Macroeconomics of Investment with Heterogeneity

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Outline

1. Catherine, Chaney, Huang, Sraer, Thesmar (2021)
2. Bierdel, Drenik, Herreño, Ottonello (2021)
3. Winberry (2021)
4. Zwick Mahon (2017)
5. Ottonello Winberry (2021)

Outline

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Motivation

- Cross-sectional effects of having more collateral on firm-investment
- Broad literature of firm excess sensitivity
- What are the TFP and output effects of collateral constraints?

Cross-Sectional Elasticity

$$\frac{i_{it}}{k_{it}} = a + \beta \frac{REValue_{it}}{k_{i,t-1}} + Offprice_{it} + \Gamma' X_{it} + v_{it}$$

- Chaney, Sraer, Thesmar (2012) AER paper all about this
- Exogenous shock to real estate value, increases the value of collateral, which increases debt capacity and investment for financially-constraint firms

Production

$$q_{it} = e^{z_{it}} \left(k_{it}^{\alpha} l_{it}^{1-\alpha} \right)$$

- Firm-level productivity AR(1)
- Downward-sloping demand curves

$$q_{it} = Q p_{it}^{-\phi}$$

- Curvature in the revenues minus wage bill

$$\pi(z_{it}, k_{it}) = b Q^{1-\theta} w^{-(1-\alpha)\theta/\alpha} e^{z_{it}\theta/\alpha} k_{it}^{\theta},$$

- For $\theta = \frac{\alpha(\phi-1)}{1+\alpha(\phi-1)}$
- Why is it important?

Capital adjustment frictions

- Law of motion of capital stock

$$k_{it+1} = k_{it} + i_{it} - \delta k_{it}$$

- Convex costs of adjustment

$$\frac{c}{2}\left(\frac{i}{k}\right)^2 k$$

Financial Frictions

- interest rate spread on debt m
- Cost of issuing equity. If cash-flows are x, post-issuance

$$G(x) = x(1 + e1_{x<0})$$

- Collateral constraint

$$(1+r)d_{it+1} \leq s((1-\delta)k_{it+1} + \mathbb{E}(p_{t+1}|p_t) \times h)$$

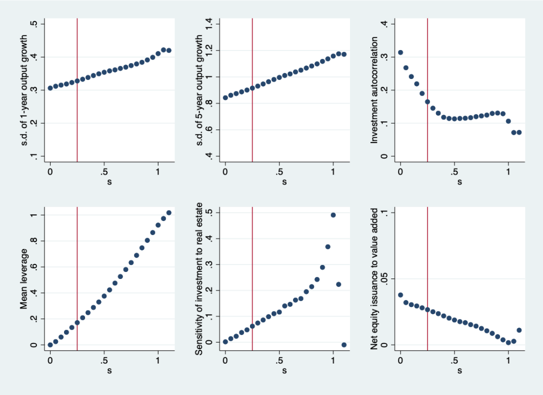
- s parameterize loose or tight the constraint is
- h is the amount of real estate (common across firms)
- Friction comes from limited enforcement
- h is a parameter

Estimation

- Autocorrelation of investment rates to infer the adjustment cost c
- This is usual in investment models (see Cooper and Haltiwanger, 2006)
- Use the cross-sectional elasticity β in an SMM to estimate s
- Use data on equity issuances to estimate e

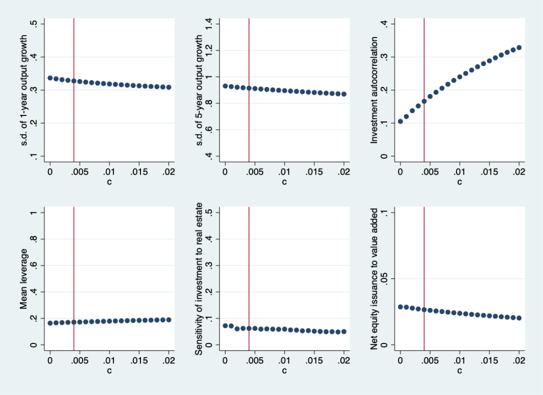
Capital or Financial frictions?

Figure E.1: Sensitivity of moments to pledgeability s



Note: In this figure, we set all estimated parameters (s, c, ρ, σ, H and e) at their SMM estimate in our preferred specification – as per column 3, Panel A in Table 2. We fix w and Q at their reference levels: $w = 0.03$ and $Q = 1$. We then vary s from 0 to 1. For each value of s that we choose, we solve the model, simulate the data, and compute four target moments, plus the average leverage ratio and the sensitivity of debt issuance to real estate value. Each panel corresponds to one moment. The red vertical line corresponds to the SMM estimate of s.

Figure E.2: Sensitivity of moments to adjustment costs c



Note: In this figure, we set all estimated parameters (s, c, ρ, σ, H and e) at their SMM estimate in our preferred specification – as per column 3, Panel A in Table 2. We fix w and Q at their reference levels: $w = 0.03$ and $Q = 1$. We then vary c from 0 to 0.02. For each value of c that we choose, we solve the model, simulate the data, and compute four target moments, plus the average leverage ratio and the sensitivity of debt issuance to real estate value. Each panel

GE Block

- Aggregate production Q is CES

- Resource constraint

$$Q_t = C_t + I_t + AC_t$$

- Quasi linear utility

$$L_t^s = \bar{L} w_t^{\varepsilon}$$

Counterfactual

- Two alternatives of creating the world with no financial constraints

  1. $s \to \infty$
  2. $e = 0$

- Which is the correct one?

RESULTS

Table 3: **Aggregate Effects of Collateral Constraints**

Specification:	(1) Model 1 $c = 0, e = +\infty$	(2) Model 2 $c > 0, e = +\infty$	(3) Model 3 $c > 0, e > 0$
Panel A: *General equilibrium results*			
Δ log(TFP)	0.031	0.027	0.014
Δ log(Output)	0.151	0.120	0.071
Δ log(wage)	0.101	0.080	0.048
Δ log(L)	0.051	0.040	0.024
Δ log(K)	0.282	0.215	0.137
Panel B: *Partial equilibrium results, holding Q fixed only*			
Δ log(TFP)	0.012	0.012	0.005
Δ log(Output)	0.110	0.088	0.052
Δ log(wage)	0.073	0.059	0.035
Δ log(L)	0.037	0.029	0.017
Δ log(K)	0.240	0.185	0.117
Panel C: *Partial equilibrium results, holding (Q, w) fixed*			
Δ log(TFP)	-0.040	-0.029	-0.020
Δ log(Output)	0.400	0.320	0.189
Δ log(wage)	-	-	-
Δ log(L)	0.400	0.320	0.189
Δ log(K)	0.531	0.417	0.254

Note: This table reports the results of the counterfactual analysis for different SMM parameter estimates. The general equilibrium analysis is described in Section 4 and reported in Panel A. Columns (1)-(3) correspond to the three different models described in Columns (1)-(3) of Table 2: Column (1) assumes no adjustment cost ($c = 0$) and infinite cost of equity issuance ($e = +\infty$). Column (2) allows for adjustment cost but still assumes infinite cost of equity issuance. Column (3) also allows for finite cost of equity issues. Panel B implements the same methodology, except that it holds the aggregate demand shifter Q constant, but the wage w clears the labor market. Panel C holds both the aggregate demand shifter Q and wage w constant. Results in both panels are shown as log deviations from the constrained estimated model to the unconstrained benchmark. The unconstrained benchmark correspond to an equilibrium where firms face the same set of parameters as in the SMM estimate – reported in the same column, Table 2, panel A – but do not face a constraint on equity issuance ($e = 0$). In this unconstrained benchmark, investment reaches first best, but firms still benefit from the debt tax shield. *Reading*: In column 1 (no adjustment cost, no equity issuance), the aggregate TFP loss compared to a benchmark without financing constraints is 3.1%.

Results

- The results depend a lot on the persistence of productivity ρ
- Why?
- Recommended reading: Moll (2014)

Mispecification

- Two alternatives to estimate the model
  - Estimate the structural parameters Θ to target (among others) β
  - Estimate the structural parameters Θ to target (among others) debt to capital ratios
- Which is better?
- Offer one metric: Effects of model mispecification
- Also: Effect of measurement error

Mispecification

- Idea: Complicate the model
    1. Intangible capital
    2. Mismeasured capital
    3. Economic depreciation $\neq$ accounting depreciation
    4. Secured debt
- Estimate the extended and restricted (benchmark) model
- What is the effect on the counterfactuals of TFP and output
- Follows Isaiah, Gentzkow, Shapiro (2017) (which I should study).

MISPECIFICATION

Table 6: Estimation Error and Distance from Correct Specification

Relative error in estimation of:	log TFP loss		log Output loss	
Misspecified SMM targets:	β	Leverage	β	Leverage
	(1)	(2)	(3)	(4)
Misspecification parameters:				
Intangible capital share ($\boldsymbol{I}$)	-.0056	-.41	-.0021	-.39
Unobserved physical capital share (U)	-.19	-.34	-.18	-.33
Price measurement error ($\boldsymbol{\sigma_u}$)	.12	-.0033	.11	-.0058
Unobserved debt capacity - need ($\boldsymbol{d_0}$)	.028	1.2	.041	1.2
Fixed unsecured debt ($\boldsymbol{\kappa}$)	.098	-.43	.075	-.42
Actual tax rate - 33% ($\boldsymbol{\tau} - 0.33$)	-.73	-.54	-.68	-.49
Constant	.063	.14	.065	.13
Observations	4,000	4,000	4,000	4,000
R^2	0.32	0.74	0.29	0.73

Note: We simulate datasets from 4,000 alternative models. Each alternative model correspond to the baseline model augmented in six different dimensions described in Section 5.3.3. Six "misspecification" parameters control the degree of departure from the baseline model along these dimensions: $\boldsymbol{\Theta} = (\boldsymbol{\mathcal{I}}, \boldsymbol{U}, \boldsymbol{\sigma_u}, \boldsymbol{d_0}, \boldsymbol{\kappa}, \boldsymbol{\tau})$. We estimate the baseline (misspecified) model on these 4,000 datasets using two separate approaches: one estimation targets leverage; another targets the reduced-form moment β. We then regress:

$$\frac{\hat{X}_i - X_i}{\frac{1}{N}\sum_j X_j} = a + b\frac{\boldsymbol{\mathcal{I}}_i}{\max_j \boldsymbol{\mathcal{I}}_j} + c\frac{\boldsymbol{U}_i}{\max_j \boldsymbol{U}_j} + d\frac{\boldsymbol{\sigma}_{\boldsymbol{u},i}}{\max_j \boldsymbol{\sigma}_{\boldsymbol{u},j}} + e\frac{\boldsymbol{d}_{\boldsymbol{0},i}}{\max_j \boldsymbol{d}_{\boldsymbol{0},j}} + f\frac{\boldsymbol{\kappa}_i}{\max_j \boldsymbol{\kappa}_j} + g\frac{\boldsymbol{\tau}_i - 0.33}{\max_j (\boldsymbol{\tau}_j - 0.33)} + \epsilon_i$$

where X stands for the estimated TFP/output losses and i index alternative models. Standard errors are omitted because they are irrelevant in this cross-section of simulations, but the number is large enough to ensure smooth, linear, relationships as shown in Appendix Figures E.7 and E.8. *Reading*: When the fraction of intangible capital increases from 0 to .5 (maximum misspecification), the misspecification bias on TFP losses estimated by targeting leverage increases from zero (correctly specified) to 41% of the average TFP loss in the cross-section.

Outline

Introduction

- Economic theories: asymmetric information plays central role in asset markets
  - affects quality, valuation, and liquidity of assets traded

    Akerlof 1970, Stiglitz Weiss 1981, Guerrieri Shimer Wright 2010

- How asymmetric information affects capital accumulation?
  - To what extent the quality of technologies that allow mkts participants to obtain info on capital quality can affect investment and income levels?

- This paper: Revisit these questions by combining
  - Capital-accumulation model with asymmetric information
  - Microlevel data informing the degree of information frictions

Neoclassical Block

- **Households**
  - Preferences $\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t)\gamma_n^t$
  - Endowed with $\bar{h}$ hours of work each period
  - Access to a linear technology to produce new capital goods using final goods
- **Firms**
  - Technology $y_{jt} = f_t(\mathscr{K}_{jt}, l_{jt}) \equiv \mathscr{K}_{jt}^{\alpha}(\gamma^t l_{jt})^{1-\alpha}$
  - With i.i.d. probability φ firms exit the economy
  - A new mass φ of firms enter the economy

Neoclassical Block

- **Households** $\Rightarrow$ hold unemployed capital, capital seller
  - Preferences $\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t)\gamma_n^t$
  - Endowed with $\bar{h}$ hours of work each period
  - Access to a linear technology to produce new capital goods using final goods
- **Firms** $\Rightarrow$ hold employed capital, capital buyer
  - Technology $y_{jt} = f_t(\mathscr{K}_{jt}, l_{jt}) \equiv \mathscr{K}_{jt}^{\alpha}(\gamma^t l_{jt})^{1-\alpha}$
  - With i.i.d. probability φ firms exit the economy
  - A new mass φ of firms enter the economy

Capital-quality heterogeneity

- Capital stock composed of infinitesimal indivisible units
- Capital units are heterogeneous in two dimensions
  - observed quality $\omega \in \Omega \equiv [\omega_1, \ldots, \omega_{N_\omega}]$
  - unobserved quality $a \in \mathscr{A} \equiv [a_1, \ldots, a_{N_a}]$
    - ★ private information of owner
- Capital services
  - unit i: $\omega_i a_i$
  - firm j's capital input: $\mathscr{K}_{jt} = \sum_{\omega \in \Omega} \sum_{a \in \mathscr{A}} \omega a k_{jt+1}(\omega, a)$

Decentralized Capital Market

- Capital goods traded in a decentralized mkt with **search-and-matching frictions**
  - Consistent with microlevel evidence (Ramey Shapiro 2001, Gavazza 2011, Ottonello 2015)
- Organized in a continuum of submarkets, indexed by $(\boldsymbol{\omega}, \hat{\boldsymbol{a}}, \boldsymbol{q}) \in \Omega \times \mathscr{A} \times \mathbb{R}_+$
- Search is directed (Shimer 1996, Moen 1997, Menzio Shi 2011)
  - Sellers list price $q(\omega, a)$ and announced quality $\hat{a}(\omega, a)$
  - Buyers dedicate hours of work to search and match $v_t(\omega, \hat{a}, q)$
- CRS matching technology in each submarket
- Tightness $\theta_t(\omega, \hat{a}, q) \equiv \frac{v_t(\omega, \hat{a}, q)}{k_t^s(\omega, \hat{a}, q)}$
- Sellers' matching probability $p(\theta_t(.))$, buyers' matching yield/hour $\mu_t(\theta_t(.))$

Degree of Asymmetric information

- Buyers have access to **inspection technology** (similar to Menzio Shi 2011)
  - prob ψ: that the buyer learns the true type (ω, a) of the capital good
  - prob $1-\psi$: inspection is uninformative

  ψ parameterizes the degree of asymmetric information in the economy

- **Trading protocol upon inspection**
  - If no new info is revealed or capital quality is not below that announced (i.e., $a' \geq \hat{a}$) $\Rightarrow$ trade at price q
  - If quality is some $a' < \hat{a}$: $\Rightarrow$ trade at $q_t^P(\omega, a', q) = \min\{\text{bargain price}, q\}$ (if there are gains from trade, no trade otherwise)

Households' Capital Accumulation

- Law of motion households' unemployed capital of type (ω, a)

$$k_{Ht+1}(\omega,a) = (1-p(\theta_{Ht}(\omega,a)))k_{Ht}(\omega,a) + g(\omega,a)i_t + \varphi K_{Ft}(\omega,a)$$

where $\theta_{Ht}(\omega,a) \equiv \theta_t(\omega, \hat{a}_{Ht}(\omega,a), q_{Ht}(\omega,a))$

- Euler equation for investment

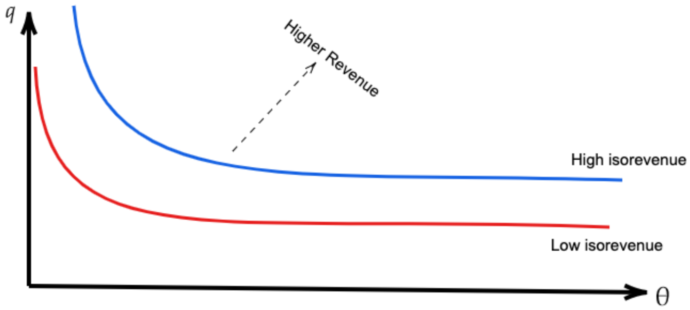
$$1 = \sum_{\omega\in\Omega}\sum_{a\in\mathscr{A}} g(\omega,a)\lambda_t(\mathbf{k})v^{s}_{t+1}(\omega,a,\mathbf{k}),$$

Q-Theory Interpretation, allowing for heterogeneity, search, and AI

Households as Capital Sellers

- Marginal value of capital

$$v_t^s(\omega, a, \mathbf{k}) = \max_{\hat{a}, q} p(\theta_t(\omega, \hat{a}, q))((1-\psi)q + \psi q_t^P(\omega, a, q))$$
$$+ (1 - p(\theta_t(\omega, \hat{a}, q)))\,(\lambda_t(\mathbf{k})v_{t+1}^s(\omega, a, k_{Ht}(\mathbf{k})) - \delta\omega a)$$



Firms' Capital Accumulation

- Law of motion firms' employed capital of type (ω, a)

$$k_{jt+1}(\omega,a) = \sum_{\hat{a}} \int_{q\in\mathbb{R}_+} \iota_t(a|\omega,\hat{a},q)\mu_t\left(\theta_t\left(\omega,\hat{a},q\right)\right) v_{jt}(\omega,\hat{a},q)\,\mathrm{d}q + k_{jt}(\omega,a)$$

where $\iota_t(a|\omega,\hat{a},q)$: share of capital quality a in submarket $(\omega,\hat{a},q)$

- Marginal value of capital

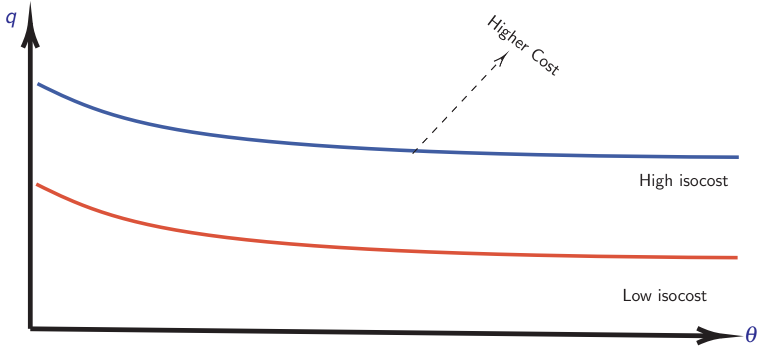
$$v_t^{\mathrm{b}}(\omega,a) = (Z_t-\delta)\omega a + \Lambda_{t,t+1}\left[(1-\varphi)v_{t+1}^{\mathrm{b}}(\omega,a) + \varphi v_{t+1}^{\mathrm{s}}(\omega,a,\mathbf{K}_{Ht})\right],$$

where $Z_t \equiv \alpha\left(\frac{\gamma^t(1-\alpha)}{w_t}\right)^{\frac{1-\alpha}{\alpha}}$

Firms as Capital Buyers

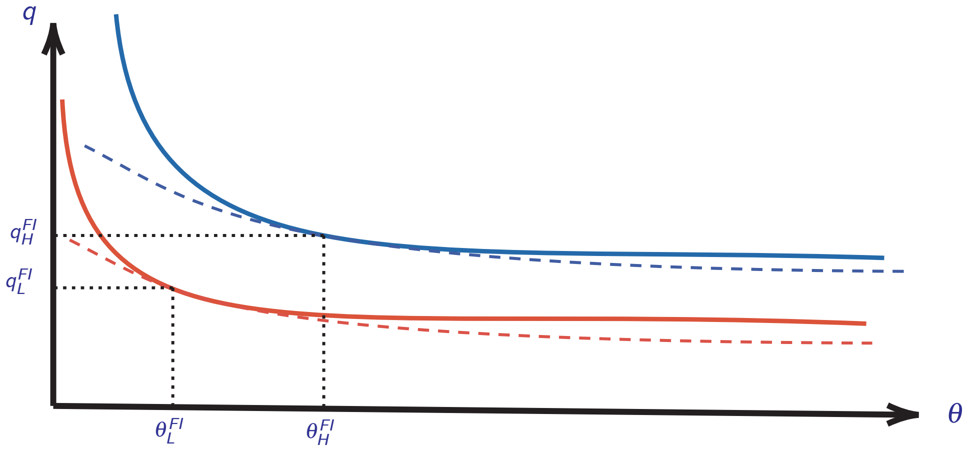
- Optimal search activity across submarkets

$$v_t(\omega,\hat{a},q)\left(\underbrace{((1-\psi)q+\psi\mathbb{E}_a(q_t^P(\omega,a,q)|\omega,\hat{a},q))}_{\text{Expected price}}+\underbrace{\frac{w_t}{\mu_t(\theta(\omega,\hat{a},q))}}_{\text{Search cost}}-\underbrace{\mathbb{E}_a\left(v_t^b(\omega,a)|\omega,\hat{a},q\right)}_{\text{Expected value}}\right)^+=0,$$



Equilibrium Under Full Information

- Suppose $\Omega = \{\omega_L, \omega_H\}$, $\mathscr{A} = \{\bar{a}\}$



Prices and Duration Under Full Information

Prediction I: Under FI there is a **negative relationship between prices and duration**

$q^{\mathrm{FI}}(\omega_H, a) > q^{\mathrm{FI}}(\omega_L, a), p\left(\theta^{\mathrm{FI}}(\omega_H, a)\right) > p\left(\theta^{\mathrm{FI}}(\omega_L, a)\right)$

Intuition: Submarkets with higher quality attract more buyers resulting on higher prices and lower matching probability for buyers

$$\underbrace{(1-\eta)\left(v^{\mathrm{b}}(\omega, a) - \beta v^{\mathrm{s}}(\omega, a)\right)}_{\text{benefit purchasing quality } (\omega, a)} = \underbrace{\frac{\theta(\omega, a)\chi}{p(\theta(\omega, a))}}_{\text{search cost}}$$

Equilibrium Under Asymmetric Information

- Suppose $\mathscr{A} = \{a_L, a_H\}$
- Consider PBE under intuitive criterion (Cho Kreps 1987)
  - fully-revealing separating and pooling equilibria
- Focus on balanced-growth path
- Results extend to multiple types and transitional dynamics

- For **low type**

$$v^{s}(\omega,a_L)=\max_{\{q(\omega,a_L)\}} p(\theta(\omega,a_L,q(\omega,a_L)))\,q(\omega,a_L)$$
$$+(1-p(\theta(\omega,a_L,q(\omega,a_L))))\,(\beta v^{s}(\omega,a_L)-\delta\omega a_L)$$

subject to

$$\theta(\omega,a_L,q(\omega,a_L))=\mu^{-1}\left(\frac{w}{v^{b}(\omega,a_L)-q(\omega,a_L)}\right)$$

Constructing the Equilibrium

- For low type
- For **high type**:

$$v^s(\omega, a_H) = \max_{\{q(\omega,a_H)\}} p(\theta(\omega, a_H, q(\omega, a_H)))\, q(\omega, a_H) + (1 - p(\theta(\omega, a_H, q(\omega, a_H))))\,(\beta v^s(\omega, a_H) - \delta \omega a_H)$$

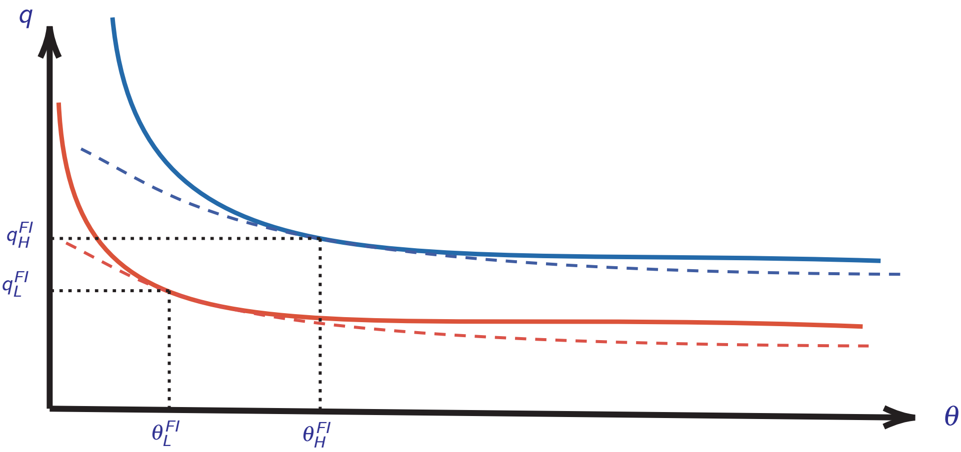
subject to

$$\theta(\omega, a_H, q(\omega, a_H)) = \mu^{-1}\left(\frac{w}{v^b(\omega, a_H) - q(\omega, a_H)}\right),$$

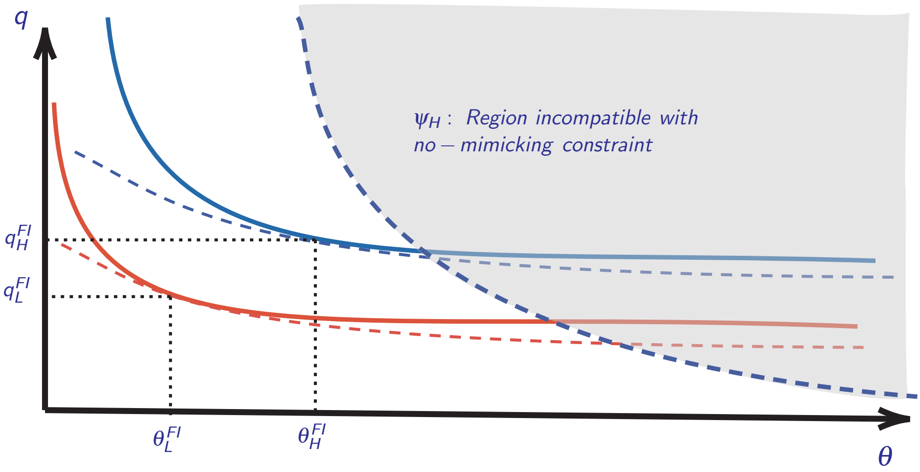
$$v^s(\omega, a_L) \geq p(\theta(\omega, a_H, q(\omega, a_H)))\left((1-\psi)q(\omega, a_H) + \psi q_t^P(\omega, a_L, q(\omega, a_H))\right) + (1 - p(\theta(\omega, a_H, q(\omega, a_H))))\,(\beta v^s(\omega, a_L) - \delta \omega a_L)$$

- Proposition: There exists a unique fully-revealing separating equilibrium that satisfies the intuitive criterion; there are no pooling equilibria

Equilibrium Under Asymmetric Information



Equilibrium Under Asymmetric Information



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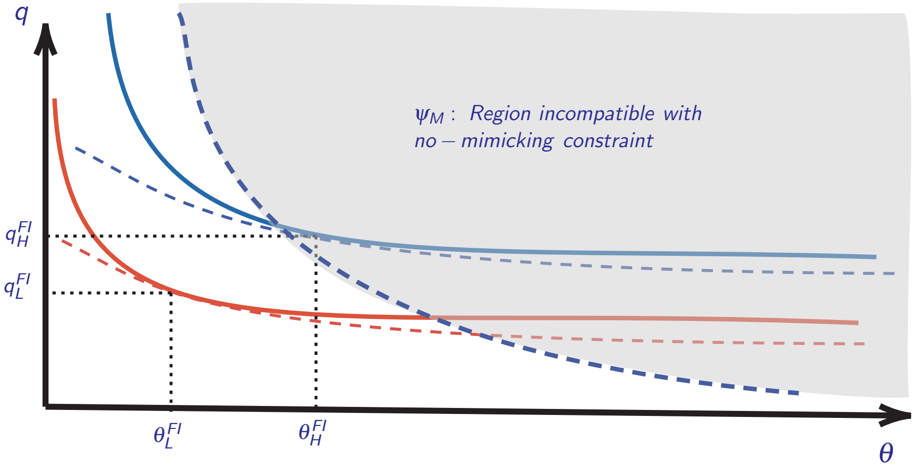

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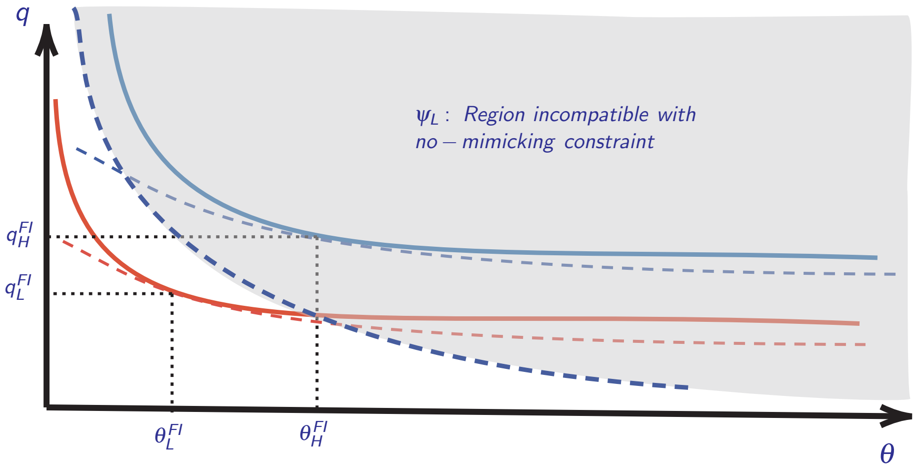
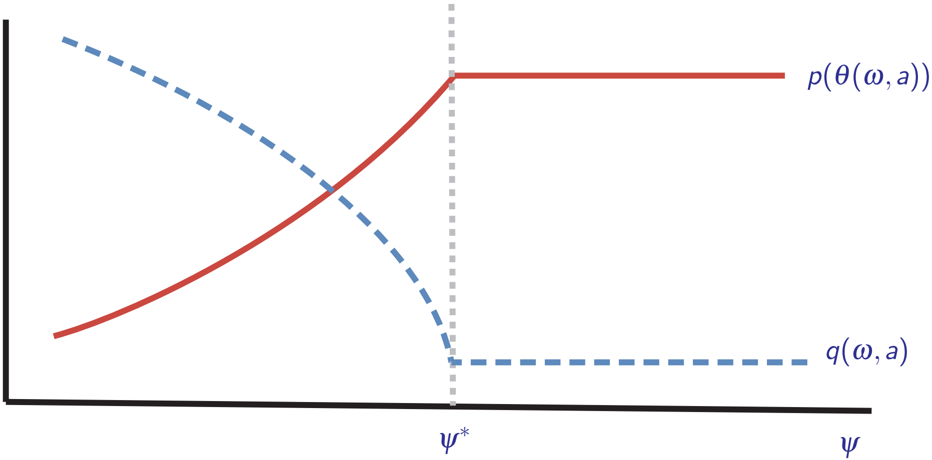


Equilibrium Under Asymmetric Information



Prices and Duration Asymmetric Information

Prediction II:

AI (i.e., $\psi < \psi^*$) affects terms of trade of high-quality capital

$q(\omega, a_H) > q^{FI}(\omega, a_H), p(\theta(\omega, a_H)) < p\left(\theta^{FI}(\omega, a_H)\right)$

- Intuition: a_H chooses higher price to signal its quality, willing to accept lower trading probability

- Distortions governed by ψ: $\left.\frac{d\left[ln \frac{p(\theta(\omega, a_L))}{p(\theta(\omega, a_H))}\right]}{d\psi}\right|_{\psi<\psi^*} < 0$

- **Relationship between prices and duration is informative about ψ**

The Data

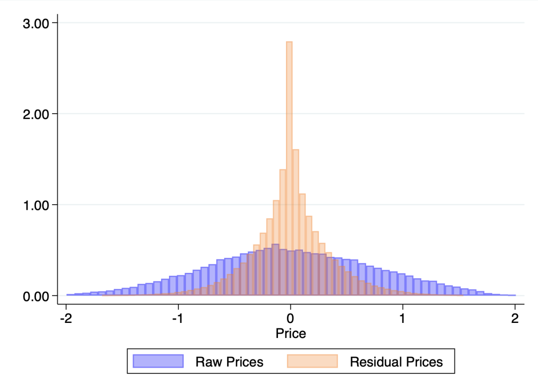
- Panel of capital structures posted for sale and rent
  - Retail, office space, and warehouses
  - Monthly listed price
  - Contain information on listed characteristics:
    location, age, size, number of rooms, etc
  - Duration and monthly search intensity (clicks and emails)
- Source: *Idealista*, leading online platform in the real estate market in Europe
- Coverage: 8.5 million observations from Spain
  - $>$ 1.1 million capital units
  - Period: 2005–2018

Price Variation Explained by Listed Characteristics

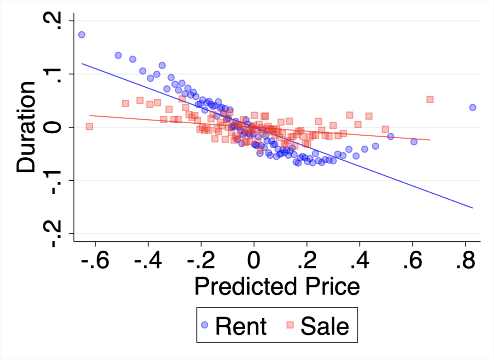
(Log) price per sq. ft. of property i in location l in month t:

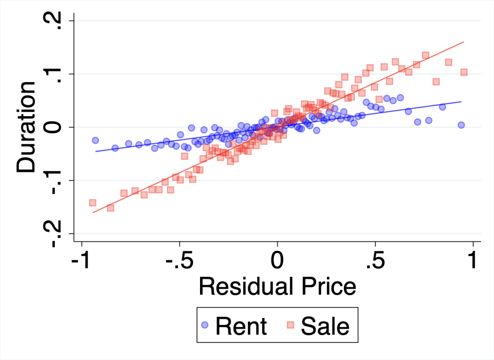
$$log(q_{ilt}) = v_{lt} + \gamma X_i + \varepsilon_{ilt}$$

	Std. Sale	R sq. Sale
Raw data	0.75	0.00
Year	0.71	0.12
Location	0.54	0.48
Year x Loc	0.49	0.57
... x Type	0.48	0.59
... x Area	0.38	0.74
... x Age	0.37	0.75
Benchmark	0.37	0.75



Duration and Prices





- Consistent with model predictions under FI and AI

Prices and Duration

	(1)	(2)
	log Dur	log Dur
log price	0.013***	
	(0.002)	
Predicted Price		-0.018*
		(0.010)
Residual Price		0.154***
		(0.004)
Constant	1.961***	2.108***
	(0.008)	(0.046)
Observations	456,351	439,680
R^2	0.000	0.202
Subsample	Sale	Sale
Fixed Effects	No	Yes

- Results robust to other measures of search behavior

Alternative Explanations

1. Sellers' indifference between price and duration
   - Expected revenues higher for higher residual prices
   - Even for impatient and risk averse sellers
2. Heterogeneity in sellers' preferences
   - Discounting and risk aversion
3. Heterogeneity in sellers' holding costs
   - To rationalize choices, holding costs must be extremely large

Parameterization

Two-step procedure

1. **Fix a subset of parameters to standard values**
2. Calibrate targeting moments on model simulated data

Parameter	Description	Value
β	Discount factor	0.9966
α	Share of capital	0.35
γ	Technology growth	1.004
γ_n	Population growth	1.0027
φ	Firms' exit rate	0.0027
ϕ	Bargaining power of sellers	0.5
η	Curvature matching technology	0.8

PARAMETERIZATION

Two-step procedure

1. Fix a subset of parameters to standard values
2. **Calibrate targeting moments on model simulated data**

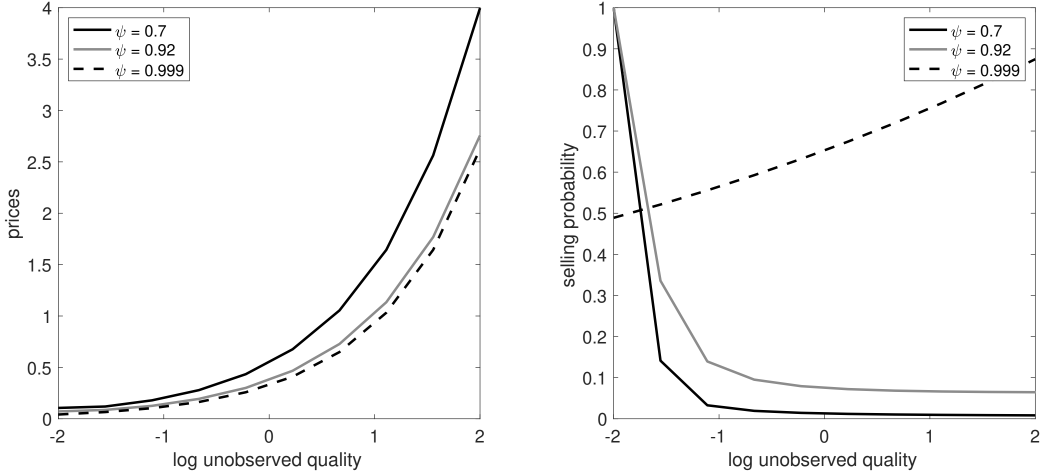
Parameter	**Description**	**Value**
$\bar{m}$	Efficiency matching technology	1.55
σ_ω	SD of observed capital quality	0.65
σ_a	SD of unobserved quality	0.61
ψ	Accuracy inspection technology	0.92

Moment	Data	Model
Mean duration	7.55	8.04
SD predicted prices	0.593	0.595
SD residual prices	0.546	0.563
slope $\log dur$ and residual prices	0.154	0.153

Identification

In the model, the extent of asymmetry of information ψ is identified by the projection of log durations on log prices controlling for the observed component of capital quality. The variance of the distribution of unobserved qualities σ_a^2 is then identified by the variance of residual prices.

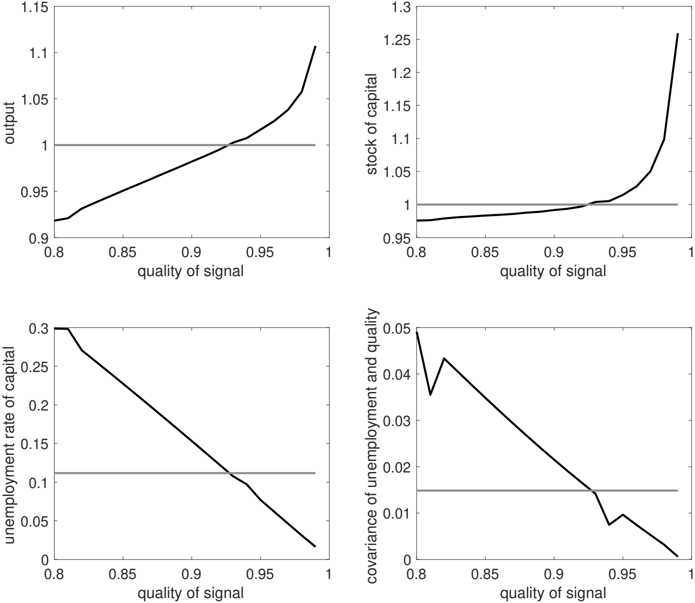
Effects of Asymmetric Informations on Capital Markets



- Aggregate output can be represented by

$$Y_t = \left(\gamma^t L_t\right)^{1-\alpha} \left(\underbrace{\left[\sum_{\omega \in \omega} \sum_{a \in \mathscr{A}} K_t(\omega, a) \right]}_{\text{capital stock}} \left[\mathbb{E}(\omega a) \left(1 - \underbrace{\mathbb{E}(u_t(\omega, a))}_{\text{capital unemployment}} \right) - \underbrace{\mathbb{C}ov\left(\omega a, u_t(\omega, a)\right)}_{\text{quality of unemployed capital}} \right] \right)^{\alpha}$$

Macroeconomic Effects of Asymmetric Information



Macroeconomic Effects of Asymmetric Information: Decomposition of Channels

Variable	Value
Output effect of full information	9.7%
Investment channel	6.5%
Capital-unemployment channel	2.8%
Capital-quality channel	0.2%

Conclusions

- Information asymmetries in capital markets have important macroeconomic implications
  - Investment, misallocation, and long-run income levels
- Results suggest importance of studying
  - capital-market policies designed to address potential inefficiencies that arise from information asymmetries
  - agents' incentives of developing data and information technologies that mitigate information frictions (e.g., Jones Tonetti 2020, Farboodi Veldkamp 2021)

Outline

Neoclassical Firms very sensitive to changes in the Real Interest Rate

- Time is discrete time, each period is a year.
- Simplest determination of capital $\delta = 0$

$$AF_k = r$$

- Assume that $F(K, L) = K^{\alpha} L^{1-\alpha}$. Therefore:

$$1 + r_t = 1 + A_t \alpha K_t^{\alpha - 1} L_t^{1-\alpha}$$

- Make a log-linear approximation. Hatted variables are log changes:

$$\hat{r}_t = \frac{r}{1+r} \left(\hat{a}_t - (1-\alpha)\hat{k}_t + (1-\alpha)\hat{l}_t \right)$$

- where $\hat{r}_t = \log \frac{1+r_t}{1+r}$

Neoclassical Firms very sensitive to changes in the Real Interest Rate

$$\hat{k}_t = -\hat{r}_t \left(\frac{1+r}{(1-\alpha)r} \right) + \frac{\hat{a}_t}{1-\alpha} + \hat{l}_t$$

- Assume an exogenous decrease of 1% in interest rates.
- Capital would have to increase 31.5%
- Including reasonable depreciation would change this number to 14%.
- Letting labor increase would further increase this number
- Assume 100% of GDP could be transformed to capital.
- Capital-output ratios are between 2 and 4 (depending on land and housing)
- To increase capital by 31%, it would take 61%-124% of GDP
- With δ: to increase capital by 14%, it would take 28-56% of GDP

Another way of seeing the same

- Another way of illustrating the same issue is to compute the semi-elasticity of investment to interest rates
- Imagine firms with DRS

$$y_j = z\varepsilon_j k_j^\alpha$$

- Then

$$\frac{\partial i_{jt}/i_{jt}}{\partial r_t} = -\frac{1}{\delta}\frac{1}{1-\alpha}\left(\frac{1+r_t}{r_t+\delta}\right)$$

- As $\alpha \to 1$, the semi-elasticity becomes infinite
- Under $\alpha = 0.7$, $\delta = 0.025$ $r_t = 0.01$
- The semi-elasticity is equal to -3,847

Capital Adjustment Frictions

- Very large literature
- 70s: Abel (1979)
- 80s: Hayashi (1982)
- 90s: Doms and Dunne (1998), Caballero (1999), Caballero and Engel (1999)
- 2000s: Thomas (2000), Cooper and Haltiwanger (2006), Khan and Thomas (2003, 2008), Gourio Kashyap (2007)
- Just to name a few

Some Context

- Capital accumulation models tend to have adjustment costs
- One reason is what we saw before
- in CT: Without any costs, in a standard model investment functions are not well-defined
- Convex Adjustment costs. Two main results:
  1. Investment is a function of q: The marginal value of one extra unit of capital
  $$\frac{i_{jt}}{k_{jt}} = h(q_t)$$
  2. Marginal (q) and average (Q) values of capital are equal, when some conditions apply
  $$q_t = Q_t$$
- Very tractable problem. Block in medium-scale DSGE models

Some Context

Issue:

- Evidence of lumpiness of investment at the individual level
- Lumpy investment: Periods of inaction followed by spikes in investment
- Obviously convex adjustment costs do not get that
- Documented originally by Doms and Dunne (1998)
- The literature proposed fixed costs of adjustment as a possible answer
- Cooper and Haltiwanger (2006) interpret the microdata as exhibiting both convex and non-convex costs
- For the purpose of our class: Does micro-level frictions of capital adjustment matter in the aggregate?

METRIC

- What does it mean that micro frictions "matter" for the aggregate
- Is the response to shocks the same in models with and without fixed costs
- One particular dimension receives interest: Pent-up demand
- Or in more technical jargon, state-dependence of the elasticity of investment to aggregate shocks
- Is the response of investment to a TFP shock higher or lower in a recession?
- RBC model: It's the same
- Alternative: Pent-up demand, the elasticity depends on the distribution of capital imbalances
- At the start of the recovery firms have "excess capital", so an additional shock may not trigger large adjustments

Early findings

- Response by Thomas (2002): No
- Micro level lumpiness is irrelevant
- Meaning: Models with and without lumpiness as observed in the data have the same aggregate dynamics

Winberry 2021

$$\frac{\partial i_{jt}/i_{jt}}{\partial r_t} = -\frac{1}{1-\alpha}\frac{1}{\delta}\frac{1+r_t}{r_t+\delta}$$

- Under a reasonable calibration:
- $\alpha = 0.7$, $\delta = 0.025$, $r_t = 0.01$: $\frac{\partial i_{jt}/i_{jt}}{\partial r_t} = -3,847$
- r_t is an equilibrium outcome, so much depends on how r_t behaves.
- The standard model has very strong strategic substitutability
- That others do not adjust induces higher incentives to adjust
- Mediated by the response of the real interest rate to aggregate shocks

Generic Setting

Firms have a DRS production function

$$y = e^z e^a k^\alpha n^\gamma$$

a captures idiosyncratic productivity (iid across firms)

$$a_{it} = \rho_a a_{t-1} + \varepsilon_{it}\sigma_a.$$

z captures aggregate productivity

$$z_t = \rho_z z_{t-1} + \xi_t \sigma_z.$$

Firms discount period τ future profits with the household stochastic discount factor $\Lambda_{t,t+\tau}$

Setting

$$V(k,a,\chi,\mathscr{S}) = \max_n [e^z e^a k^\alpha n^\gamma - w(\mathscr{S})n] + \max[V^n(k,a,\chi,\mathscr{S}), V^a(k,a,\chi,\mathscr{S}) - \chi w(\mathscr{S})]$$

The value function conditional on non-adjustment is given by:

$$V^n(k,a,\chi,\mathscr{S}) = \mathbb{E}(\Lambda(\mathscr{S},\mathscr{S}')V(k',a',\chi',\mathscr{S}')|a,\mathscr{S}),$$

subject to

$$k' = k(1-\delta)$$

The value function conditional on adjustment is given by:

$$V^a(k,a,\chi',\mathscr{S}) = \max_i -i - \phi\left(\frac{i}{k}\right)^2 k + \mathbb{E}((\Lambda(\mathscr{S},\mathscr{S}')V(k',a',\chi',\mathscr{S}')|a,\mathscr{S}),$$

subject to

$$k' = k(1-\delta) + i$$

.

Setting

In the background there is a representative household that supplies labor, and consumes.

- There is a labor supply function in the background

- The Stochastic Discount Factor will capture household preferences for consumption smoothing

Habits in Consumption

- Fix the dynamics of r by changing optimal consumption decisions

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \log \left(C_t - \chi \frac{N_t^{1+\xi}}{1+\xi} - X_t \right)$$

$$X_t = \lambda \hat{C}_t$$

$$\hat{C}_t = C_t - \chi \frac{N_t^{1+\xi}}{1+\xi}$$

WINBERRY 2021

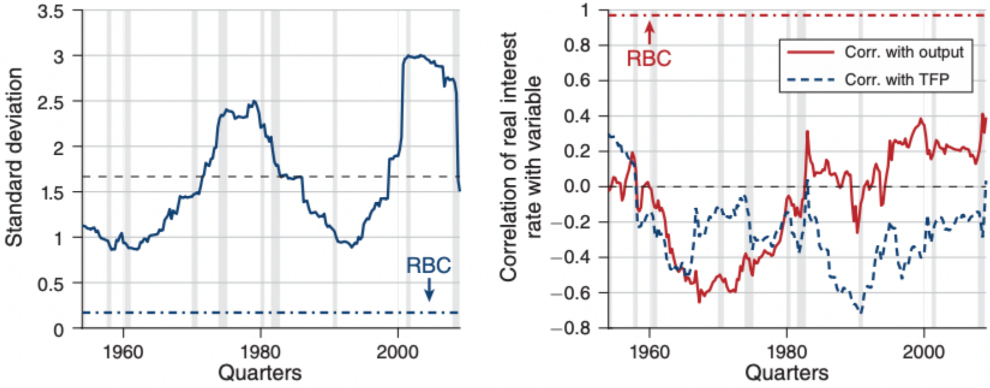


FIGURE 1. STABILITY OF CYCLICAL DYNAMICS OF RISK-FREE RATE

Winberry 2021

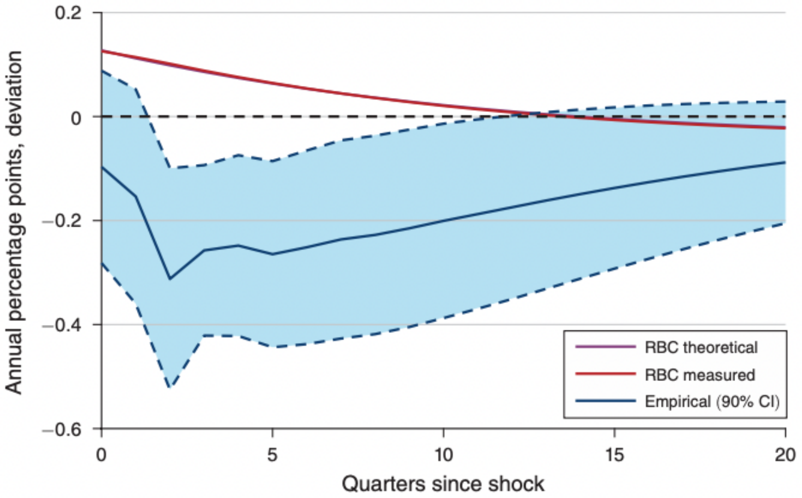


Figure 2. Impulse Response of the Real Interest Rate to TFP Shock

Winberry 2021

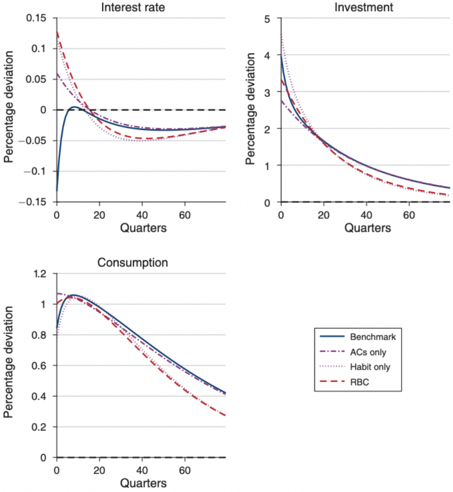


Figure 3. Identification of Habit Formation and Adjustment Costs

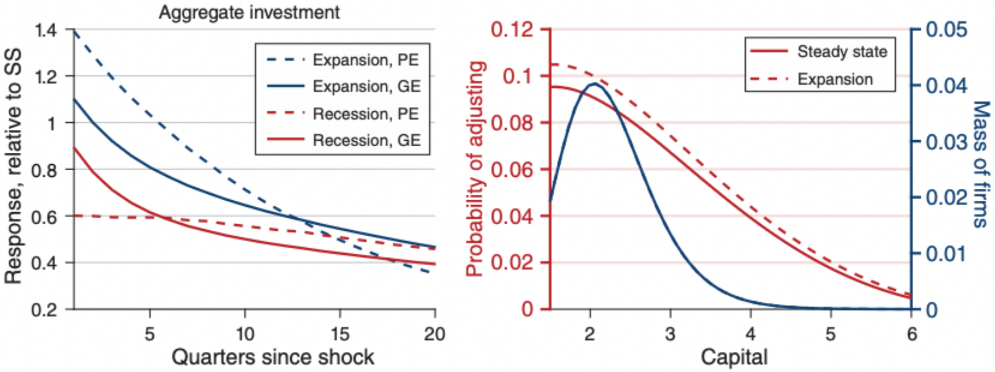


FIGURE 5. PROCYCLICAL IMPULSE RESPONSES OF AGGREGATE INVESTMENT

How to tell models apart?

- Koby and Wolf (2021) proposal: Use Zwick and Mahon (2017)
- Semi-elasticity of investment to bonus depreciation reforms
- Preview: Semi-Elasticity of investment in the data is consistent with Winberry (2021), not with Khan and Thomas (2008)

Outline

Bonus Depreciation

- Firms pay taxes on income net of business expenses
- Can fully expense wages, advertising, etc. immediately
- Investment gets expensed over time according to tax depreciation schedules
- Bonus depreciation accelerates this depreciation schedule

Table 1—Regular and Bonus Depreciation Schedules for Five-Year Items

Year:	0	1	2	3	4	5	Total
Normal depreciation							
Deductions (000s)	200	320	192	115	115	58	1,000
Tax benefit ($\tau = 35$ percent)	70	112	67.2	40.3	40.3	20.2	350
Bonus depreciation (50 percent)							
Deductions (000s)	600	160	96	57.5	57.5	29	1,000
Tax benefit ($\tau = 35$ percent)	210	56	33.6	20.2	20.2	10	350

Notes: This table displays year-by-year deductions and tax benefits for a $1 million investment in computers, a five-year item, depreciable according to the Modified Accelerated Cost Recovery System (MACRS). The top schedule applies during normal times. It reflects a half-year convention for the purchase year and a 200 percent declining balance method (2× straight line until straight line is greater). The bottom schedule applies when 50 percent bonus depreciation is available.

Source: Authors' calculations. See IRS publication 946 for the recovery periods and schedules applying to other class lives (https://www.irs.gov/uac/about-publication-946).

Source: Zwick-Mahon (2017)

- Bonus depreciation allows firm to deduct a per dollar bonus of θ at the time of investment and the remaining $1-\theta$ according to regular schedule

- Table shows bonus depreciation of $\theta = 0.5$

Value of Bonus Depreciation

Frictionless markets view:

- Bonus depreciation only matters due to discounting

$$z^0 = D_0 + \sum_{t=1}^{T} \frac{1}{(1+r)^t} D_t$$

- D_t allowable deduction in period t per dollar of investment in period 0
- r risk-adjusted discount rate used by firm
- Without discounting $z_0 = 1$ (100%), with discounting $z_0 < 1$
- Bonus raises z_0 by bringing deductions forward in time

$$z = \theta + (1 - \theta) z_0$$

Value of Bonus Depreciation

- Frictionless markets view:
  - Value of bonus modest for short-lived investments
  - E.g., with $r = 0.07$, bonus in Table 1 raised z by 2%
  - Value of bonus greater for long-lived investments
- With financial frictions, bonus may have large effect on investment
  - Effect on current cash flow large ($140,000 in Table 1)

Zwick-Mahon (2017)

- Estimate the effect of bonus on investment
- Bonus occurs in recessions
  - Correlated with other determinants of investment
- Use difference-in-difference identification strategy
  - Bonus more valuable for industries with longer lived investments
  - Compare effect of bonus on industries with differing duration of investments

Zwick-Mahon (2017): Policy Variable

- Main policy variable: $z_{N,t}$
  - Where N is a 4-digit NAICS industry
- Compute baseline z_N for pre-period (1993-2000)
  - For each firm-year: weighted average of z across duration categories using a 7% discount rate
  - z_N computed as simple average of these firm-year z
- In bonus years adjust z_N for bonus

$$z_{N,t} = \theta_t + (1 - \theta_t) z_N$$

Zwick-Mahon (2017): Specification

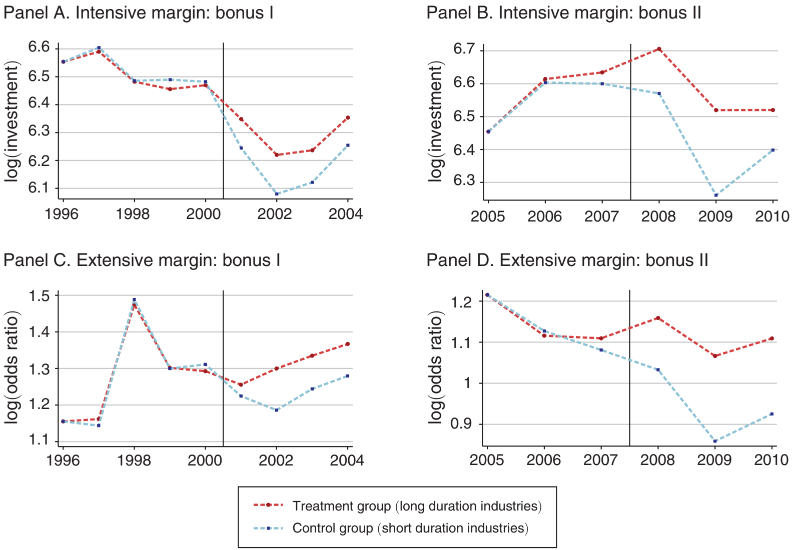
- Baseline difference-in-difference specification:

$$\log(I_{it}) = \alpha_i + \beta z_{N,t} + \gamma X_{it} + \delta_t + \varepsilon_{it}$$

  - β is coefficient of interest
  - Industry fixed effects: Allow for average differences in industry investment
  - Time fixed effects: Take out aggregate effects

Zwick-Mahon (2017): Identification

- Identifying assumption: **Parallel trends**
  - Industries with long- and short-duration investment patterns would have evolved in parallel absent bonus
- Threat to identification:
  - Durable investment industries more resilient in downturns



Source: Zwick-Mahon (2017)

$$f(I_{it}) = \alpha_i + \delta_t + \beta g(z_{N,t}) + \gamma X_{it} + \varepsilon_{it}$$

	All	CF	Pre-2005	Post-2004	Controls	Trends
	LHS Variable is Log(Eligible Investment)					
$z_{N,t}$	3.69***	3.78***	3.07***	3.02***	3.73***	4.69***
	(0.53)	(0.57)	(0.69)	(0.81)	(0.70)	(0.62)
Observations	735341	580422	514035	221306	585914	722262
Clusters (Firms)	128001	100883	109678	63699	107985	124962
R^2	0.71	0.74	0.73	0.80	0.72	0.71
	LHS Variable is Log(Odds Ratio)					
$z_{N,t}$	3.79**	3.87**	3.12	3.59**	3.99*	4.00***
	(1.24)	(1.21)	(2.00)	(1.14)	(1.69)	(1.13)
Observations	803659	641173	556011	247648	643913	803659
Clusters (Industries)	314	314	314	274	277	314
R^2	0.87	0.88	0.88	0.93	0.90	0.90
	LHS Variable is Eligible Investment/Lagged Capital					
$\frac{1-t_c z}{1-t_c}$	-1.60***	-1.53***	-2.00***	-1.42***	-2.27***	-1.50***
	(0.096)	(0.095)	(0.16)	(0.13)	(0.14)	(0.10)
Observations	637243	633598	426214	211029	510653	631295
Clusters (Firms)	103890	103220	87939	57343	90145	103565
R^2	0.43	0.43	0.48	0.54	0.45	0.44

All regressions include firm and year effects. Controls: cash flow in (2); 4-digit Q, quartics in sales, assets, profit margin, age in (5); 2-digit NAICS $\times t^2$ in (6).

Source: Zwick-Mahon (2017)

Zwick-Mahon (2017): Effects Are Large

- Average change in $z_{N,t}$:
  - Early episode: 4.8 cents
  - Later episode: 7.8 cents
- Average change in investment:
  - Early episode: 17.7 log points ($3.69 \times 0.048 = 0.177$)
  - Later episode: 28.8 log points ($3.69 \times 0.078 = 0.288$)

Zwick-Mahon (2017): Effects Are Large

- In simple investment model:
  - Elasticity of investment with respect to net of tax rate, $1-\tau z$, equals price and interest elasticity

$$\log(I_{it}) = \alpha + \beta \log(1-\tau z_{N,t}) + \varepsilon_{it}$$

- Zwick-Mahon's regressor is $z_{N,t}$ not $\log(1-\tau z_{N,t})$
- Linear approximation:

$$\log(1-\tau z_{N,t}) = \log(1-\tau z_N) - \frac{\tau}{1-\tau z_N}(z_{N,t} - z_N)$$

- Imply price and interest rate elasticities of investment equal to

$$-3.69 \div \frac{\tau}{1-\tau z} \approx -7.2$$

Outline

1. Catherine, Chaney, Huang, Sraer, Thesmar (2021)
2. Bierdel, Drenik, Herreño, Ottonello (2021)
3. Winberry (2021)
4. Zwick Mahon (2017)
5. Ottonello Winberry (2021)

Motivation

- Investment is the most cyclical component of aggregate demand
- Investment Channel of Monetary Policy
- What determines the strength of this effect?
- Underlying notion of state-dependence

Two Possibilities

- Two possibilities on which firms respond more:

  1. More constrained firms: Monetary policy expansions ease financial frictions. More constrained firms respond by more. Financial accelerator story

  2. Less constrained firms: More constrained firms have steeper marginal cost curves, so they react by less to the same aggregate demand shock

- Ultimately an empirical question

Specification

- Basic specification

$$\Delta \log k_{j,t+1} = \alpha_j = \alpha_j + \alpha_{st} + \beta(x_{jt-1} - \mathbb{E}_j(x_{jt}))\varepsilon_t^m + \Gamma' Z_{jt-1} + e_{jt}$$

- Where ε^m is determined using HFI

$$\varepsilon_t^m = \tau(t) \times (ffr_{t+\Delta_+} - ffr_{t-\Delta_-})$$

- Size of the window: -15 to +45 minutes

Basic Result

TABLE III

HETEROGENEOUS RESPONSES OF INVESTMENT TO MONETARY POLICY[a]

	(1)	(2)	(3)	(4)	(5)
leverage × ffr shock	−0.69	−0.57		−0.26	−0.14
	(0.29)	(0.27)		(0.35)	(0.58)
dd × ffr shock			1.14	1.01	1.16
			(0.41)	(0.40)	(0.47)
ffr shock					2.14
					(0.61)
Observations	219,402	219,402	151,027	151,027	119,750
R^2	0.113	0.124	0.141	0.142	0.151
Firm controls	no	yes	yes	yes	yes
Time sector FE	yes	yes	yes	yes	no
Time clustering	yes	yes	yes	yes	yes

[a]Results from estimating $\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta(x_{jt-1} - \mathbb{E}_j[x_{jt}])\varepsilon_t^{\mathrm{m}} + \Gamma' Z_{jt-1} + e_{jt}$, where α_j is a firm fixed effect, α_{st} is a sector-by-quarter fixed effect, $x_{jt} \in \{\ell_{jt}, \mathrm{dd}_{jt}\}$ is leverage or distance to default, $\mathbb{E}_j[x_{jt}]$ is the average of x_{jt} for firm j in the sample, $\varepsilon_t^{\mathrm{m}}$ is the monetary shock, and Z_{jt-1} is a vector of firm-level controls containing x_{jt-1}, sales growth, size, current assets as a share of total assets, an indicator for fiscal quarter, and the interaction of demeaned financial position with lagged GDP growth. Standard errors are two-way clustered by firms and quarter. We have normalized the sign of the monetary shock $\varepsilon_t^{\mathrm{m}}$ so that a positive shock corresponds to a decrease in interest rates. We have standardized $(\ell_{jt} - \mathbb{E}[\ell_{jt}])$ and $(\mathrm{dd}_{jt} - \mathbb{E}[\mathrm{dd}_{jt}])$ over the entire sample. Column (5) removes the sector-quarter fixed effect α_{st} and estimates $\Delta \log k_{jt+1} = \alpha_j + \alpha_{sq} + \gamma \varepsilon_t^{\mathrm{m}} + \beta(x_{jt-1} - \mathbb{E}_j[x_{jt}])\varepsilon_t^{\mathrm{m}} + \Gamma_1' Z_{jt-1} + \Gamma_2' Y_{t-1} + e_{jt}$, where Y_t is a vector with four lags of GDP growth, the inflation rate, and the unemployment rate.

Dynamic Response

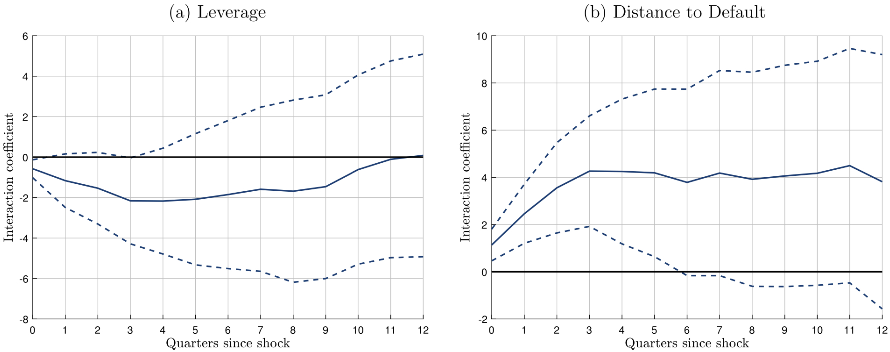


FIGURE 1.—Dynamics of differential response to monetary shocks. Notes: dynamics of the interaction coefficient between financial positions and monetary shocks over time. Reports the coefficient β_h over quarters h from $\log k_{jt+h} - \log k_{jt} = \alpha_{jh} + \alpha_{sth} + \beta_h(x_{jt-1} - \mathbb{E}_j[x_{jt}])\varepsilon_t^{\mathrm{m}} + \Gamma'_h Z_{jt-1} + e_{jth}$, where all variables are defined in the notes for Table III. Dashed lines report 90% error bands.

Model - Financial structure

- No aggregate uncertainty
- MIT shock later on
- Firms can borrow in defaultable debt
  - This is the optimal contract of Costly State Verification models (Townsend 1979)
  - Backbone of financial accelerator models (BGG 1999)
- Retain earnings, not issue equity (think of infinite costs of equity issuance)
- Without financial frictions need to keep track of only net worth, not k and b separately. Not possible with financial frictions
- Economics: External finance premium/One unit of external finance is more costly

Capital Producers

- Capital producer sector
- Relative price of investment q
- q-theory FOC

$$q_t = \frac{1}{\Psi'(I_t/K_t)}$$

Retailers - NK firms

- Set prices subject to Rotemberg (1982) frictions
- Relative price of retail goods p
- Gives rise to a standard NK Phillips Curve

Lenders

- Intermediary, gets funds from the household, lends to firms
- CSV block. Upon default (or verification) the lender gets α fraction of the market value of the firm stock
- Price contracts at $\mathscr{Q}(z, k', b')$ to get zero profits (free entry in the background)

Production Firms

- DRS
- exit shocks
- Fixed costs of operation
- Need a source of variation that suddenly brings firms closer to default
- Capital quality shock *We view capital quality shocks as capturing unmodeled forces which reduce the value of the firm's capital, such as frictions in the resale market, breakdown of machinery, or obsolescence.*
- Effective units of capital ωk
- Firms decide whether to default or not

When to default

- A firm receives a capital-quality shock ω
- The firm has some debt b and the value of its capital goes down ωk
- Its net worth $n = \max_l p_t z(\omega k)^\theta l^\nu - w_t l + q_t(1-\delta)\omega k - b\frac{1}{\Pi_t} - \xi$ goes down
- $\exists\ \underline{n}$ such that the firm cannot respect the non-negativity on equity issuance

$$n - q_t k' + \mathcal{Q}(z, k', b')b' \geq 0$$

Main Mechanism

Impact on Decision Rules. The optimal choice of investment k' and borrowing b' satisfy the following two conditions:

$$q_t k' = n + \frac{1}{R_t(z, k', b')} b', \tag{9}$$

$$\left(q_t - \varepsilon_{Q,k'}(z, k', b') \frac{Q_t(z, k', b')b'}{k'}\right) \frac{R_t^{\mathrm{sp}}(z, k', b')}{1 - \varepsilon_{R,b'}(z, k', b')}$$

$$= \frac{1}{R_t} \mathbb{E}_t[\mathrm{MRPK}_{t+1}(z', k')]$$

$$+ \frac{1}{R_t} \frac{\mathbb{C}ov_t(\mathrm{MRPK}_{t+1}(z', \omega' k'), 1 + \lambda_{t+1}(z', \hat{n}_{t+1}(z', \omega', k', b')))}{\mathbb{E}_t[1 + \lambda_{t+1}(z', \hat{n}_{t+1}(z', \omega', k', b'))]}$$

$$- \frac{1}{R_t} \mathbb{E}_{\omega'}[v_{t+1}^0(\omega', k', b') g_z(\underline{z}(\omega', k', b') | z) \hat{\underline{z}}_{t+1}(\omega', k', b')], \tag{10}$$

INTUITION MAIN MECHANISM

2488 P. OTTONELLO AND T. WINBERRY

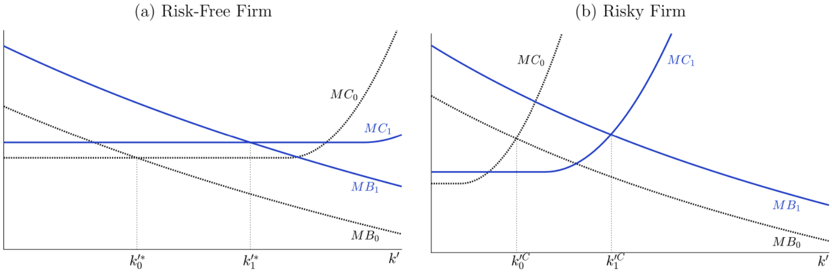


FIGURE 2.—Response to monetary policy for risk-free and risky firms. Notes: Marginal benefit and marginal cost curves as a function of capital investment k' for firms with same productivity. Left panel is for a firm with high initial net worth and right panel is for a firm with low initial net worth. Marginal cost curve is the left-hand side of (10) and marginal benefit the right-hand side of (10). Dashed black lines plot the curves before an expansionary monetary policy shock, and solid blue lines plot the curves after the shock.

Intuition Main Mechanism

2496 P. OTTONELLO AND T. WINBERRY

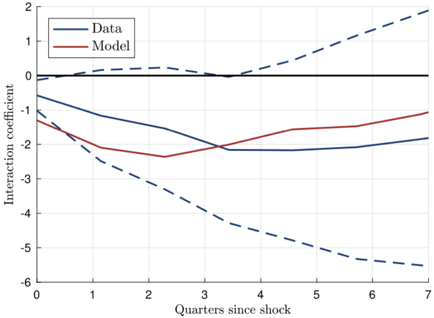


FIGURE 5.—Dynamics of differential responses, model vs. data. Notes: dynamics of the interaction coefficient between leverage and monetary shocks. Reports the coefficient β_h over quarters h from $\log k_{jt+h} - \log k_{jt} = \alpha_{jh} + \alpha_{sth} + \beta_h(\ell_{jt-1} - \mathbb{E}_j[\ell_{jt}])\varepsilon_t^{\mathrm{m}} + \Gamma_h' Z_{jt-1} + \Gamma_{2h}'(\ell_{jt-1} - \mathbb{E}_j[\ell_{jt}])Y_{t-1} + e_{jt}$, where all table notes from Columns (1) and (2) of Table VII apply. Dashed lines report 90% error bands.

Intuition Main Mechanism

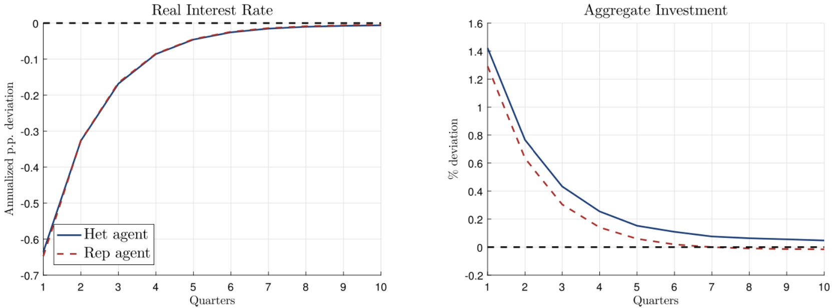


FIGURE 8.—Aggregate impulse responses in full model vs. rep firm model. Notes: "Het agent" refers to calibrated heterogeneous firm model from the main text. "Rep agent" refers to a version of the model in which the heterogeneous production sector is replaced by a representative firm with the same production function and no financial frictions.

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TABLE VIII

AGGREGATE RESPONSE DEPENDS ON INITIAL DISTRIBUTION[a]

(everything rel. to steady state)	Bad distribution	Medium distribution
Avg. capital response	0.67	0.84
Avg. net worth	0.48	0.75
Frac. risky constrained	1.37	1.17

[a] Dependence of aggregate response on initial distribution. We compute the change in aggregate capital for different initial distributions as described in the main text. “Bad distribution” corresponds to $\widehat{\omega} = 1$ and “Medium distribution” corresponds to $\widehat{\omega} = 0.5$.