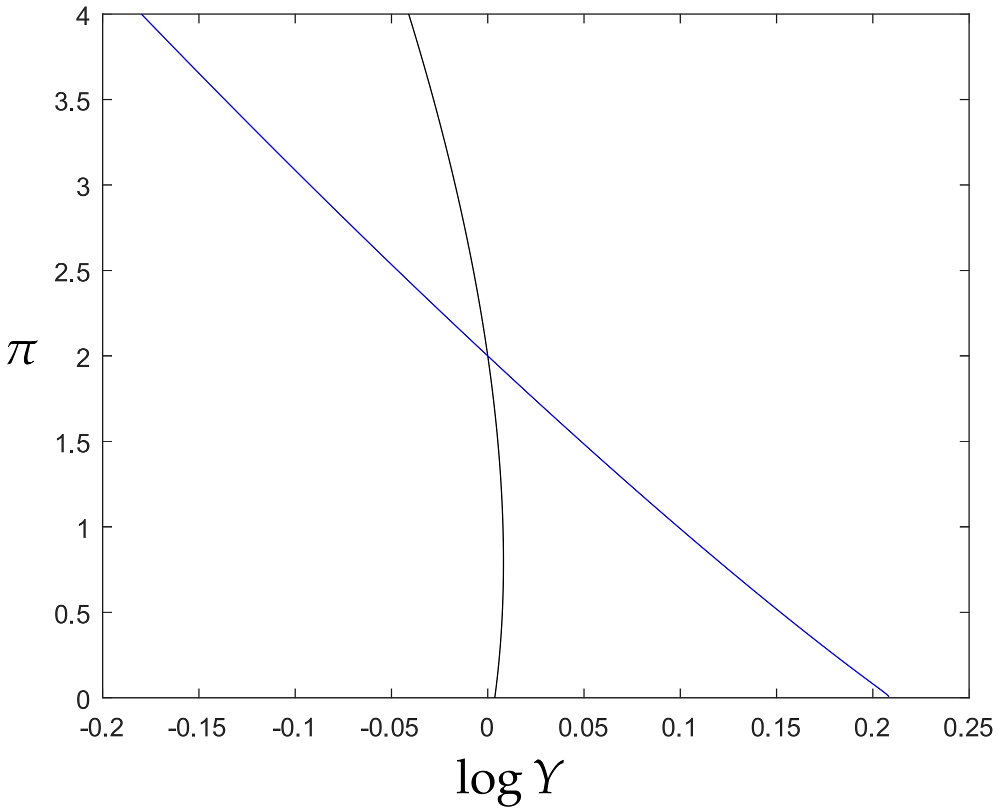


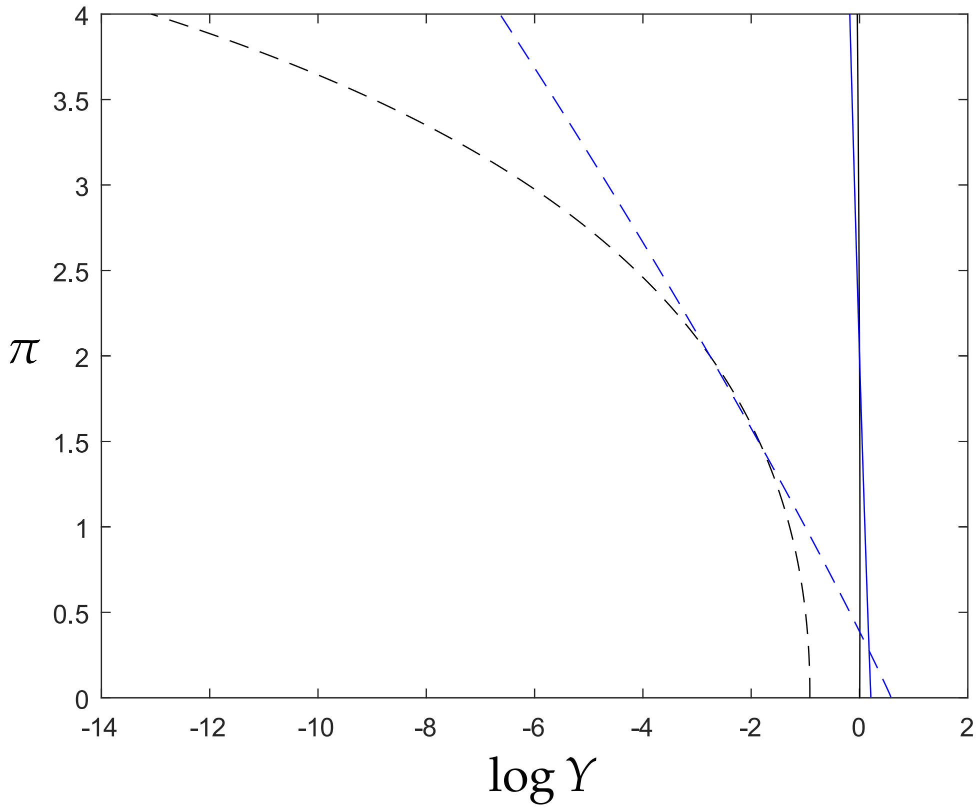


When inflation is high, firms with new prices set high mark-ups, giving them a low probability of rationing.

But as mark-ups are eroded by inflation, the probability of rationing increases. The old firms dominate.

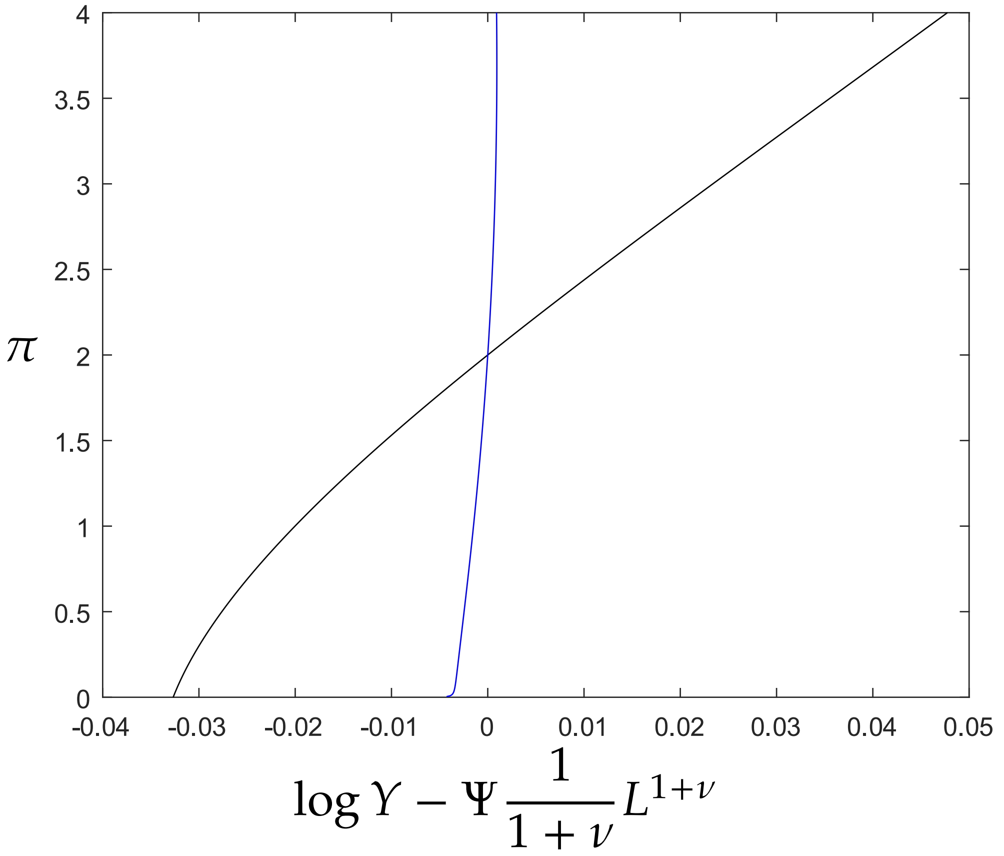
The long-run Phillips curve

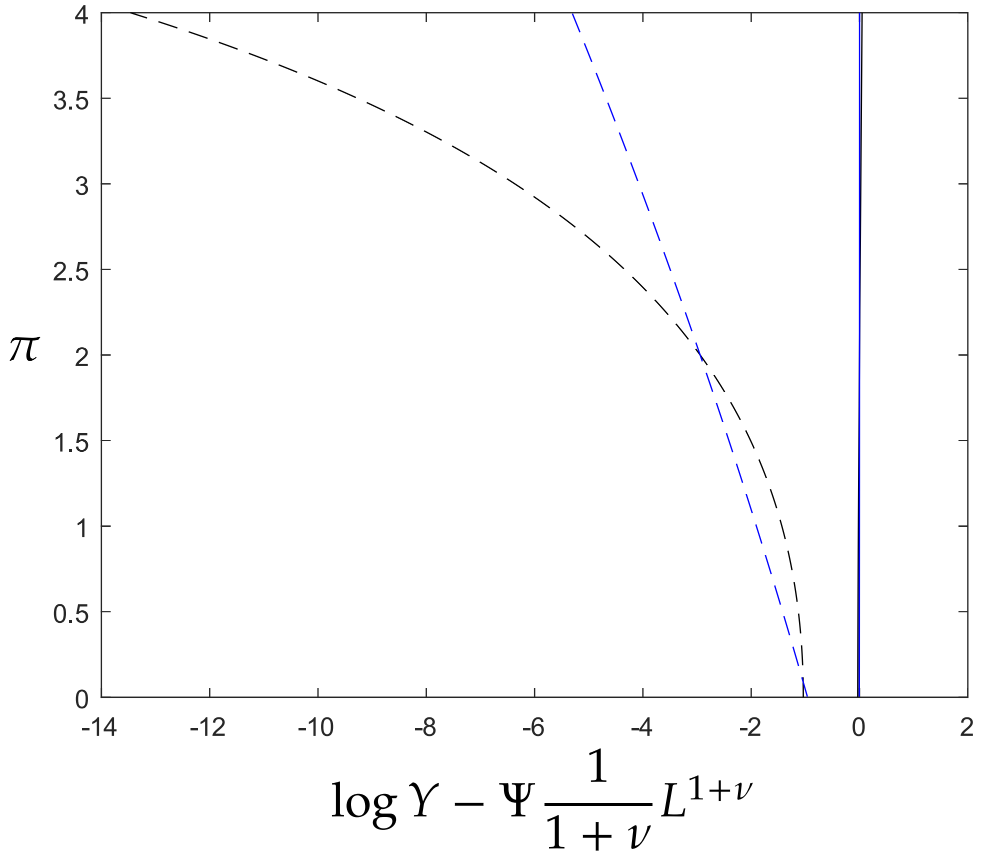




Output costs of inflation are much lower under rationing. 1% is about optimal for output with rationing and fixed λ.

Welfare as a function of inflation

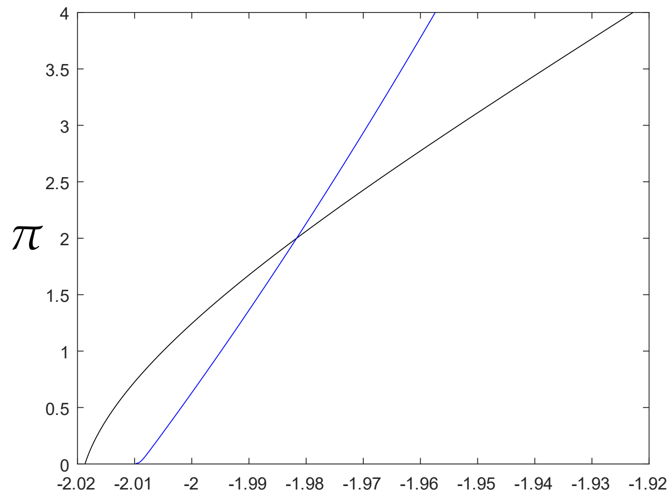


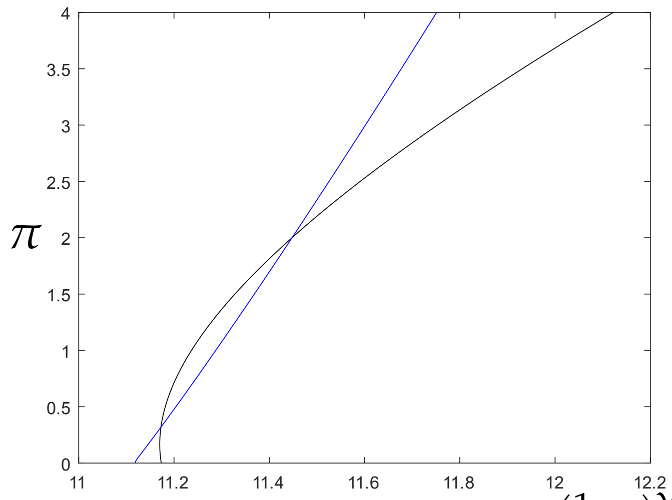


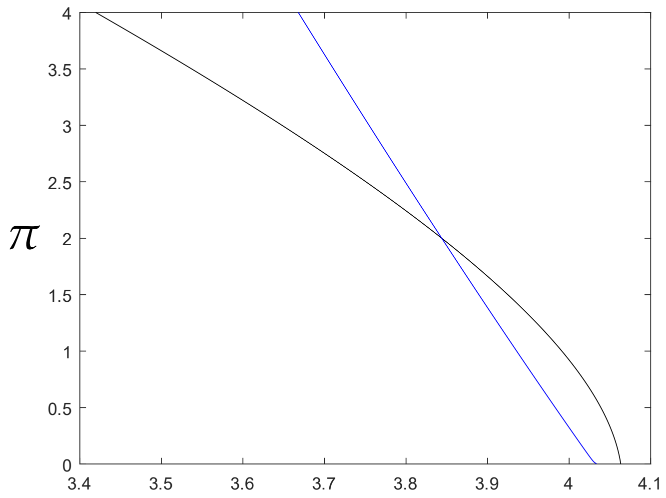
High inflation is bad for welfare without rationing, but it actually improves welfare if rationing is allowed!

Whereas without rationing, high inflation leads to greater distortion, with rationing it reduces misallocation.

Rationing is good actually!



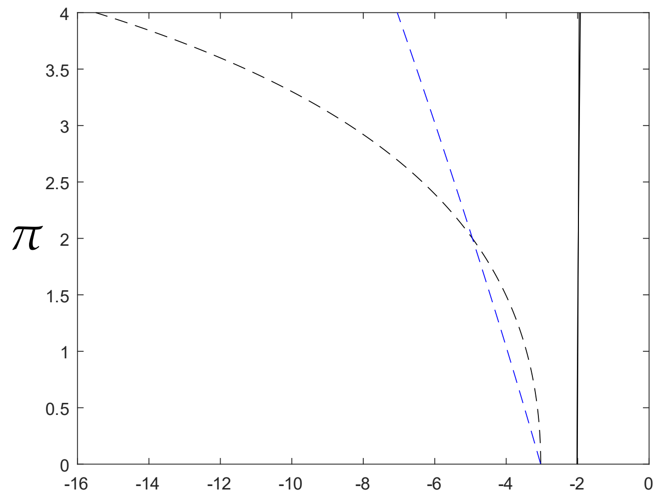


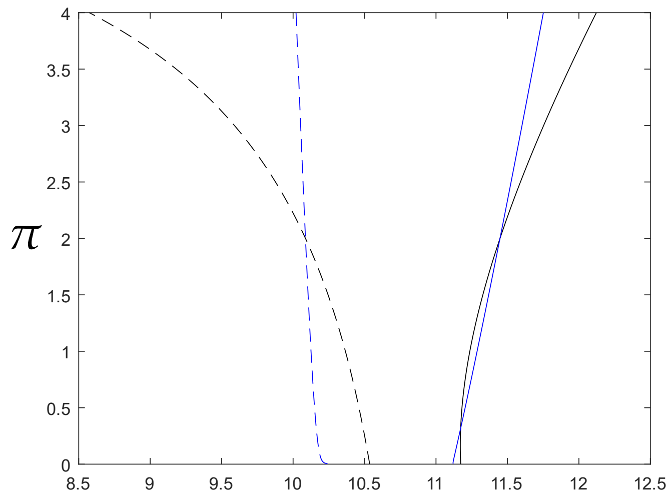


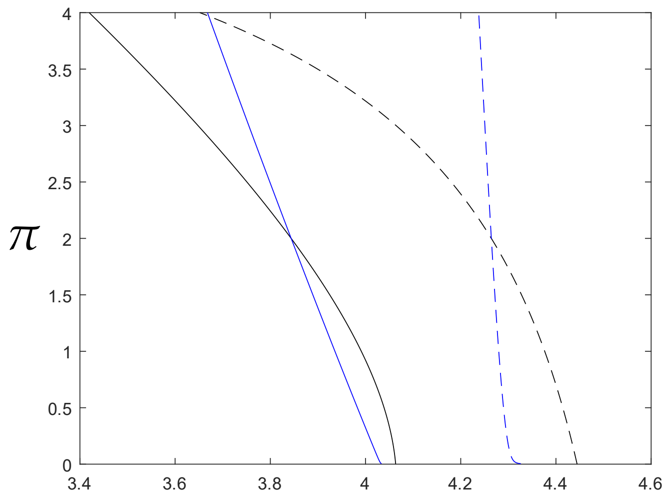
Effective TFP (Relative to fully flex)

Aggregate mark-ups: $\log \frac{(1-\alpha)Y}{WL}$

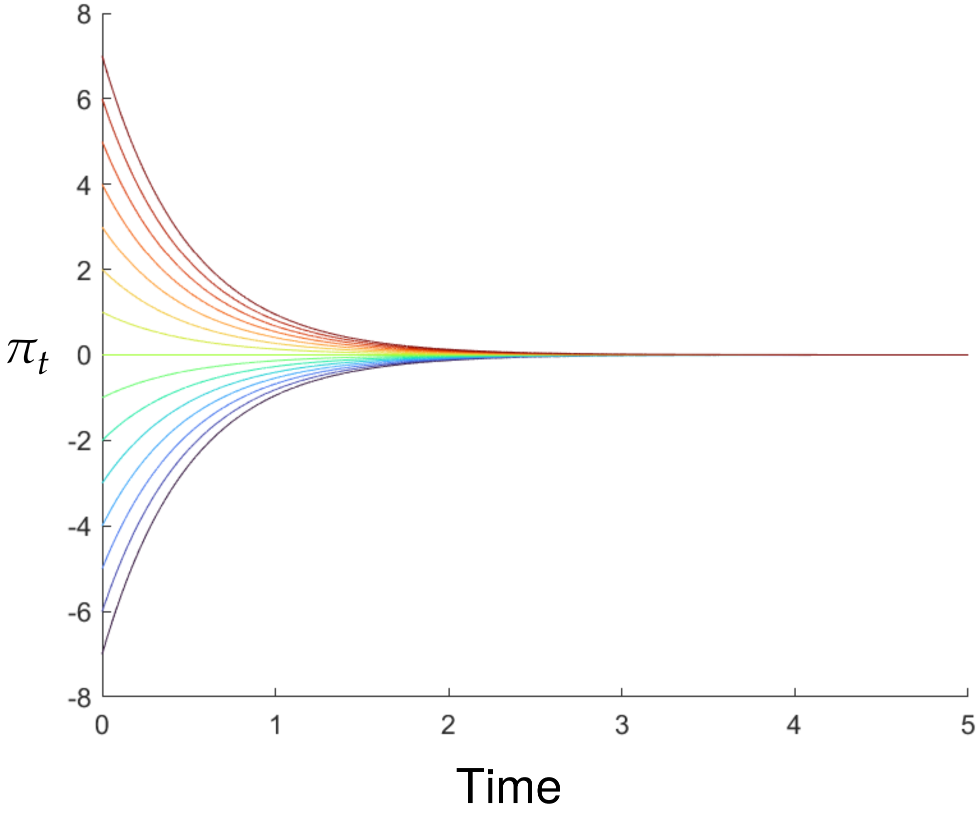
Excess firm profit share of output

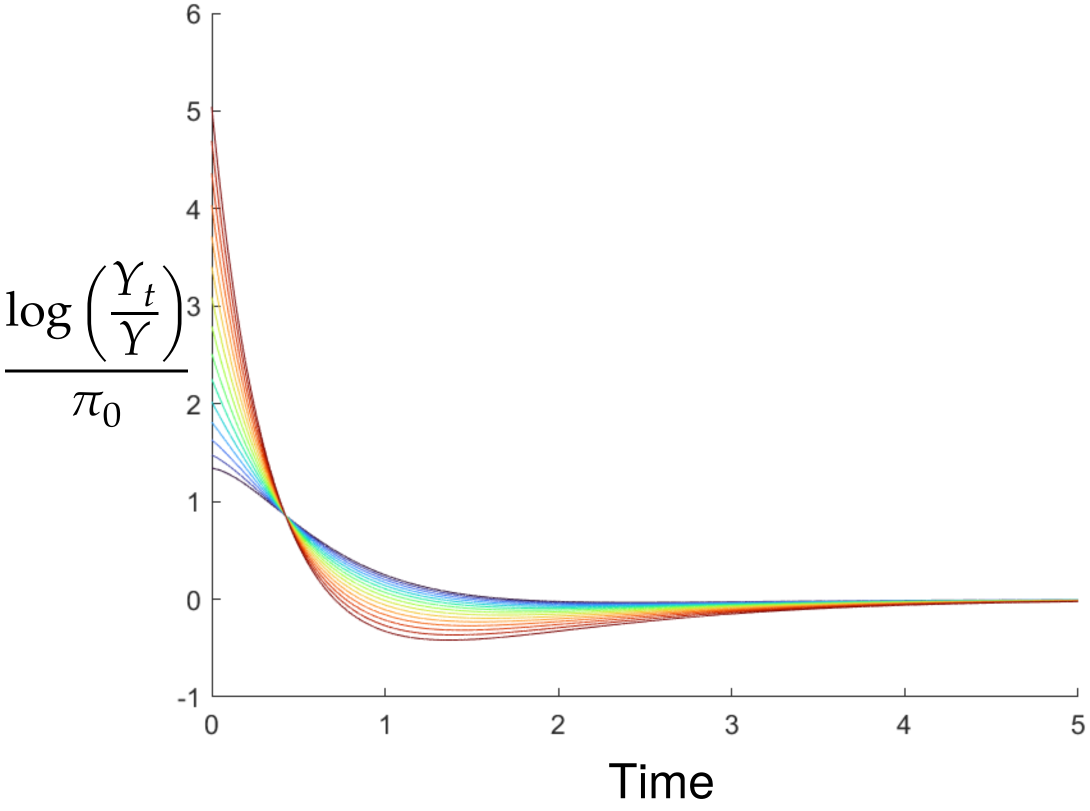






IRFs to π shocks (without rationing, without endo. λ)

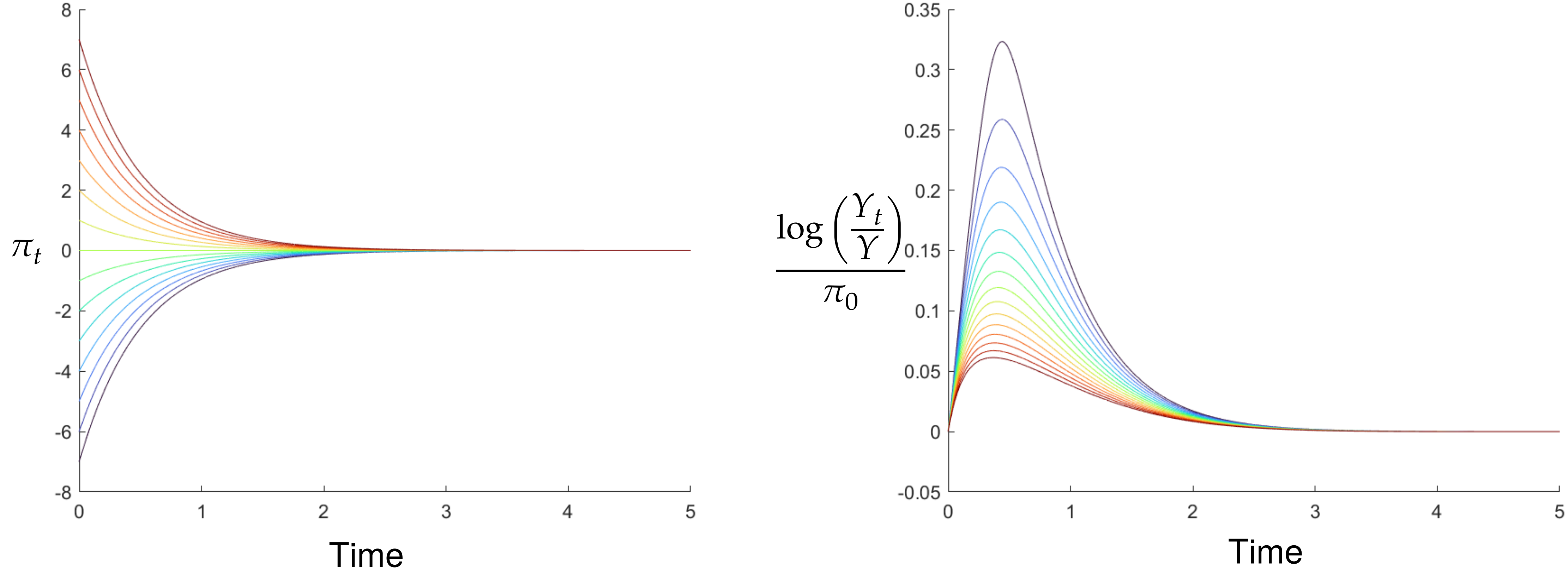




Positive shocks have an amplified effect on output (flat PC). Negative shocks have a dampened impact (steep PC).

Counterfactual!

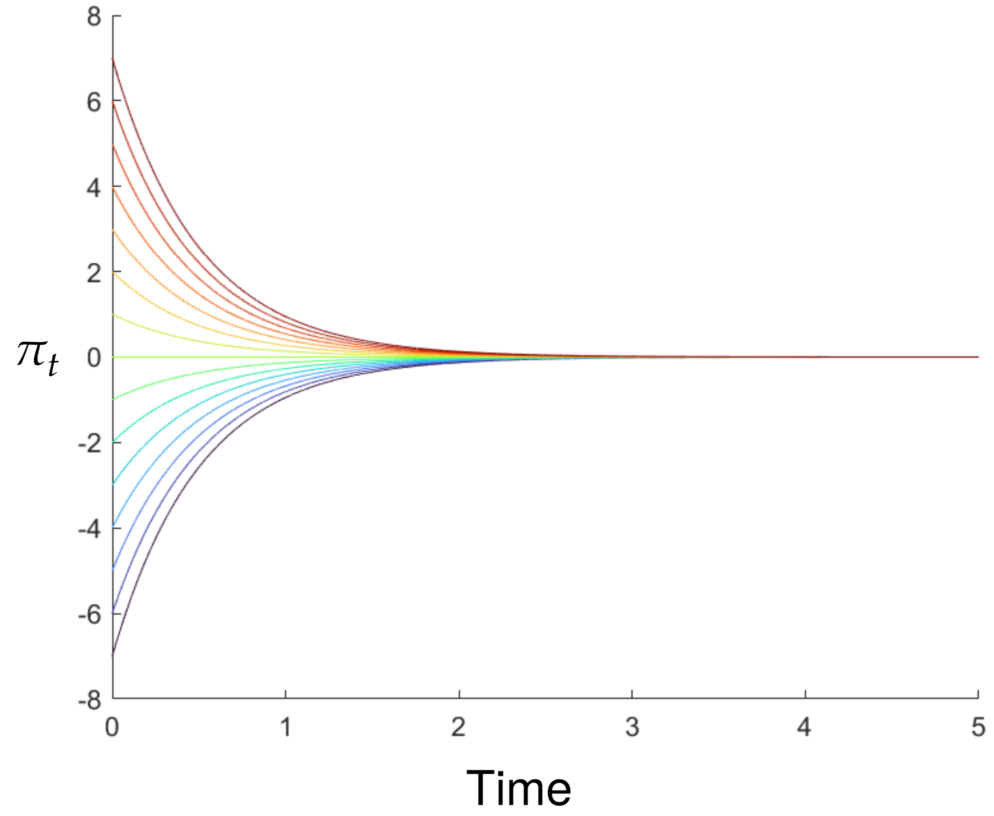
IRFs to π shocks (with rationing, without endo. λ)

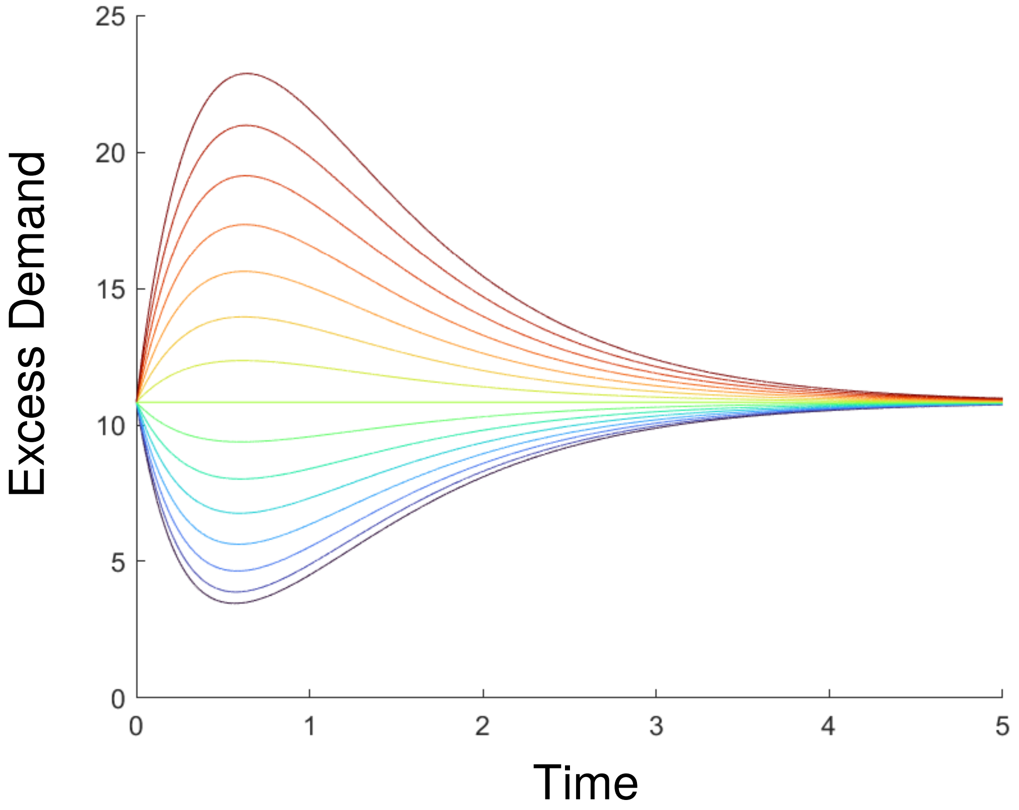


Positive shocks have a dampened effect on output (steep PC). Negative shocks have an amplified impact (flat PC).

As in the data!

IRFs to π shocks (with rationing, without endo. λ)

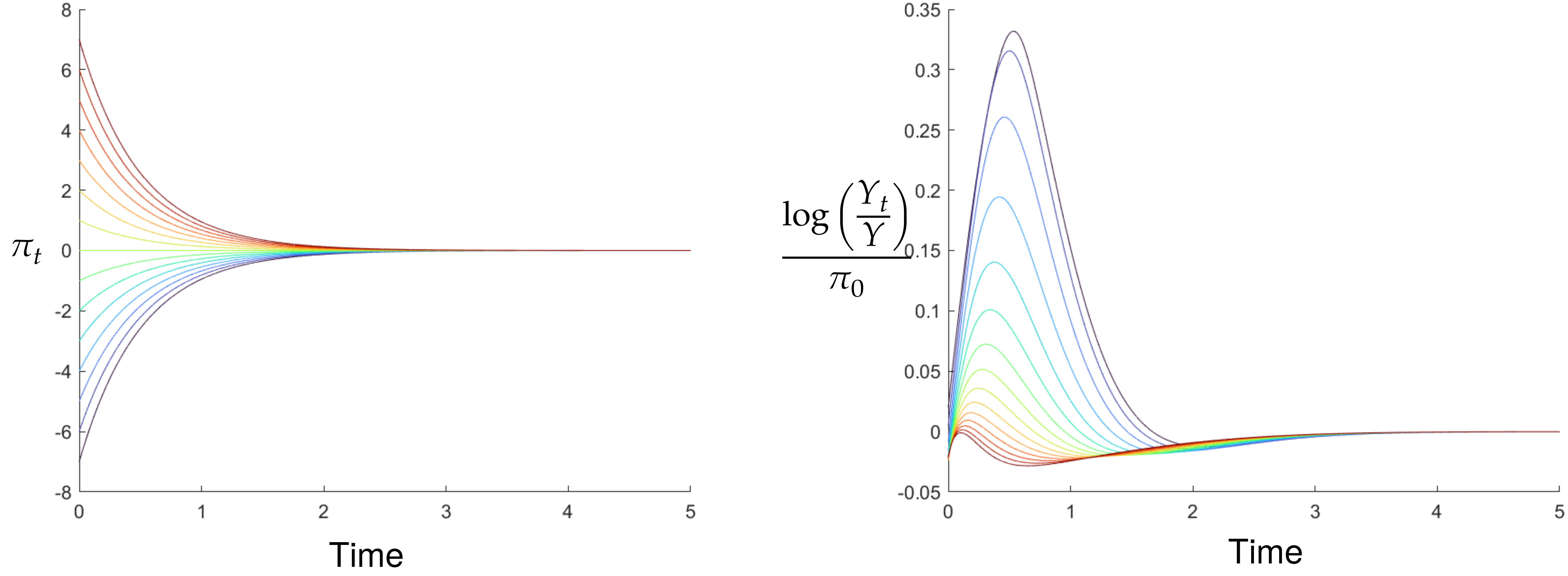




A 7% inflation shock increases excess demand by around 12%, i.e. from 11% to 23%.

As in Cavallo & Kryvtsov (2023) (untargeted)!

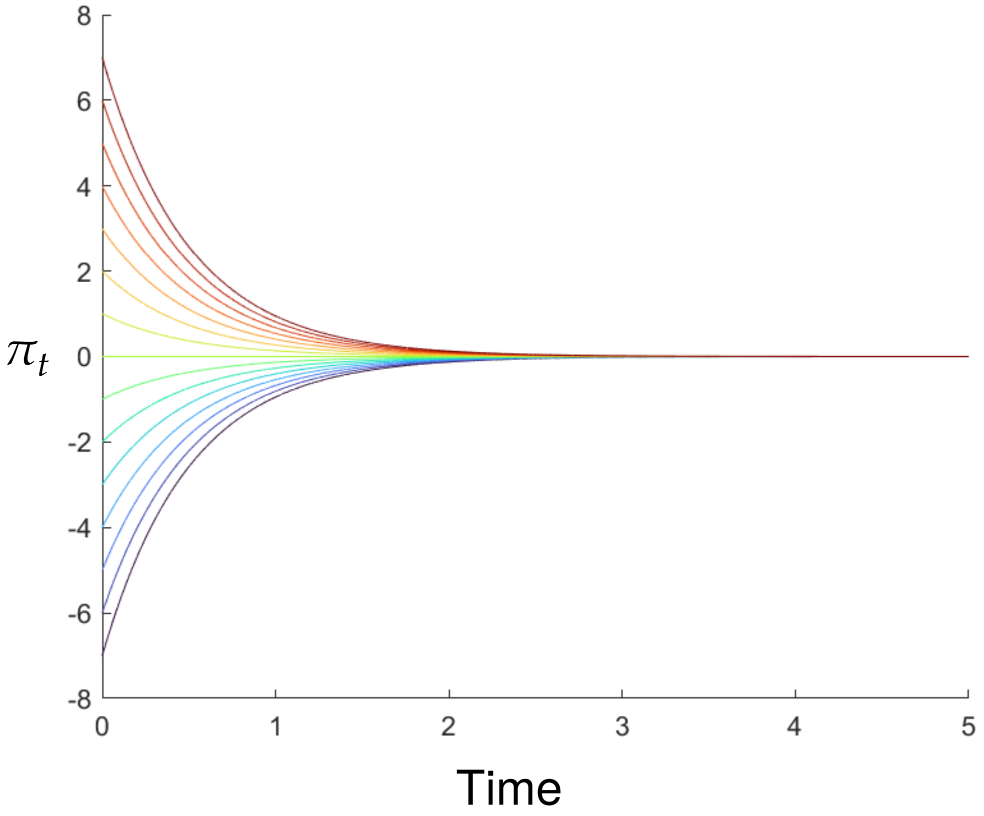
IRFs to π shocks (with rationing, with endo. λ)

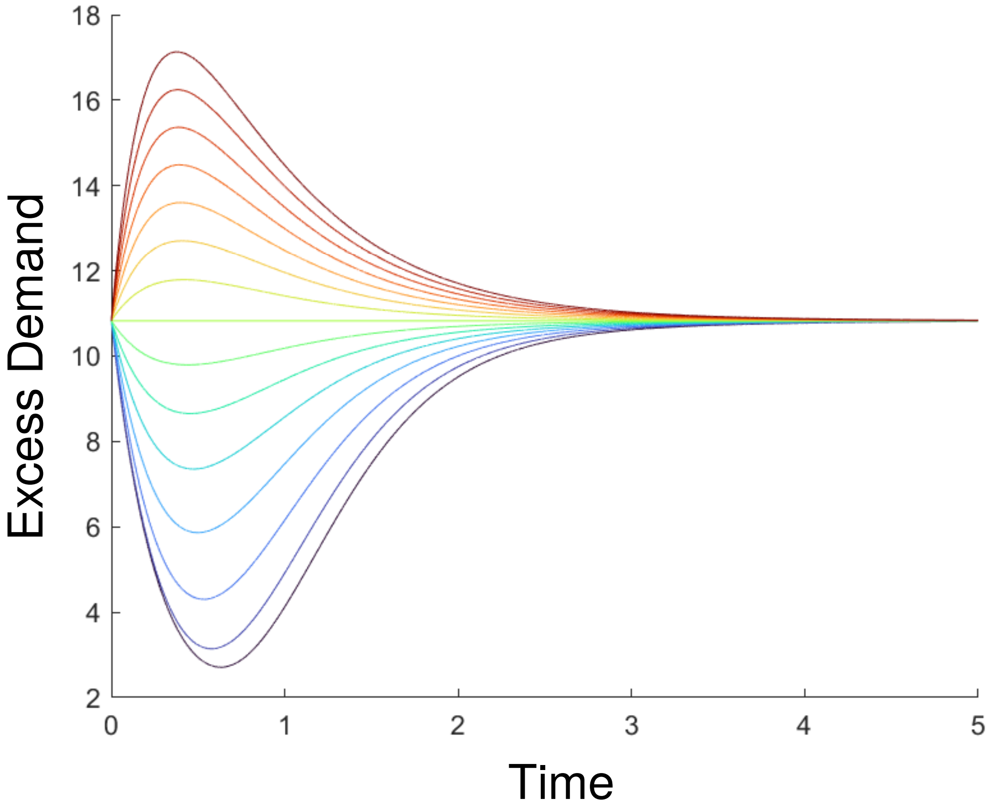


Positive shocks have almost no (or negative) effect on output (steep / backward bending PC).

Negative shocks have an amplified impact (flat PC). Monetary policy can do harm but not good?

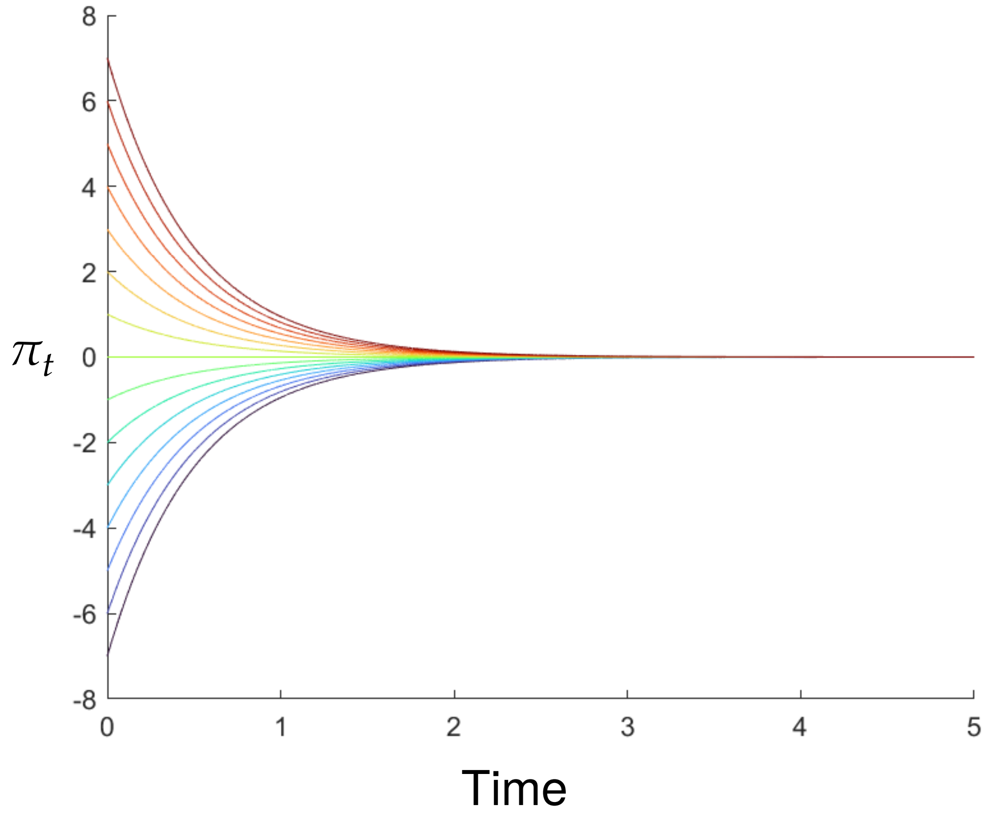
IRFs to π shocks (with rationing, with endo. λ)

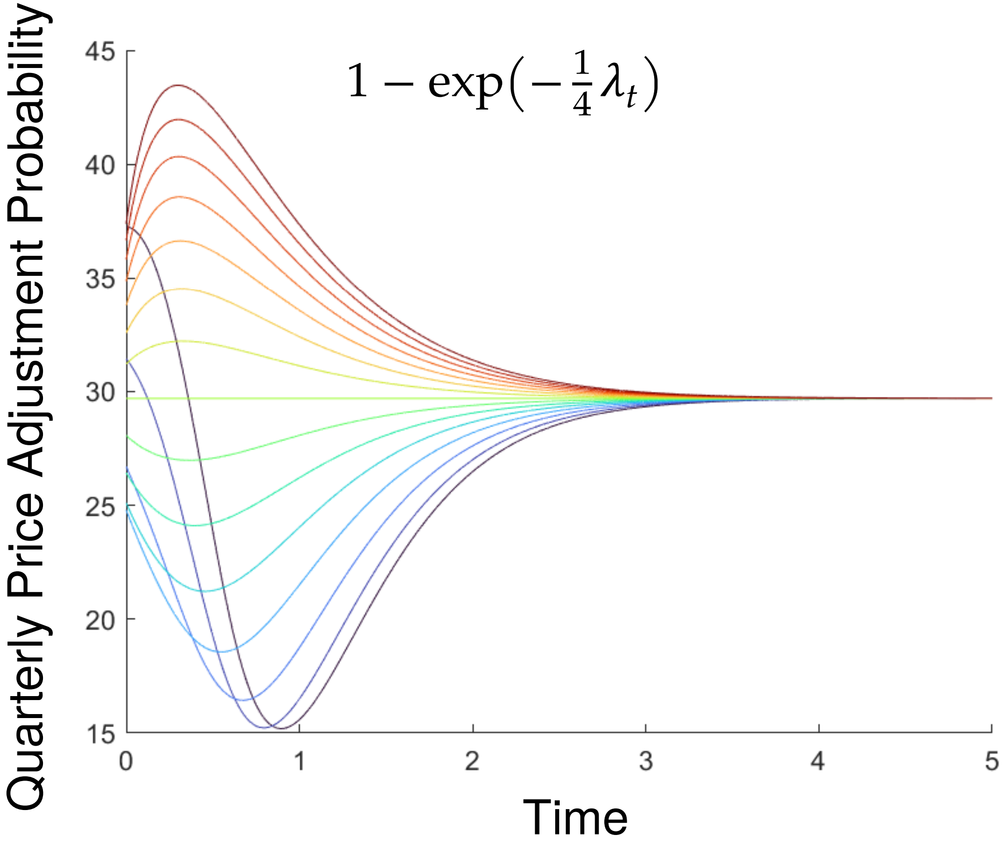




Dampened impact on excess demand for positive shocks due to increased flexibility.

IRFs to π shocks (with rationing, with endo. λ)

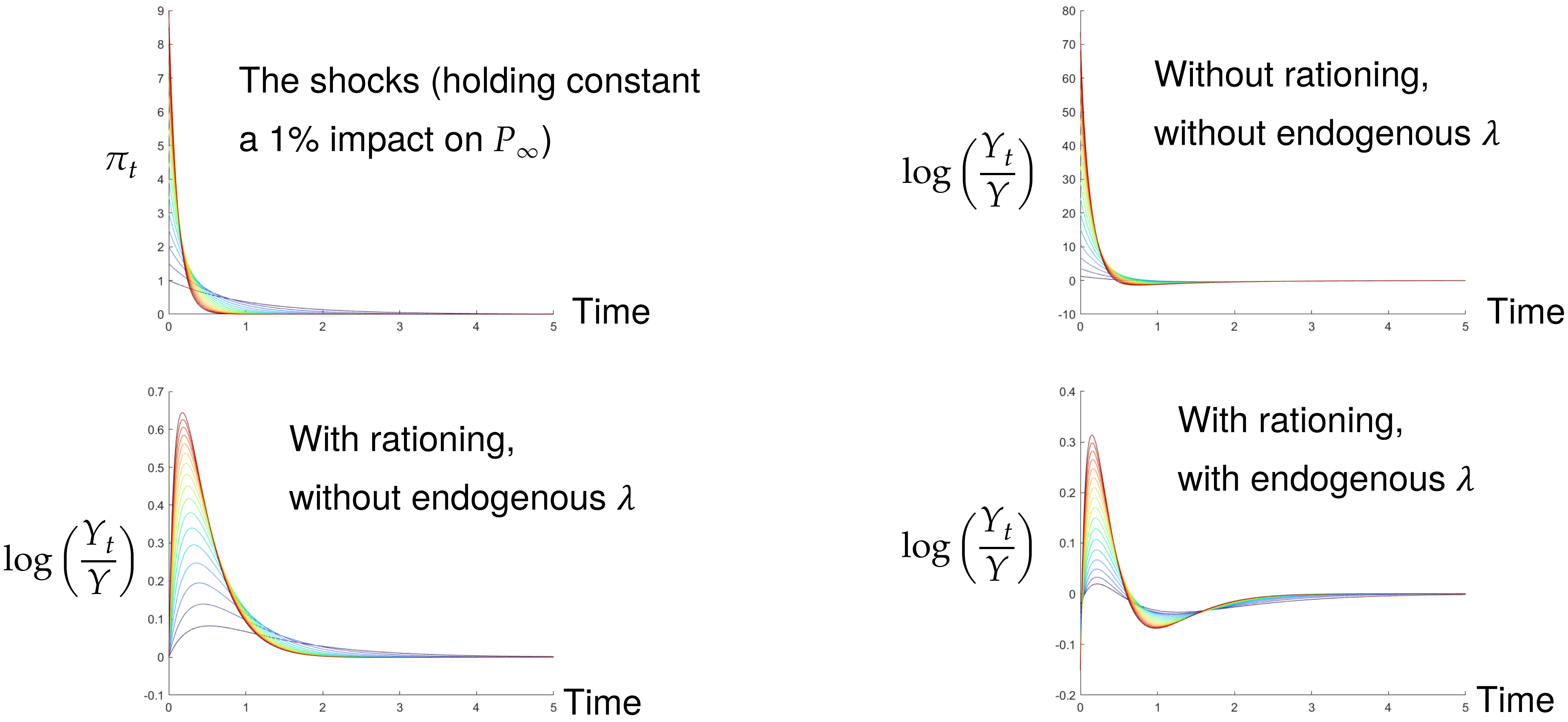




Positive shocks (and large negative ones) produce large increases in price flexibility.

Blanco et al. (2024) find that the quarterly adjustment probability peaked at around 55% in 2022.

IRFs to π shocks (varying persistence)



Without rationing, jumps in the price level have crazy impacts on output. With rationing, their impact is bounded.

Conclusion

- The standard assumption that firms always satisfy all demand is not innocuous.
- It is responsible for much of the strange behaviour of the non-linear Calvo model.

- Allowing rationing produces a model that fits the data better and performs more reasonably in extreme conditions.
- The model is actually more tractable with rationing than without, so it can be easily scaled to policy models.

- Allowing rationing drastically reduces the welfare costs of inflation.

- Extensions in final paper: firm specific capital, partially fixed intermediaries, long-run growth and costs of rationing.
- I am interested to hear thoughts on other essential extensions, or crucial empirical results to establish.

Extra slides

References

Abraham, Filip, Yannick Bormans, Jozef Konings & Werner Roeger. 2024. 'Price-Cost Margins, Fixed Costs and Excess Profits'. *The Economic Journal*: ueae037.

Alessandria, George, Joseph P. Kaboski & Virgiliu Midrigan. 2010. 'Inventories, Lumpy Trade, and Large Devaluations'. *American Economic Review* 100 (5): 2304–2339.

Barro, Robert J. 1977. 'Long-Term Contracting, Sticky Prices, and Monetary Policy'. *Journal of Monetary Economics* 3 (3): 305–316.

Bauer, Michael D. & Eric T. Swanson. 2023. 'A Reassessment of Monetary Policy Surprises and High-Frequency Identification'. *NBER Macroeconomics Annual* 37: 87–155.

Bils, Mark. 2016. 'Deducing Markups from Stockout Behavior'. *Research in Economics* 70 (2): 320–331.

Blanco, Andrés, Corina Boar, Callum J. Jones & Virgiliu Midrigan. 2024. 'The Inflation Accelerator'. Working Paper. Working Paper Series. National Bureau of Economic Research.

Cavallo, Alberto & Oleksiy Kryvtsov. 2023. 'What Can Stockouts Tell Us about Inflation? Evidence from Online Micro Data'. *Journal of International Economics* 146. NBER International Seminar on Macroeconomics 2022: 103769.

Corsetti, Giancarlo & Paolo Pesenti. 2005. 'International Dimensions of Optimal Monetary Policy'. *Journal of Monetary Economics* 52 (2): 281–305.

Drèze, Jacques H. 1975. ‘Existence of an Exchange Equilibrium under Price Rigidities’. *International Economic Review* 16 (2): 301–320.

Forbes, Kristin J., Joseph E. Gagnon & Christopher G. Collins. 2022. ‘Low Inflation Bends the Phillips Curve around the World’. *Economia* 45 (89): 52–72.

Gerke, Rafael, Sebastian Giesen, Matija Lozej & Joost Röttger. 2023. ‘On Household Labour Supply in Sticky-Wage HANK Models’. SSRN Scholarly Paper. Rochester, NY.

Hahn, Volker. 2022. ‘Price Dispersion and the Costs of Inflation’. *Journal of Money, Credit and Banking* 54 (2–3): 459–491.

Holden, Tom D. 2024. *Robust Real Rate Rules*. Working Paper. Kiel, Hamburg: ZBW – Leibniz Information Centre for Economics.

Holden, Tom D., Ales Marsal & Katrin Rabitsch. 2024. ‘From Linear to Nonlinear: Rethinking Inflation Dynamics in the Calvo Pricing Mechanism’.

Huo, Zhen & José-Víctor Ríos-Rull. 2020. ‘Sticky Wage Models and Labor Supply Constraints’. *American Economic Journal: Macroeconomics* 12 (3): 284–318.

Klenow, Peter J. & Benjamin A. Malin. 2010. ‘Microeconomic Evidence on Price-Setting☆’. In *Handbook of Monetary Economics*, edited by Benjamin M. Friedman & Michael Woodford, 3:231–284. Elsevier.

Kryvtsov, Oleksiy & Virgiliu Midrigan. 2013. ‘Inventories, Markups, and Real Rigidities in Menu Cost Models’. *The Review of Economic Studies* 80 (1): 249–276.

Miranda-Agrippino, Silvia & Giovanni Ricco. 2021. ‘The Transmission of Monetary Policy Shocks’. *American Economic Journal: Macroeconomics* 13 (3): 74–107.

Posch, Olaf. 2018. ‘Resurrecting the New-Keynesian Model: (Un)Conventional Policy and the Taylor Rule’. *CESifo Working Paper Series*. CESifo Working Paper Series.

Posch, Olaf, Juan F. Rubio-Ramírez & Jesús Fernández-Villaverde. 2011. ‘Solving the New Keynesian Model in Continuous Time’. *2011 Meeting Papers*. 2011 Meeting Papers.

Smets, Frank & Rafael Wouters. 2007. ‘Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach’. *American Economic Review* 97 (3): 586–606.

Svensson, Lars EO. 1984. *Sticky Goods Prices, Flexible Asset Prices, and Optimum Monetary Policy*. IIES.