Firm Heterogeneity, Capital Misallocation and Optimal Monetary Policy

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

How does firm heterogeneity affect the optimal conduct of monetary policy

- Firm heterogeneity affects the transmission of monetary policy (e.g. Ottonello and Winberry, 2020; Jeenas, 2019; Koby and Wolf, 2020; Jungherr et al., 2022, ...)
- One particular channel of interest is through changes in the allocation of capital when financial frictions matter (Reis 2013, Gopinath et al 2017, Asriyan et al. 2021,...).
- Which are the implications of firm heterogeneity and financial frictions for the optimal conduct of monetary policy?
  - Challenge: net-worth / productivity distribution is an infinite-dimensional object.

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.
  - Standard New Keynesian block.
  - Heterogeneous firms block as in Moll (2014).

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- Benchmark model to understand the impact of monetary policy on misallocation and endogenous TFP.
  - Standard New Keynesian block.
  - Heterogeneous firms block as in Moll (2014).
- New algorithm to solve nonlinearly for Ramsey optimal policies with heterogeneous agents using continuous time and Dynare.
  - Previous methods by Nuño and Thomas (2020), LeGrand, Martin-Baillon, and Ragot (2019) and Bhandari et al (2020)

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    - ⋆ Expansionary monetary policy increases investment of more productive firms relatively more, channeling resources towards high-productivity constrained firms ("misallocation channel")
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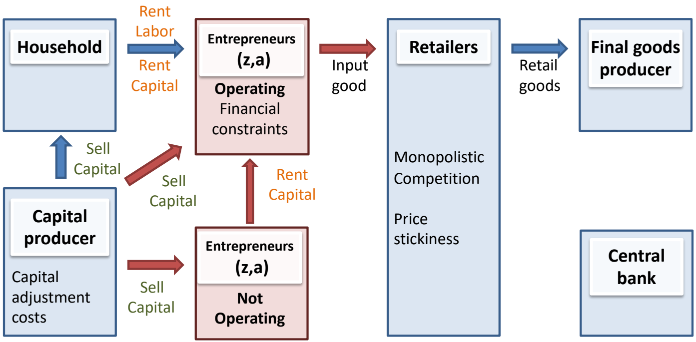
    - ★ Expansionary monetary policy increases investment of more productive firms relatively more, channeling resources towards high-productivity constrained firms ("misallocation channel")
  - Empirical support for the mechanism based on Spanish firm-level micro data.
- Optimal monetary policy:
  - Misallocation creates a *time inconsistent* motive to temporarily expand the economy.
  - Timeless response to demand shocks: "divine coincidence"...
  - ... but at the ZLB: low for much longer.

Model

The model in a nutshell



Continuum of heterogeneous firms operated by entrepreneurs

- Heterogeneity in entrepreneurs' net worth (a_t) and productivity (follows OU-diffusion process, $d\log(z_t) = -\log z\ dt + \sigma\ dW$;).
- 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:

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

- 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

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

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

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  - She lends her net worth to other entrepreneurs.

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  - She lends her net worth to other entrepreneurs.
- If $z \geq z_t^*$, operate at maximum capacity $k_t(z,a) = \gamma a \rightarrow$ Entrepreneur is constrained
- Optimal choices and profits are linear in capital/net worth

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

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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.

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

- d_t: dividends
- R_t: rental rate of capital
- q_t: price of capital
- a_t: net worth (capital owned by firm)

Distribution in net worth shares and aggregation

- Entrepreneur's behavior is linear in net worth but nonlinear in productivity.

  ▸ Joint distribution of net worth and 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 $\tilde{Z}_t$.

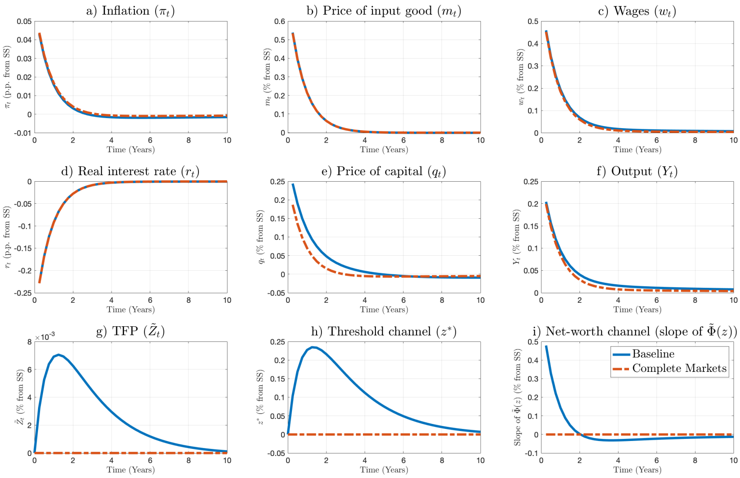
- Aggregate output Y_t and TFP $\tilde{Z}_t$ are

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

New Keynesian block

Monetary policy transmission

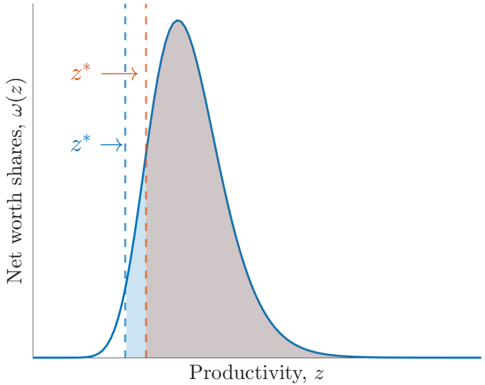
Expansionary monetary policy shock increases TFP...



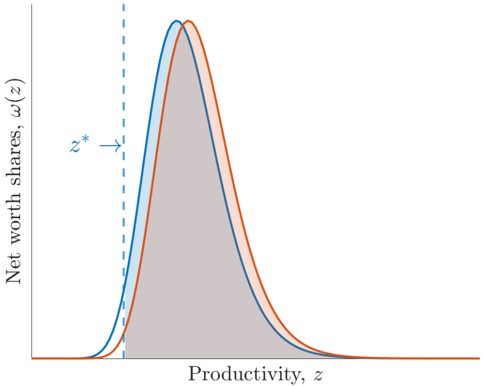
... by reducing misallocation

Monetary policy affects TFP by reducing the share of constrained firms in the economy (z_t^* - *productivity-threshold channel*) and by redistributing resources towards high productivity firms ($\omega_t(z)$ - *net-worth distribution channel*)

Productivity-threshold channel

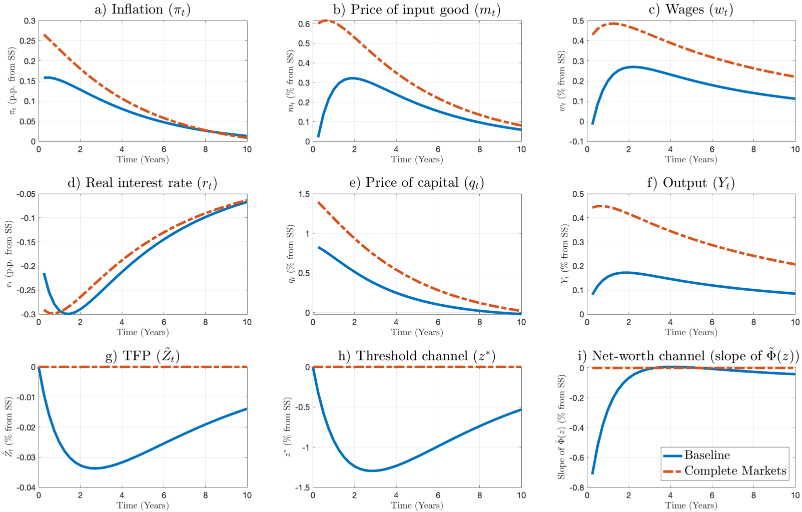


Net-worth distribution channel



▸ Empirical evidence supporting the mechanism in the data

A demand shock can also increase misallocation (ex. decline in natural rate)



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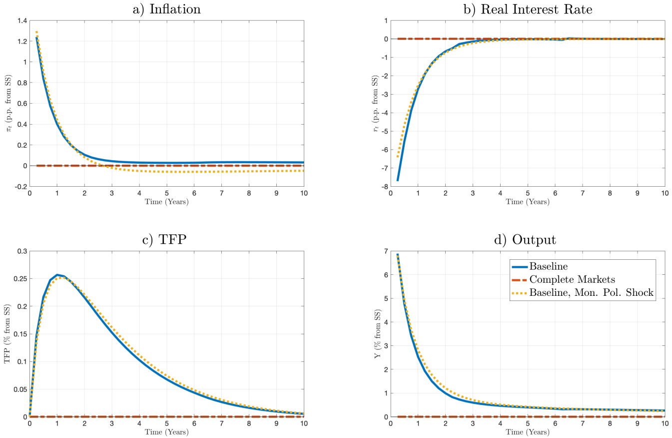
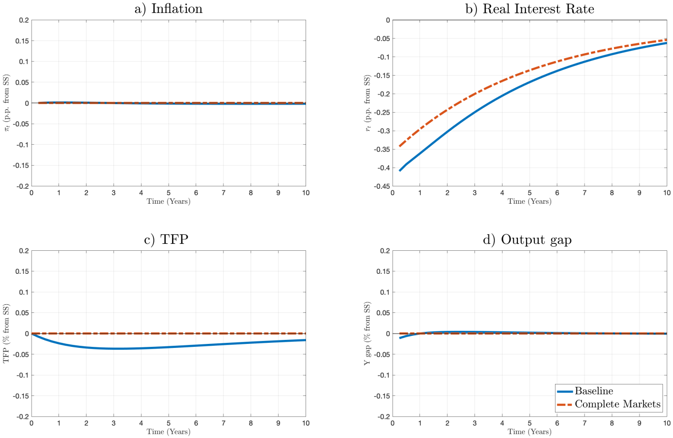
- Need to keep track of the whole distribution of firms $\omega_t(z)$
- We propose a new algorithm to solve for Ramsey optimal policies with heterogeneous agents.
  - Discretize the continuous time and continuous-space problem and use standard software (Dynare) to solve non-linearly for the optimal monetary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

Optimal Ramsey policy: a new time inconsistency

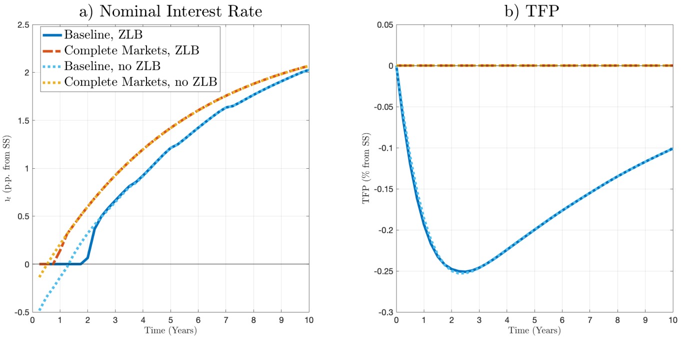


- Complete Markets economy (CM): zero inflation is optimal (steady state is first-best due to subsidy undoing mark-up distortion) CE vs Baseline
- Baseline economy: surprise inflation is optimal since it temporarily reduces capital misallocation

Timeless optimal response to a demand shock: 'divine coincidence'



Timeless optimal response to a demand shock with ZLB: low for even longer



- Heterogeneity and financial frictions calls for '*low for longer*' compared to the complete markets case (orange)

Conclusions

- New model of heterogeneous firms, financial frictions and monetary policy
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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 inflationary time inconsistency: undoing financial frictions.
  - 'Divine coincidence holds when facing demand shocks (timeless)
    - Zero-Lower Bound: *Low for even longer*.

Appendix

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)

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

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

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

- ι_t: investment *rate*,
- $\Xi\left(\iota_t\right) = \frac{\phi^k}{2}\left(\iota_t - \delta\right)^2$: 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

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

- $\pi_t = \frac{\dot{P}}{P_t}$ 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 $r_t \equiv \frac{R_t - \delta q_t + \dot{q}_t}{q_t}$.

Distribution of entrepreneurs

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

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

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

Back

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

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

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

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,
  - the set of discretized non-linear equilibrium conditions of the private economy,
  - the planner's objective function.
- 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!

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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). ▸ more
- Use MRPK as proxy for productivity.
- Empirical specification following Ottonello and Winberry (2020):

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

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	(1)	(2)
ϵ_t^{MP1} x $MRPK_{t-1}$	0.141**	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

Yes!

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Empirical evidence: Details

MP shock

- 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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Productivity

- $MRPK_t = \frac{\partial m_t f_t(z,k,l^*)}{\partial k} = \left[\left(\frac{1-\alpha}{w_t} \right)^{\frac{1-\alpha}{\alpha}} m_t^{\frac{1}{\alpha}} \right] z \propto z.$
- Demean MRPK to ensure that the results are not driven by permanent heterogeneity in responsiveness across firms.
- Controls $Z_{j,t-1}$ include: MRPK, total assets, leverage, sales growth, net financial assets as a share of total assets, MRPK $\times$ GDP growth.

Empirical evidence: Robustness

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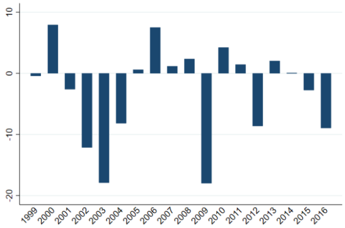
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ϵ_t^{MP} x $MRPK_{t-1}$	0.238***	0.299***	0.177**	0.432***				
	(0.06)	(0.07)	(0.07)	(0.09)				
Inv_{t-1}	-0.0310***	-0.0259***						
	(0.00)	(0.00)						
ϵ_t^{MP2} x $MRPK_{t-1}$					0.166*	0.345***		
					(0.10)	(0.10)		
ϵ_t^{MP} x $MRPK_{t-1}$ (not demeaned)							0.0906**	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}