Macroeconomía y Costos de Ajuste
Cátedras 5 y 6
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III. Investment

1. Basics
2. Lumpy investment in partial equilibrium:
   1. The cautionary effect of uncertainty
   2. Increasing hazards and time-varying IRFs
   3. Uncertainty shocks and an application to 9/11
3. Lumpy investment in general equilibrium

3. Lumpy Investment in General Equilibrium

- Thomas (JPE, 2002), Khan and Thomas (JME, 2003; ECMA, 2008)
- Bachmann, Caballero and Engel (2008)

Thomas and Khan-Thomas papers

- If prices fixed: micro lumpiness has macro impact (as in Caballero and Engel, 1999)
- Yet in a DSGE model, with an endogenous interest rate, Khan-Thomas's calibration is such that lumpiness washes away and aggregate investment dynamics becomes indistinguishable from how it behaves in an economy with no adjustment costs
- Next slide: figure from Khan and Thomas (2003) with aggregate capital after a positive productivity shock followed by a negative shock:
  - two sample paths: standard RBC, lumpy adjustment
  - indistinguishable

Irrelevance of Lumpy Adjustment in General DSGE?

354 A. Khan, J.K. Thomas / Journal of Monetary Economics 50 (2003) 331–360

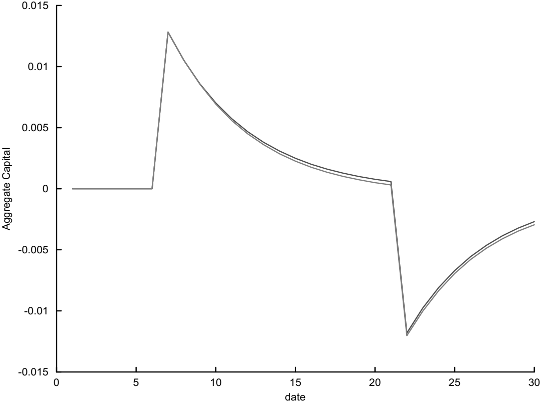


Fig. 8. The absence of nonlinearities in equilibrium.

Bachmann, Caballero, and Engel (2008)

1. Motivation
2. Model
3. Calibration
4. Aggregate Investment Dynamics
5. Conclusion

3.1. Motivation

The question

- Is lumpy capital adjustment relevant for aggregate investment dynamics?

The answer

- Yes ... in partial equilibrium: Caballero–Engel–Haltiwanger (1995), Caballero and Engel (1999), Cooper–Haltiwanger–Power (1999).
- No ... in general equilibrium: Thomas (2002), Khan–Thomas (2003, 2006)
- Yes ... in general equilibrium: This paper

What does it mean to be relevant?

Three possibilities (CE–1999)

A. Skewness and kurtosis of aggregate investment series

B. Better out-of-sample forecasts

C. Time-varying impulse response function

How should we evaluate these "relevance" criteria

- Enough statistical power?
- Relevant for macroeconomics?

A. Skewness and kurtosis

Statistical power

- Caballero–Engel (1999): 20 2-digit manufacturing sectors $\surd$
- General equilibrium models (Thomas, Khan–Thomas, this paper): work with one aggregate investment series: $\times$
    - less skewness and kurtosis at higher levels of aggregation
    - less data

Should macroeconomists care?

- Skewness and kurtosis do not matter per se

B. Out-of-sample forecasts

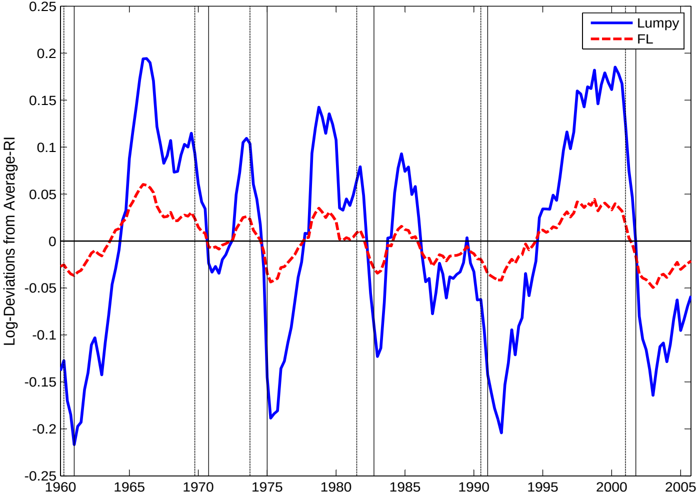
Statistical power

- Caballero–Engel (1999): 20 2-digit manufacturing sectors $\surd$
  - Equipment: 6.6% avge. reduction in forecast error
  - Structures: 31.3% avge. reduction in forecast error
- General equilibrium models (Thomas, Khan–Thomas, this paper): work with one aggregate investment series $\times$

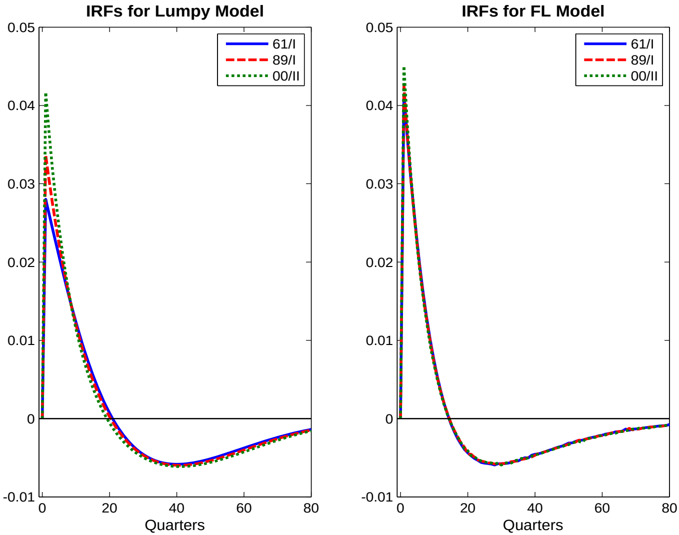
Should macroeconomists care?

- Yes? Maybe?

C. Time-varying IRF_0 implied by the model



C. Time-varying IRF implied by the model



Time-varying IRF

Should macroeconomists care?

- Yes!

Statistical power: A Time-Series Approach

- Latest version of the paper manages to detect the type of time-varying IRF predicted by lumpy-adjustment models

Time-varying IRF: A Time Series Approach

- Let: $x_t \equiv I_t/K_{t-1}$
- Consider a GARCH model:

$$x_t = \phi x_{t-1} + \sigma_t e_t, \tag{1a}$$
$$\sigma_t = h(x_{t-1}, x_{t-2}, \cdots) \tag{1b}$$

  where $h(x_{t-1}, x_{t-2}, \cdots)$ summarizes "recent investment" and the e_t are i.i.d. (0,1)
- Will have:

$$\mathrm{IRF}_0 = \frac{\partial x_t}{\partial \varepsilon_t} = \sigma_t = h(x_{t-1}, x_{t-2}, \cdots).$$

Time-Series Evidence on time-varying IRFs

- Use quarterly U.S. data, 1960.I–2005.IV, BLS.
- Use OLS to estimate

$$x_t = \phi x_{t-1} + e_t$$

- Two possibilities to estimate h:

1. Estimate via OLS:

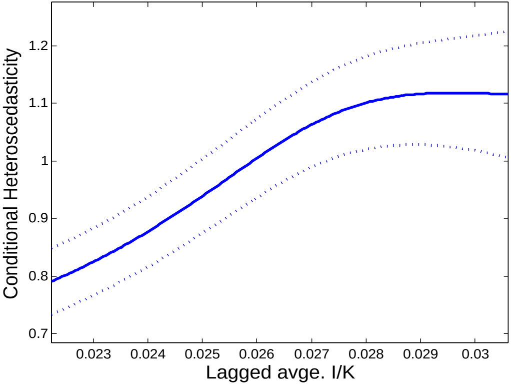
$$|\hat{e}_t| = \hat{\alpha}_0 + \hat{\alpha}_1 \bar{x}^k_{t-1} + \text{error},$$

2. Use a Gaussian kernel smoother and cross-validation to estimate $h(x_{t-1})$ based on $|\hat{v}_t|$s

Time-Series Evidence on time-varying IRFs

	k						
	1	2	3	4	5	6	7
ϕ:	0.9599	0.9599	0.9599	0.9599	0.9599	0.9599	0.9599
	(0.0299)	(0.0300)	(0.0298)	(0.0302)	(0.0300)	(0.0295)	(0.0296)
$10^3 \times \alpha_0$:	0.4828	0.4849	0.4823	0.4822	0.4805	0.4820	0.4837
	(0.0351)	(0.0353)	(0.0355)	(0.0363)	(0.0386)	(0.0390)	(0.0397)
α_1:	0.0209	0.0239	0.0282	0.0300	0.0330	0.0336	0.0331
	(0.0172)	(0.0173)	(0.0172)	(0.0174)	(0.0179)	(0.0179)	(0.0182)
p-value ($\alpha_1 > 0$):	0.0507	0.0369	0.0222	0.0179	0.0170	0.0189	0.0210
No. obs. 1st regr.:	183	183	183	183	183	183	183
No. obs. 2nd regr.:	183	182	181	180	179	178	177

Time-Series Evidence on time-varying IRFs



Taking Stock

- Q.: How do we determine whether lumpy investment is relevant for aggregate investment dynamics?
- A.: See whether lumpy adjustment affects the impulse response function, in particular, it it leads to a time-varying IRF
- ARCH-evidence suggests that this is the case: implied ratio over our sample of maximum and minimum IRF_0 is approximately 1.5
- Objective: build a DSGE model that delivers a time-varying IRF for aggregate investment similar to that obtained via time-series methods from the actual data

3.2. Model

- We follow closely Khan and Thomas (2005)
- Departures:

  1. sector specific productivity shocks
  2. maintenance investment

Production Units

- No entry or exit
- Unit's production function:

$$y_t = z_t \epsilon_{S,t} \epsilon_{I,t} k_t^{\theta} n_t^{\nu}.$$

  with log-AR(1) shocks
- $\theta + \nu < 1$
- I.i.d. cost of adjusting capital, ξ, drawn from a $U[0, \bar{\xi}]$, measured in units of labor

Households

- A continuum of identical households with access to a complete set of state-contingent claims
- Felicity function:

$$U(C, N^h) = \begin{cases} \frac{C^{1-\sigma_c}}{1-\sigma_c} - AN^h, & \text{if} \quad \sigma_c \neq 0 \\ \log C - AN^h, & \text{otherwise.} \end{cases}$$

- The intertemporal price:

$$p(z, \mu) \equiv U_C(C, N^h) = C(z, \mu)^{-\sigma_c}.$$

- The intratemporal price:

$$\omega(z, \mu) = -\frac{U_N(C, N^h)}{p(z, \mu)} = \frac{A}{p(z, \mu)}.$$

Production Units: Bellman Equation

- Unit's problem:

$$V^1(\epsilon_S, \epsilon_I, k, \xi; z, \mu) = \max_n \{CF + \max(V_i, \max_{k'}[-AC + V_a])\},$$

where

$$\begin{aligned}
CF &= [z\epsilon_S\epsilon_I k^\theta n^\nu - \omega(z,\mu)n - i^M]p(z,\mu), \\
V_i &= \beta \mathrm{E}[V^0(\epsilon'_S, \epsilon'_I, \psi(1-\delta)k/\gamma; z', \mu')], \\
AC &= \xi\omega(z,\mu)p(z,\mu), \\
V_a &= -ip(z,\mu) + \beta \mathrm{E}[V^0(\epsilon'_S, \epsilon'_I, k'; z', \mu')], \\
\mu &= \text{distribution of } (\epsilon_S, \epsilon_I, k).
\end{aligned}$$

Recursive Equilibrium

A recursive competitive equilibrium is a set of functions

$$\omega, p, V^1, N, K', C, N^h, \Gamma$$

such that

1. *Production unit optimality*: Taking ω, p and Γ as given, demand N and K'
2. *Household optimality*: Taking ω and p as given, the household optimally chooses consumption C and labor N^h
3. *Commodity market clearing*
4. *Labor market clearing*
5. *Model consistent dynamics*: $\mu' = \Gamma(z, \mu)$.

Equilibrium Computation

- μ: infinite dimensional
- We follow Krusell and Smith:
  - approximate μ by its first moment over capital
  - approximate $\mu' = \Gamma(z, \mu)$ by a log-linear rule
- To simplify computations: $\rho_S = \rho_I$, the unit then only cares about $\epsilon \equiv \epsilon_S \epsilon_I$.

Mandated Investment

- We have:

$$k' = \begin{cases} k^*(\epsilon; z, \bar{k}), & \text{if } \xi \leq \xi^T(\epsilon, k; z, \bar{k}), \\ (1 - \delta + \chi\delta)k, & \textit{otherwise}. \end{cases}$$

- We define mandated investment for a unit with current state $(\epsilon, z, \bar{k})$ and current capital k as:

$$x(\epsilon; z, \bar{k}) \;\equiv\; \log k^*(\epsilon; z, \bar{k}) \;-\; \log[1 - \delta + \chi\delta]k.$$

3.3. Calibration

- A central element of this paper is its calibration strategy
- It differs in fundamental way from calibrations in the Thomas and Khan-Thomas papers
- This difference is relevant for calibration of macro models in general

Sources of Smoothing in Macroeconomics

$$
\begin{array}{ccccc}
 & & \text{Aggregate Shocks} & & \\
 & \swarrow & & \searrow & \\
\text{micro frictions} & & \downarrow & & \text{price responses} \\
 & \searrow & & \swarrow & \\
 & & \text{Macro Aggregates} & &
\end{array}
$$

Sources of Smoothing: Lumpy Investment Models

1. Micro frictions $\equiv$ PE smoothing:
   - it isn't only the size of adjustment costs
   - aggregation is central
   - Caplin and Spulber (1987) as an extreme example
2. Price responses $\equiv$ GE smoothing:
   - quasi labor supply
   - supply of funds

Calibration in Khan-Thomas (2008)

- Khan and Thomas: choose parameters to various statistics of the distribution of establishment level adjustments in the LRD, for example, the fraction of establishments that adjust by more than 20%
- We argue that using plant level moments is not robust:
    - how many micro units in the model correspond to one observed micro unit?

New Calibration Strategy: Overview

- Match volatility of sectoral (3-digit) I/K instead of moments at the establishment level
- Mainly (assume only) partial equilibrium effects at this level
- Also match volatility of aggregate (entire economy) I/K
- And to capture time-varying IRF we match the heteroscedasticity range: $\pm \log(\sigma_{\max}/\sigma_{\min})$ with $+$ iff the max lies to the right of the min

Calibration: Two Approaches

Most parameters: standard values and/or values obtained from TFP data (when possible)
Two approaches:

1. EIS=1 approach:
   - set EIS $= 1$
   - attractive if you take the EIS in these model literally
   - choose χ, $\bar{\xi}$ and σ_A to match the heteroscedasticity range and the volatility of sectoral and aggregate I/K
2. EIS estimated:
   - for those that believe the EIS is a shortcut for many things in these models
   - RBC model shortcomings for investment:
     - flatter supply of funds (who finances US investment?)
     - flatter labor supply?
   - fix σ_A at values standard value

Results

- Reasonable values for adjustment costs
- Very high EIS for the second approach
- Time-varying IRF in both cases (and very similar)
- Unless stated otherwise, in what follows we concentrate on the EIS $= 1$ case

Results: Economic Magnitude of Adjustment Costs

Model	Tot. adj. costs/ Aggr. Output (1)	Tot. adj. costs/ Aggr. Investment (2)	Adj. costs/ Unit Output (3)	Adj. c Unit W (4
Lumpy quarterly:	0.35%	2.41%	9.53%	14.8
Lumpy annual:	0.41%	2.84%	3.60%	5.6

Smoothing and $\sigma(I/K)$: This Paper in a Nutshell

No frictions

$\swarrow$ $\downarrow$ $\searrow$

only PE
81.0%

only GE
84.6%

$\searrow$ $\swarrow$

PE and GE
100%

Smoothing and $\sigma(I/K)$: RBC

No frictions

$\swarrow \qquad \searrow$

only PE $\qquad \downarrow \qquad$ only GE

0% $\qquad\qquad$ 100%

$\searrow \qquad \swarrow$

PE and GE

100%

Smoothing and $\sigma(I/K)$: Khan and Thomas (2005)

No frictions

$\swarrow$ $\downarrow$ $\searrow$

only PE
16.1%

only GE
100%

$\searrow$ $\swarrow$

PE and GE
100%

Why the Difference?

Model	$\log(\sigma_{\max}/\sigma_{\min})$
Data	*0.3971*
This paper:	0.4008
Frictionless:	0.0767
Khan-Thomas (2008):	0.0998

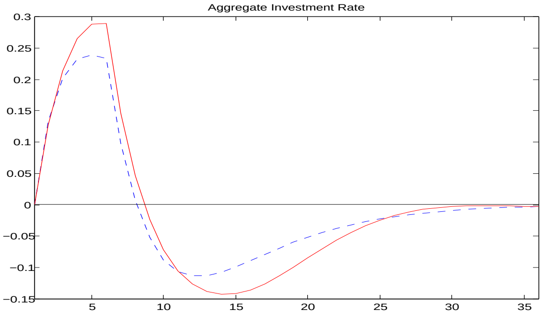
Why the Difference?

- When you calibrate a model you implicitly decide on the relative importance of PE and GE smoothing
- There are many combinations of PE and GE smoothing that achieve the same degree of aggregate smoothing
- We use 3-digit sectoral data to calibrate the relative importance of PE and GE smoothing: at this level of aggregation we mainly have PE-smoothing
- Also: the importance of matching aggregate IRF volatility

An Illustrative Exercise

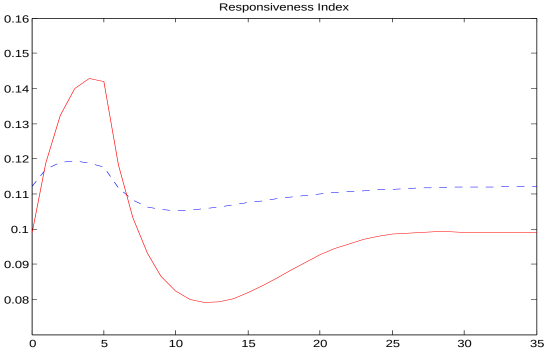
- Particular sample path of aggregate shocks:
  - 5 consecutive innovations of $2\sigma_A$
  - followed by no innovations
- Economy starts at steady-state
- Compare:
  - frictionless economy
  - our lumpy economy ($\chi = 0.50$)

Evolution of Aggregate Investment Rates



- Eventually the lumpy economy responds by more to further positive shocks
- Lumpy economy's larger boom comes with a more protracted slump

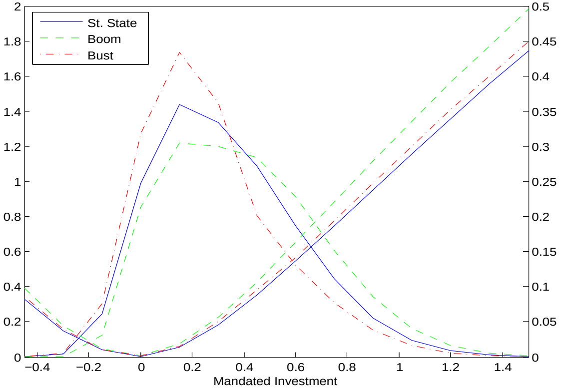
Evolution of the Responsiveness Index



- First element in IRF
- Conditional on history of shocks (summarized by μ)

- A decline in the strength of PE-smoothing explains the rise in the index during the boom phase
  - the responsiveness index fluctuates much less in the frictionless economy
  - frictionless economy only has GE-smoothing
  - hence: contribution of GE smoothing to fluctuations in responsiveness index of lumpy economy is small
- As the boom proceeds, the economy comes “closer” to the Caplin-Spulber scenario

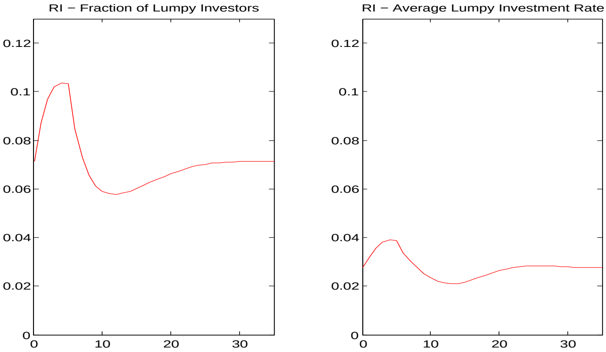
PE-Smoothing and the Boom-Bust Episode



Evolution of the Cross-section and Hazards

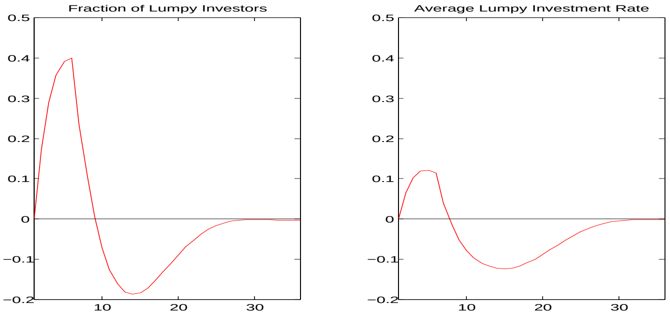
- Have the increasing hazard property
- During the boom:
  - the fraction of units with mandated investment close to zero decreases
  - the fraction of units with mandated investment above 40% increases
  - the fraction of units with negative mandated investment decreases
- During the boom the x-section moves intro regions where the probability of adjusting is higher
  - this effect is not present in a frictionless (or Calvo) model

Decomposing the Responsiveness Index



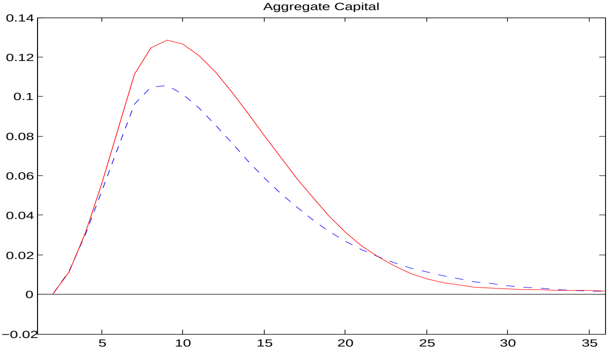
Fluctuations in responsiveness index driven mainly by variations in the fraction of units adjusting (extensive margin)

Decomposing Aggregate I/K



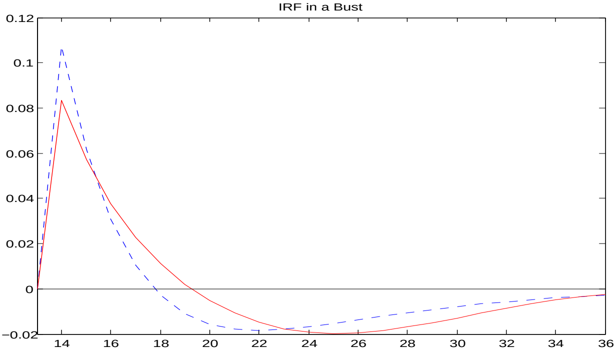
Doms and Dunne (1998): it's the fraction of units undergoing major investment episodes

Understanding the Bust



- More capital accumulation in the lumpy economy
- Large fraction in region where units are unresponsive to shocks (see previous figure)

Impulse Responses at the Trough



Lumpy economy less responsive to a positive stimulus

3.5. Conclusion

- The data suggest time-varying IRFs
- Lumpy adjustment DSGE models with mainly GE-smoothing forces cannot deliver history dependent IRFs
- Lumpy adjustment DSGE models where both PE and GE-smoothing are relevant deliver time-varying IRFs
- Bonus: reducing the burden of GE-smoothing leads to a substantial improvement in moment-matching of Y, C and N