Aggregate Implications of Lumpy Adjustment

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Cowles Lunch.
March 3rd, 2010
1. Motivation

Micro adjustment is lumpy for many aggregates of interest:

- stock of durable good
- nominal prices
- capital stock
- employment

Is this relevant for aggregate dynamics?

Investment:

- No ... in general equilibrium: Thomas (2002), Khan - Thomas (2003, 2008)
- Yes ... in general equilibrium: This paper
Relevant in what sense?

- Better micro foundations important per se
- Better match of the data
- Better out-of-sample forecasts
- Matters for relevant policy questions

In this paper:

- IRF with significant and systematic history dependence
In a nutshell

Time-series model

Lumpy Model

FL−Model

Quarters

1961:I

1989:I

2000:II

Quarters

1961:I

1989:I

2000:II

Quarters

Eduardo Engel
Outline

1. Motivation
2. Basic mechanism
3. Time series evidence
4. Model
5. Confronting the evidence
6. Aggregate dynamics
7. Conclusion
2. Basic mechanism

- Rationalize lumpy micro behavior via non-convex (fixed) adjustment costs
- Need to take heterogeneous firms seriously
- Main ingredients:
  - cross-section of mandated investment: $f(x)$
  - inaction range: $L \leq x \leq U$
- $f(x)$ and $L, U$ depend on the state of the economy:
  - aggregate shocks
  - distribution of firm specific shocks
  - distribution of capital stock
Aggregate Implications of Lumpy Adjustment

\[ \frac{l_t}{k_t} \equiv \int_U^{+\infty} x |f(x, t)| dx - \int_{-\infty}^{L} x |f(x, t)| dx \]

\[ \text{IRF}_{0,t} \equiv \left( F(L) + (1 - F(U)) \right) + \left| L f(L) + U f(U) \right| \]

intensive margin \hspace{2cm} extensive margin

Ss policy: prob of adjusting
\[ f(x, t): x - \text{section mandated investment} \]
Lumpy Investment and Time-Varying IRFs

After a sequence of above avg. shocks (‘boom’):

- \( f(x, t) \) with more mass close to upper trigger
- investment more responsive to a marginal shock

Similarly: investment less responsive during downturns,
Continuous time for a formal result
Beware of linear models when predicting the impact of a stimulus

To what an extent does this intuition extend to a fully specified DSGE model?
3. Time series evidence

- Let: \( x_t \equiv l_t / K_{t-1} \)
- Consider the following GARCH-type model:

\[
x_t = \sum_{j=1}^{p} \phi_j x_{t-j} + \sigma_t e_t,
\]

\[
\sigma_t = h(x_{t-1}, x_{t-2}, \cdots),
\]

- It follows that:

\[
\text{IRF}_{0,t} = \frac{\partial x_t}{\partial \varepsilon_t} = \sigma_t = h(x_{t-1}, x_{t-2}, \cdots)
\]

- Consider two specifications (also kernel estimators):

\[
h(x_{t-1}, x_{t-2}, \cdots) = \alpha_0 + \alpha_1 \bar{x}_{t-1}^k,
\]

\[
h(x_{t-1}, x_{t-2}, \cdots) = (\tilde{\alpha}_0 + \tilde{\alpha}_1 \tilde{x}_{t-1}^k)^2,
\]

with \( \bar{x}_t^k \equiv \frac{1}{k} \sum_{j=1}^{k} x_{t-j} \).
Data:

- private, fixed, non-residential investment-to-capital-ratio

<table>
<thead>
<tr>
<th>Series:</th>
<th>All</th>
<th>Equip</th>
<th>Str</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$:</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>$k$:</td>
<td>8</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>$\alpha_1 \times 10^2$:</td>
<td>3.142</td>
<td>2.488</td>
<td>3.279</td>
</tr>
<tr>
<td>t-$\alpha_1$:</td>
<td>2.588</td>
<td>2.254</td>
<td>4.123</td>
</tr>
<tr>
<td>one sided p-$\alpha_1$:</td>
<td>0.005</td>
<td>0.013</td>
<td>0.000</td>
</tr>
<tr>
<td>$\pm \log(\sigma_{95}/\sigma_5)$:</td>
<td>0.505</td>
<td>0.468</td>
<td>0.895</td>
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<tr>
<td>$\pm \log(\sigma_{90}/\sigma_{10})$:</td>
<td>0.429</td>
<td>0.334</td>
<td>0.771</td>
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<tr>
<td>no. obs. est. $p$:</td>
<td>180</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>no. obs. est. $k$:</td>
<td>176</td>
<td>176</td>
<td>176</td>
</tr>
</tbody>
</table>
4. Model

- Incorporates lumpy investment (and therefore firm heterogeneity) into an otherwise standard stochastic growth model

- Producer side: interesting

- Household side: simple

- Follows closely Khan and Thomas (2008)

- Two differences:
  - sector specific productivity shocks
  - maintenance investment: necessary to continue operation (fraction $\chi$ of depreciated capital)
Production Units

- No entry or exit
- Aggregate, sectoral and idiosyncratic productivity shocks
- 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, \( \zeta \), drawn from a \( U[0, \bar{\zeta}] \), measured in units of labor
Production Units: Bellman Equation

Unit’s problem:

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

where

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

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

\[
U(C, N^h) = \log C - AN^h
\]

- The intertemporal price:

\[
p(z, \mu) \equiv U_C(C, N^h) = 1/C(z, \mu).
\]

- The intratemporal price:

\[
\omega(z, \mu) \equiv -\frac{U_N(C, N^h)}{p(z, \mu)} = \frac{A}{p(z, \mu)}.
\]
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 $\omega$, $p$ and $\Gamma$ as given, demand $N$ and $K'$
2. **Household optimality**: Taking $\omega$ 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

- \( \mu \): infinite dimensional

- We follow Krusell and Smith:
  - approximate \( \mu \) 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 \( \epsilon \equiv \epsilon_S \epsilon_I \).
5. Confronting the evidence

Most parameters: standard values suggested by micro studies

No such values available for the adjustment cost parameter $\bar{\xi}$ and the maintenance parameter $\chi$

Some options:

- Maximum likelihood?
- Match certain moments
- Moments from the distribution of plant level investment?
  - how many micro units in the model correspond to one observed micro unit?
- Moments suitable to gauge the relative importance of PE and GE smoothing
Sources of Smoothing in Macroeconomics

Aggregate Shocks

micro frictions

price responses

Macro Aggregates
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
Our Calibration

- There are many combinations of PE and GE smoothing that achieve the same degree of aggregate smoothing.
- Use 3-digit sectoral data to calibrate the relative importance of PE and GE smoothing.
  - mainly partial equilibrium effects at this level:
  - Benchmark calibration:
    - Match: $\sigma_{\text{sect}}(I/K)$, $\sigma_{\text{agg}}(I/K)$, $\pm \log(\sigma_{95}/\sigma_5)$
    - Parameters: $\bar{\xi}$, $\chi$, $\sigma_A$
  - Robustness check:
    - Match: $\sigma_{\text{sect}}(I/K)$, $\sigma_{\text{agg}}(I/K)$
    - Parameters: $\bar{\zeta}$, $\sigma_A$
Standard Choices

- Model period: quarter
- Standard choices: $\beta = 0.9942$, $\delta = 0.022$, $\rho_A = 0.95$,...
- $\nu = 0.64$ and $\theta = 0.18$:
  - labor share: 0.64
  - revenue-elasticity of capital: 0.50

- $\sigma_S = 0.0273$, $\rho_S = 0.8612$: standard Solow residual calculation on annual 3-digit manufacturing data, taking into account sector-specific trends and time-aggregation
- $\sigma_I = 0.0472 \Rightarrow$ total s.d. = 0.10
- Non-trivial choices: $\bar{\xi}$ and $\chi$
## Results: Economic Magnitude of Adjustment Costs

<table>
<thead>
<tr>
<th></th>
<th>Tot. adj. costs/ Agg. Output</th>
<th>Tot. adj. costs/ Agg. Invest.</th>
<th>Adj. costs/ Unit Output</th>
<th>Adj. costs/ Unit Wage Bill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>quart.</strong></td>
<td>0.35%</td>
<td>2.41%</td>
<td>9.53%</td>
<td>14.88%</td>
</tr>
<tr>
<td><strong>annual</strong></td>
<td>0.41%</td>
<td>2.84%</td>
<td>3.60%</td>
<td>5.62%</td>
</tr>
</tbody>
</table>
Smoothing and $\sigma(I/K)$: RBC

No frictions

Only PE

0%

Only GE

100%

PE and GE

100%
Smoothing and $\sigma(I/K)$: Khan and Thomas

No frictions

only PE
16.1%

only GE
100%

PE and GE
100%
Smoothing and $\sigma(I/K)$: This Paper

No frictions

only PE 81.0%

only GE 84.6%

PE and GE 100%
# Why the Difference?

We choose to match sectoral investment volatility:

<table>
<thead>
<tr>
<th></th>
<th>3-dig. Agg. Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Data</em></td>
<td>1.66</td>
</tr>
<tr>
<td>This paper:</td>
<td>1.66</td>
</tr>
<tr>
<td>Frictionless/Khan-Thomas (2008):</td>
<td>18 - 44</td>
</tr>
</tbody>
</table>

We choose to match IRF volatility:

<table>
<thead>
<tr>
<th></th>
<th>$\log(\sigma_{95}/\sigma_{5})$</th>
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</thead>
<tbody>
<tr>
<td><em>Data</em></td>
<td>0.30</td>
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<tr>
<td>This paper:</td>
<td>0.29</td>
</tr>
<tr>
<td>Frictionless/Khan-Thomas (2008):</td>
<td>0.05</td>
</tr>
</tbody>
</table>
6. Aggregate Investment Dynamics

- Explain why our DSGE model with lumpy adjustment generates a procyclical IRF
- Is it variations in PE- or GE-smoothing?
- Is it related to the intensive or extensive margin?
- Relation to the “basic mechanism”
Responsiveness Index

Define:

\[ \mathcal{I}^+ (\mu_t, \log z_t) \equiv \left[ \frac{I}{K}(\mu_t, \log z_t + \sigma_A) - \frac{I}{K}(\mu_t, \log z_t) \right] / \sigma_A, \]

\[ \mathcal{I}^- (\mu_t, \log z_t) \equiv \left[ \frac{I}{K}(\mu_t, \log z_t - \sigma_A) - \frac{I}{K}(\mu_t, \log z_t) \right] / (-\sigma_A) \]

Responsiveness Index at time \( t \) defined as:

\[ \text{RI}_t \equiv 0.5 \left[ \mathcal{I}^+ (\mu_t, \log z_t) + \mathcal{I}^- (\mu_t, \log z_t) \right]. \]
IRF upon impact from model (1960–2005)
Robustness check – Second calibration
Why strongly procyclical?

- 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 limit
Mandated Investment

- We have:

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

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

\[ x(\epsilon; z, \bar{k}) \equiv \log k^*(\epsilon; z, \bar{k}) - \log[1 - \delta + \chi \delta]k. \]
Mandated Investment Cross-Section and Hazard
Why strongly procyclical?

During booms:

- 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
- the x-section moves into regions where the probability of adjusting is higher and steeper
  - this effect is not present in a frictionless (or Calvo) model
RI: Intensive and Extensive Margins

Fluctuations in responsiveness index driven mainly by variations in the fraction of units adjusting (extensive margin)
I/K: Intensive and Extensive Margins

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
7. Conclusion

- Time-series evidence suggests 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 can