Firm Heterogeneity, Capital Misallocation and Monetary Policy

Beatriz González (BdE) Galo Nuño (BdE) Dominik Thaler (ECB) Silvia Albrizio (IMF)

Firm heterogeneity, capital misallocation and monetary policy

- Firms' investment decisions are one of the key transmission channels of monetary policy.
- In the presence of firm heterogeneity and financial frictions, the distribution of capital across firms matters for aggregate productivity.
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What are the channels through which monetary policy affects capital misallocation and endogenous TFP?

How do these channels modify the optimal conduct of monetary policy?

What we do: analyze monetary policy in a model with heterogeneous firms and capital misallocation

- Benchmark model to understand the impact of monetary policy on misallocation and endogenous TFP.
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  - Heterogeneous firms block as in Moll (2014).

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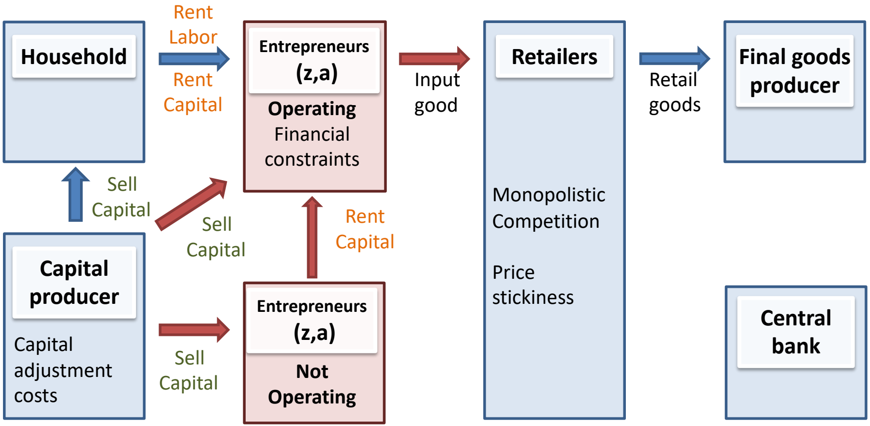
- General equilibrium: an expansionary monetary policy shock decreases misallocation.
  - Empirical support for the second channel in Spanish firm-level micro data.
- Optimal monetary policy:
  - Misallocation creates a *time inconsistent* motive to temporarily expand the economy.
  - Timeless response to cost push shock: 'lean *with* the wind' (vs complete markets - lean *against* the wind).

Road map

1. Model
2. Positive analysis
   - How does monetary policy affect misallocation
   - Empirical evidence
3. Normative analysis
   - Optimal monetary policy

Model

The model in a nutshell



Continuum of heterogeneous firms operated by entrepreneurs

- Heterogeneity in entrepreneurs' net worth (a_t) and productivity (z_t; follows OU-diffusion process) .
- Firms produce the input good using labor (l_t) and capital (k_t).
- Entrepreneurs can borrow capital $b_t = k_t - a_t$, subject to a borrowing constraint $k_t \leq \gamma a_t$.

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- Firms maximize profits:

$$\begin{aligned} \Phi_t(z_t, a_t) &= \max_{k_t, l_t} \{ m_t f_t(z_t, k_t, l_t) - w_t l_t - R_t k_t \} \\ s.t.\ q_t k_t &\leq \gamma q_t a_t \end{aligned}$$

- m_t: real price of input good p_t^y / P_t
- $f_t(z_t, k_t, l_t) \equiv (z_t k_t)^\alpha (l_t)^{1-\alpha}$
- w_t: real wage

- R_t: real rental rate of capital
- $\gamma > 1$: borrowing constraint

Entrepreneurs' optimal production plan

$$k_t(z,a) = \begin{cases} \gamma a, & \text{if } z \geq z_t^*, \\ 0, & \text{if } z < z_t^*, \end{cases}$$

$$z_t^* = \frac{R_t}{\alpha\left(\frac{(1-\alpha)}{w_t}\right)^{(1-\alpha)/\alpha} m_t^{\frac{1}{\alpha}}}$$

- Each entrepreneur operates a firm at maximum size if $\Phi_t(z_t, a_t) > 0$ (CRS!),
  - Otherwise she lends his net worth to other entrepreneurs.

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- Profits are linear in capital

$$\Phi_t(z,a) = \underbrace{\left(z\alpha \left(\frac{(1-\alpha)}{w_t} \right)^{(1-\alpha)/\alpha} m_t^{\frac{1}{\alpha}} - R_t \right)}_{\text{Excess investment rate } \tilde{\Phi}_t(z)} \underbrace{\gamma a}_{k_t}.$$

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$$V_0(z,a) = \max_{a_t, d_t \geq 0} \mathbb{E}_0 \int_0^\infty e^{-\int_0^t (r_s+\eta) ds} \left(d_t + \overbrace{\eta q_t a_t}^{\text{liquidation value}} \right) dt$$

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s.t.

$$\dot{a}_t q_t + d_t = \underbrace{\left(\overbrace{\max\{\tilde{\Phi}_t(z), 0\}\gamma}^{\text{operating profits}} + \overbrace{(R_t - \delta q_t)}^{\text{return on capital}} \right)}_{S_t(z) q_t} a_t$$

- d_t: dividends
- R_t: rental rate of capital
- δ: capital depreciation
- q_t: price of capital
- a_t: net worth (capital owned by firm)
- r_t: real interest rate

Entrepreneurs never distribute dividends until liquidation

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  - Intuition: return of funds inside the firm is always at least the real rate $(R_t/q_t - \delta)$, and the liquidation value of the firm is all its net worth .

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- New entrepreneurs enter replacing exiting ones.
  - Inherit the same firm (same productivity)
  - Start with lower net worth $\psi q_t a_t$, $0 < \psi < 1$.

Distribution of entrepreneurs

- The evolution of the joint distribution of net worth and productivity $g_t(z,a)$ is given by the KFE:

$$\frac{\partial g_t(z,a)}{\partial t} = \underbrace{-\frac{\partial}{\partial a}[g_t(z,a)s_t(z)a]}_{\text{Entrepreneurs' savings}} \underbrace{-\frac{\partial}{\partial z}[g_t(z,a)\mu(z)] + \frac{1}{2}\frac{\partial^2}{\partial z^2}[g_t(z,a)\sigma^2(z))]}_{\text{idiosyncratic TFP shocks}}$$

$$\underbrace{-\eta g_t(z,a)}_{\text{Entrepreneurs retire}} \quad \underbrace{+\eta g_t(z,a/\psi)/\psi}_{\text{New entrepreneurs}}$$

Distribution in net worth shares and aggregation

- Entrepreneur's behavior is linear in net worth but nonlinear in productivity.
- Only need the distribution of net worth shares $\omega_t(z) = \frac{1}{A_t}\int_0^\infty a g_t(z,a)da$.

$$\frac{\partial \omega_t(z)}{\partial t} = \left[s_t(z) - \frac{\dot{A}_t}{A_t} - (1-\psi)\eta\right]\omega_t(z) - \frac{\partial}{\partial z}\mu(z)\omega_t(z) + \frac{1}{2}\frac{\partial^2}{\partial z^2}\sigma^2(z)\omega_t(z)$$

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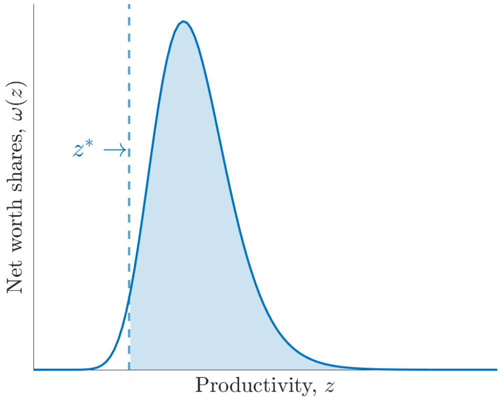
- Model is isomorphic to standard RANK with endogenous TFP $\tilde{Z}_t$.
- Aggregate output Y_t and TFP $\tilde{Z}_t$ are

$$Y_t = Z_t K_t^\alpha L_t{}^{1-\alpha}, \quad Z_t = \left(\underbrace{\mathbb{E}_{\omega_t(z)} \left[z \mid z > z_t^* \right]}_{\text{Endogenous TFP}} \right)^\alpha .$$

Endogenous TFP



$$\tilde{Z}_t = \left(\mathbb{E}_{\omega_t(z)}\left[z \mid z > z_t^*\right]\right)^{\alpha}$$

New Keynesian Block

- Representative Household ▸ More
- Capital good producer ▸ More
- Retailers ▸ More
  - New Keynesian Phillips Curve ▸ More
- Final good producers ▸ More

Effect of monetary policy on misallocation

Monetary policy and misallocation

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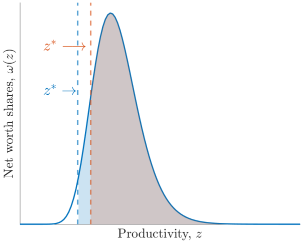
Productivity-threshold channel



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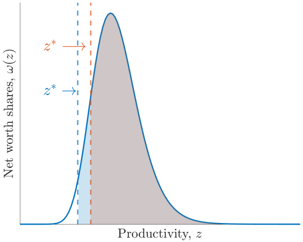

Direct effect: $\frac{\partial z_t^*}{\partial r_t} > 0$, $\frac{\partial Z_t}{\partial r_t} > 0$.

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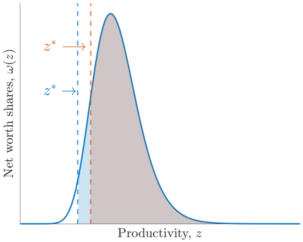
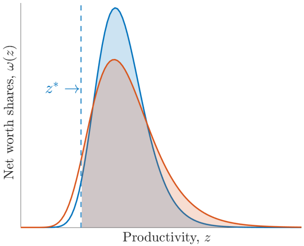


Net-worth distribution channel



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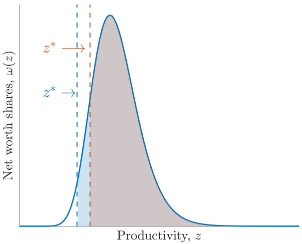

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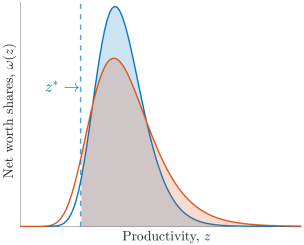

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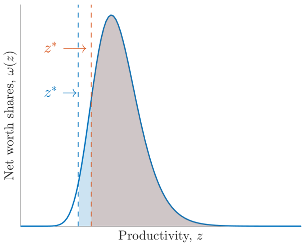

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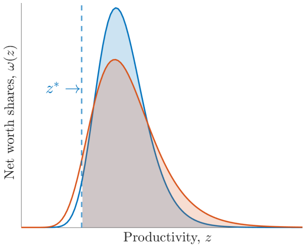

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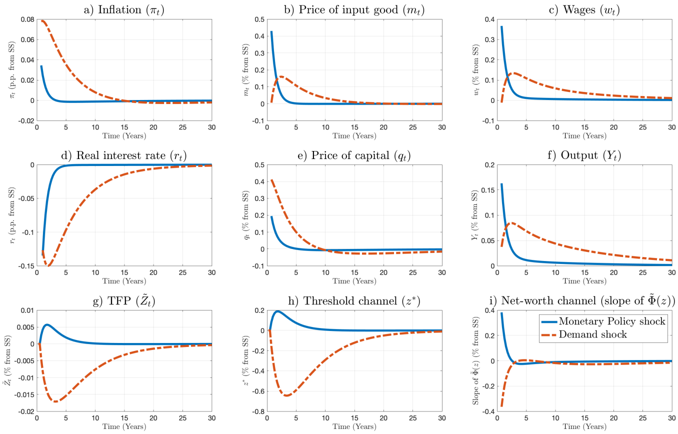
- by changing slope of profit function $\tilde{\Phi}_t(z)$

- Direct effect of monetary policy on TFP is positive, overall effect ambigous

Calibration

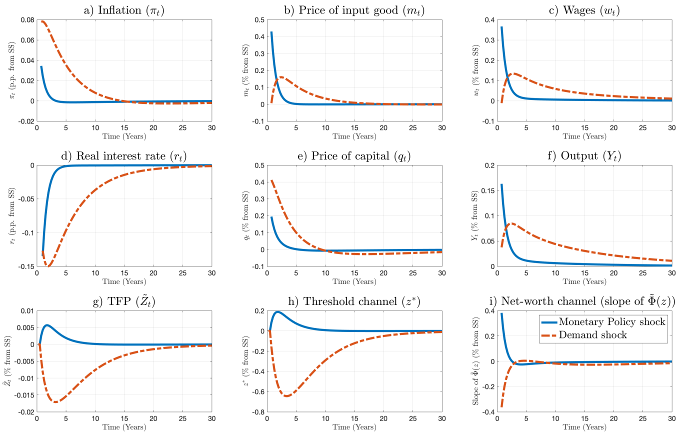
	Parameter	Value	Source/target
ρ^h	Household's discount factor	0.025	Av. 10Y bond return of 2.5% (FRED)
δ	Capital depreciation rate	0.065	Aggregate depreciation rate (NIPA)
ψ	Fraction firms' assets at entry	0.1	Av. size at entry 10% (OECD, 2001)
η	Firms' death rate	0.12	Av. real return on equity 11% (S&P500)
γ	Borrowing constraint parameter	1.43	Corporate debt to net worth of 43% (FRED)
α	Capital share in production function	0.3	Standard
ζ	Relative risk aversion parameter HH	1	Log utility in consumption
ϑ	Inverse Frisch Elasticity	1	Kaplan et al. (2018)
Υ	Constant in disutility of labor	0.71	Normalization $L = 1$
ϕ^k	Capital adjustment costs	10	VAR evidence
ϵ	Elasticity of substitution retail goods	10	Mark-up of 11%
θ	Price adjustment costs	100	Slope of PC of 0.1
$\bar{\pi}$	Inflation target	0	-
ϕ	Slope Taylor rule	1.25	-
υ	Persistence Taylor rule	0.8	-
Γ	SS Aggregate Productivity	1	Normalization
ς_z	Mean reverting parameter	0.8	Persistence Gilchrist et al. (2014)
σ_z	Volatility of the shock	0.30	Volatility Gilchrist et al. (2014)

Expansionary monetary policy shock reduces misallocation



- MP easing shock increases threshold and tilts net-worth distribution towards high-productivity firms.

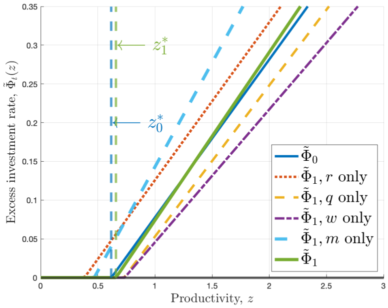
Demand shock reduces real rates and increases misallocation



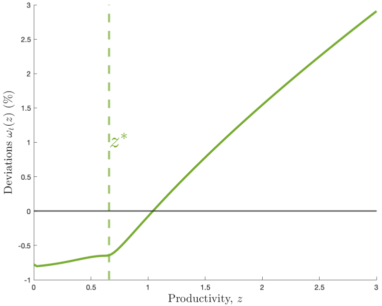
- Temporary increase patience of HH decreases threshold and tilts net-worth distribution towards low-productivity firms.

Why does expansionary monetary policy reduce misallocation?

(a) Excess investment rate before the shock $\tilde{\Phi}_0(z)$ and after 1 year $\tilde{\Phi}_1(z)$.



(b) - Deviations of net-worth shares after 1 year



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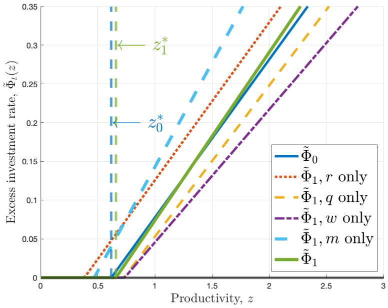

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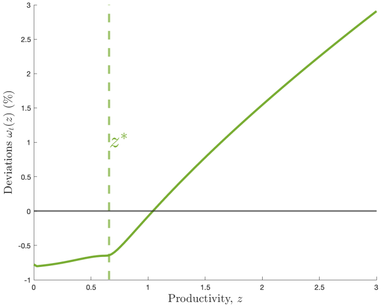

Can we see this pattern in the data after an expansionary MP shock?

Empirical evidence

After a monetary policy expansion, high productivity firms increase their investment relatively more than low productivity firms.

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- Data: yearly balance sheet and cash flow data for the quasi-universe of Spanish firms.
- Monetary policy shocks identified à la Jarociński and Karadi (2020).
  - high-frequency data and sign restrictions in a SVAR to identify monetary policy shocks in the Euro area at the monthly level, aggregated at a yearly frequency.
  - renormalized so that ε_t^{MP} is a 100bps expansionary monetary policy shock.

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  - renormalized so that ε_t^{MP} is a 100bps expansionary monetary policy shock.
- Use MRPK as proxy for productivity

$$MRPK_t = \frac{\partial m_t f_t(z, k, l^*)}{\partial k} = \left[\left(\frac{1-\alpha}{w_t} \right)^{\frac{1-\alpha}{\alpha}} m_t^{\frac{1}{\alpha}} \right] z \propto z.$$

Empirical evidence

Robustness

- Empirical specification following Ottonello and Winberry (2020),

$$\Delta log\ k_{j,t} = \alpha_j + \alpha_{st} + \beta\left(MRPK_{j,t-1} - \mathbb{E}_j\left[MRPK_j\right]\right)\varepsilon_t^{MP} + \Lambda' Z_{j,t-1} + u_{j,t}.$$

  - Demean MRPK to ensure that the results are not driven by permanent heterogeneity in responsiveness across firms.
  - Controls $Z_{j,t-1}$ include standardized demeaned MRPK, total assets, leverage, sales growth, and net financial assets as a share of total assets; and the interaction of demeaned MRPK with GDP growth.

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	(1)	(2)
ϵ_t^{MP1} x $MRPK_{t-1}$	$\boxed{0.141^{**}}$	$\boxed{0.293^{***}}$
	(0.06)	(0.07)
Observations	5,567,706	4,169,950
R^2	0.267	0.285
MRPK control	YES	YES
Controls	NO	YES
Time-sector FE	YES	YES
Time-sector clustering	YES	YES

Optimal Monetary Policy

Central Bank's Ramsey problem

$$\max_{\{\omega_t(z),\ \text{Prices}_t, \text{Quantities}_t\}_{t \in\ [0,\ \infty)}} \mathbb{E}_0 \int_0^\infty e^{-\rho^h t} u(C_t, L_t) dt$$

subject to private equilibrium conditions $\forall t \in [0, \infty)$ and initial conditions

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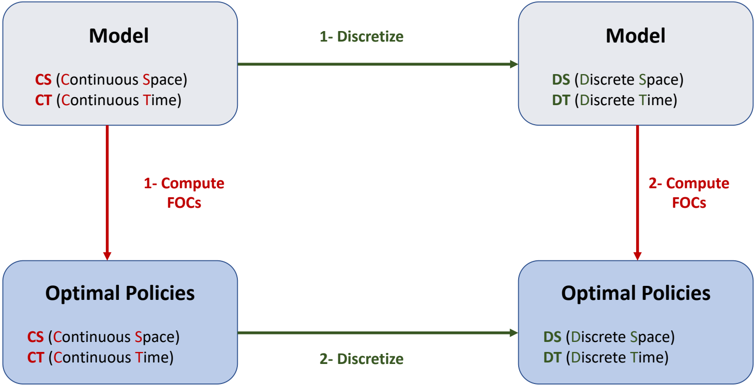
subject to private equilibrium conditions $\forall t \in [0, \infty)$ and initial conditions

- Need to keep track of the whole distribution of firms $\omega_t(z)$
- We propose a new algorithm to solve for Ramsey optimal policies with heterogeneous agents.
  - Discretize the continuous time and continuous-space problem and use standard software (Dynare) to solve non-linearly for the optimal monetary policy. More

Sketch of solution algorithm



Proposition: Solutions converge as $\Delta t \to 0$.
Results practically coincide across methods for Nuño and Thomas (2020) model.

Sketch of solution algorithm

Back

1. Discretize the time space (Δt); and the state space (Δz) into J grid points using finite differences (Achdou et al, 2017):
   - system of $2J$ equations and $2J$ unknowns for the HJB and the KFE equation (we don't have a HJB).

$$\begin{pmatrix} \frac{1}{\Delta t}\left(\mathbf{v}^{n+1} - \mathbf{v}^{n}\right) + \rho \mathbf{v}^{n+1} & = \mathbf{u}^{n+1} + \mathbf{A}^{n+1}\mathbf{v}^{n+1} \\ \frac{\mathbf{g}^{n+1} - \mathbf{g}^{n}}{\Delta t} & = \left(\mathbf{A}^{n+1}\right)^{T} \mathbf{g}^{n+1} \end{pmatrix}$$

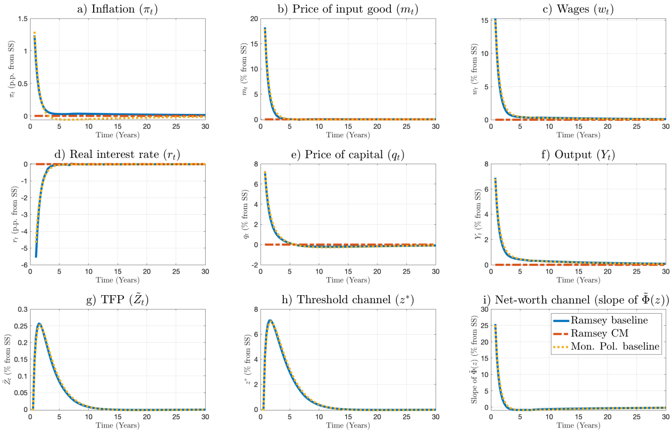
   - set of X equilibrium conditions (MC, FOCs of representative agents)

2. Compute the planner's optimality conditions on discretized problem : $(2J + X) + (2J + X + 1)$ equations using symbolic differentiation

3. Solve the transitional dynamics up to horizon T using a Newton algorithm to solve a large equation set of $[(2J + X) + (2J + X + 1)]\ T$ equations (cf. Auclert et al., 2020)

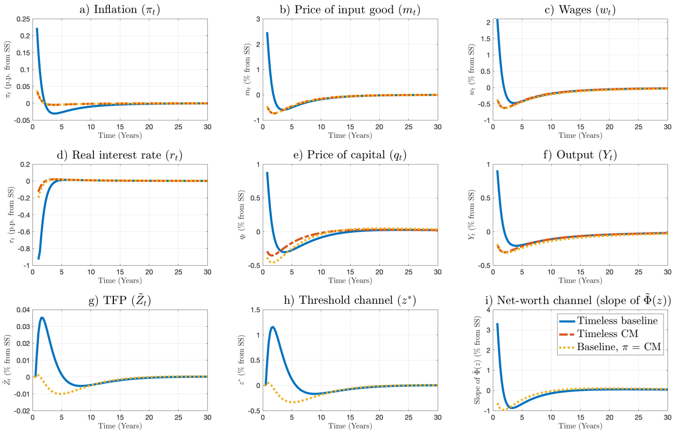
Using Dynare

Optimal Ramsey policy: a new time inconsistency

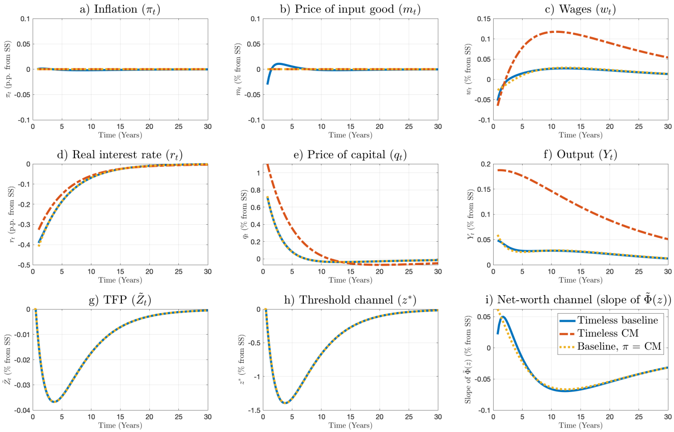


- Complete Markets economy (CM): zero inflation is optimal (steady state is first-best due to subsidy undoing mark-up distortion) CE vs Baseline
- Baseline economy: surprise inflation is optimal since it reduces capital misallocation

Timeless optimal monetary policy response to cost-push shock: leaning *with* the wind



Timeless optimal monetary policy response to demand shock: *divine coincidence* holds



Conclusions

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Conclusions

- New model of heterogeneous firms, financial frictions and monetary policy
  - Including a new algorithm to solve and compute optimal policy
- Positive analysis: expansionary MP reduces misallocation through the productivity-threshold and net-worth channels
  - Empirical evidence supporting higher investment of high productivity firms after expansionary monetary policy shock
- Normative analysis: important implications for optimal monetary policy
  - New source of time inconsistency
  - Different response facing cost-push shock (lean with the wind)

Appendix

Representative household

Back

Standard consumption-labor-savings choice

$$\max_{C_t, L_t, D_t, B_t^N} \mathbb{E}_0 \int_0^\infty e^{-\rho^h t} u(C_t, L_t) dt$$

$$s.t.$$

$$\dot{D}_t q_t + \dot{B}_t^N + C_t = (R_t - \delta q_t) D_t + (i_t - \pi_t) B_t^N + w_t L_t + T_t$$

- C_t: consumption
- D_t: capital holdings
- B_t^N holdings of nominal bonds (zero net supply)
- L_t: labor supply
- i_t: nominal interest rate
- T_t : profits of *retailers*, *capital good producer* and *net dividends* from firms

Capital good producer

Produces capital and sells it to the household and the firms at price q_t

Back

$$\max_{\iota_t, K_t} \mathbb{E}_0 \int_0^\infty e^{-\int_0^t r_s ds} \left(q_t \iota_t - \iota_t - \Xi(\iota_t) \right) K_t dt.$$

$$s.t. \quad \underbrace{\dot{K}_t = (\iota_t - \delta) K_t}_{\text{LOM of } K_t}.$$

- ι_t: investment *rate*,
- $\Xi(\iota_t) = \frac{\phi^k}{2}(\iota_t - \delta)^2$: quadratic adjustment costs.

New Keynesian block

Back

- Final good producers aggregate varieties $j \in [0,1]$. Cost minimization implies demand for variety j is given by

$$y_{j,t}\left(p_{j,t}\right) = \left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t, \text{ where } \underbrace{P_t = \left(\int_0^1 {p_{j,t}}^{1-\varepsilon} dj\right)^{\frac{1}{1-\varepsilon}}}_{\text{Agg. Price index}}.$$

- Retailers maximize

$$\max_{p_{j,t}} \int_0^\infty e^{-\int_0^t r_s ds} \left\{ \underbrace{\left(\frac{p_{j,t}}{P_t} - m_t\right)}_{\text{Mark-up}} \left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t - \frac{\theta}{2}\left(\frac{\dot{p}_{j,t}}{p_{j,t}}\right)^2 Y_t \right\} dt$$

  - ε: elasticity of substitution across goods $\varepsilon > 0$.
  - $p_{j,t}$: price of variety j.
  - θ: price adjustment cost parameter.

New Keynesian block

Back

- The symmetric solution to the pricing problem yields the New Keynesian Phillips curve

$$\left(r_t - \frac{\dot{Y}_t}{Y_t}\right)\pi_t = \frac{\varepsilon}{\theta}(m_t - m^*) + \dot{\pi}_t, \qquad m^* = \frac{\varepsilon - 1}{\varepsilon},$$

- $\pi_t = \frac{\dot{P}}{P_t}$ is inflation,
- m_t are relative prices of intermediate good (inverse mark-ups of retailers),
- m^* is the optimal inverse mark-up,
- Real rates are defined as $r_t \equiv \frac{R_t - \delta q_t + \dot{q}_t}{q_t}$.

Back

$$
\begin{aligned}
w_t =& (1-\alpha) m_t Z_t K_t^{\alpha} L_t{}^{-\alpha}, \\
R_t =& \alpha m_t Z_t K_t^{\alpha-1} L_t{}^{1-\alpha} \frac{z_t^*}{\mathbb{E}\left[z \mid z > z_t^*\right]}, \\
\frac{\dot{A}_t}{A_t} =& \frac{1}{q_t}\left[\gamma(1-\Omega(z_t^*))\left(\alpha m_t Z_t K_t^{\alpha-1} L_t{}^{1-\alpha} - R_t\right) + R_t - \delta q_t - q_t(1-\psi)\eta)\right].
\end{aligned}
$$

RANK vs HANK

▸ Back

RANK

- All capital is owned by HH $D_t = K_t$
- No financial frictions.
- TFP is exogenous
  $Z = 1$

HANK

- Capital is owned by HH and entrepreneurs: $D_t + A_t = K_t$
- Financial frictions: $k_t \leq \gamma a_t$
- TFP is endogenous
  $Z = (\mathbb{E}_t [z \mid z > z_t^*])^\alpha$

- Introduce subsidies in both economies, such that the SS mark-up distortion is undone.

Direct and indirect effects on profits and threshold

Back

Profits

$$\Phi_t(z,a) = \underbrace{(z\varphi_t - R_t)}_{\tilde{\Phi}_t}\gamma a = \left(z\alpha\left(\frac{(1-\alpha)}{w_t}\right)^{(1-\alpha)/\alpha} m_t^{\frac{1}{\alpha}} - (q_t(r_t+\delta)+\dot{q}_t)\right)\gamma a$$

Productivity threshold z^*

$$z_t^* = \frac{R_t}{\varphi_t} = \frac{(q_t(r_t+\delta)+\dot{q}_t)}{\alpha\left(\frac{(1-\alpha)}{w_t}\right)^{(1-\alpha)/\alpha} m_t^{\frac{1}{\alpha}}}$$

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- $\downarrow q_t$ and $\downarrow r_t$ increase profits *homogenously* for all firms, and *decrease*threshold z^*.

Direct and indirect effects on profits and threshold

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Profits

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- $\downarrow q_t$ and $\downarrow r_t$ increase profits *homogenously* for all firms, and *decrease*threshold z^*.
- $\downarrow w_t$ and $\uparrow m_t$ increase profits *relatively more* for more productive firms, and *decrease*threshold z^*.

Use Dynare to solve the OMP problem in Discrete Time / Discrete Space non-linearly

Back

- Provide
  - the SS of the problem conditional on the policy instrument,
  - the set of discretized non-linear equilibrium conditions of the private economy,
  - the planner's objective function.

Use Dynare to solve the OMP problem in Discrete Time / Discrete Space non-linearly

Back

- Provide
  - the SS of the problem conditional on the policy instrument,
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- Use *ramsey_model* command:
  - Dynare computes FOCs for the Ramsey problem by symbolic differentiation.
- Use *steady* command:
  - Dynare computes SS of the Ramsey problem.
- Use *perfect_foresight_solver* command:
  - Uses Newton method to solve simultaneously all the non-linear equations for every period, using sparse matrices.

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Easy to use and general!

Robustness

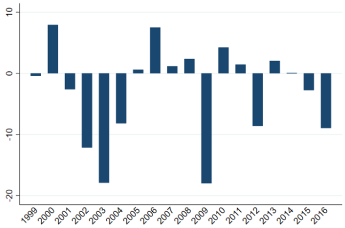
Back

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ϵ_t^{MP} x $MRPK_{t-1}$	0.238***	0.299***	0.177**	0.432***				
	(0.06)	(0.07)	(0.07)	(0.09)				
Inv_{t-1}	-0.0310***	-0.0259***						
	(0.00)	(0.00)						
ϵ_t^{MP2} x $MRPK_{t-1}$					0.166*	0.345***		
					(0.10)	(0.10)		
ϵ_t^{MP} x $MRPK_{t-1}$ (not demeaned)							0.0906**	0.243***
							(0.04)	(0.04)
Observations	4,162,114	4,094,537	283,835	263,397	5,567,706	4,169,950	5,567,706	4,169,950
R^2	0.279	0.283	0.153	0.162	0.267	0.285	0.267	0.286
MRPK control	YES	YES	YES	YES	YES	YES	YES	YES
Controls	NO	YES	NO	YES	NO	YES	NO	YES
Time-sector FE	YES	YES	YES	YES	YES	YES	YES	YES
Time-sector clustering	YES	YES	YES	YES	YES	YES	YES	YES
Panel	FULL	FULL	BALANCED	BALANCED	FULL	FULL	FULL	FULL

MP shocks

Back

Panel 1 - Baseline weighting - ε_t^{MP}



Panel 2 - Alternative weighting - ε_t^{MP2}