LUMPY INVESTMENT AND ENDOGENOUS BUSINESS CYCLES

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Motivations

- Many robust stylized facts concerning
  
  I. Business Cycles
  
  II. Firm Productivities: Distributions and Dynamics
  
  III. Firm Size Distributions
  
  IV. Firms' Investment Decisions

- Theoretical Interpretations: the state of the art

  - Current lack of models which build upon investment stylized facts and are able to jointly explain the stylized facts concerning business cycles, firm productivity dynamics and firm size distribution.

- This paper: An evolutionary model which accounts for SFs I, II and III building on SFs IV.
Outline of the Talk

1. Stylized Facts
2. Theoretical Roots and Antecedents
3. The Model
4. Simulation Results
5. Conclusions
Stylized Facts (1/2)

- **Business Cycles**
  (e.g. Stock and Watson, 1999; Napoletano, Roventini and Sapio, 2004)
  - **SF1**: Investment considerably more volatile than GDP
  - **SF2**: Consumption less volatile than GDP
  - **SF3**: Investment, Consumption and Change in Stocks procyclical and coincident variables
  - **SF4**: Employment and Unemployment Rate lagging variables. Aggregate Employment procyclical; Unemployment Rate anticyclical

- **Investment**
  - **SF5**: Investment is lumpy (Doms and Dunne, 1998)
  - **SF6**: Investment is influenced by firms’ financial structure (e.g. Fazzari, Hubbard and Petersen 1988)
### Variance and Auto-Correlation Structure of GDP and of its components for the U.S. economy

<table>
<thead>
<tr>
<th>Series</th>
<th>Std. Dev.</th>
<th>Cross-correlations with GDP (lags)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abs.</td>
<td>Rel.</td>
</tr>
<tr>
<td>GDP</td>
<td>1.66</td>
<td>1.00</td>
</tr>
<tr>
<td>Investment</td>
<td>4.97</td>
<td><strong>2.99</strong></td>
</tr>
<tr>
<td>Consumption</td>
<td>1.26</td>
<td><strong>0.76</strong></td>
</tr>
<tr>
<td>Change in Inventories</td>
<td>0.38</td>
<td>-</td>
</tr>
<tr>
<td>Employment</td>
<td>1.39</td>
<td>0.84</td>
</tr>
<tr>
<td>Unemployment rate</td>
<td>0.76</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Quarterly data have been detrended with a bandpass filter (6,32,12).

Source: Stock & Watson, 1999
Stylized Facts (2/2)

- Firm Productivity Dynamics (e.g. Bartelsman and Dooms, 2000)
  - **SF10**: Productivity dispersion among firms is large
  - **SF11**: Inter-firm productivity differentials are quite persistent over time

- Firm Size Distributions (e.g. Bottazzi and Secchi, 2003; 2004)
  - **SF12**: Firm size distributions tend to be right-skewed, with upper-tails made of few large firms. These patterns vary considerably across different sectors
  - **SF13**: Firms growth-rate distributions are not Gaussian and can be well proxied by fat-tailed, tent-shaped densities
Theoretical Roots and Antecedents (1/2)

⇒ Models explaining investment stylized facts

- Investment Lumpiness
  - Non-convex adjustment costs
    (e.g. Caballero, Engel and Haltiwanger, 1995; Caballero and Engel 1999; Cooper, Haltiwanger and Power (1999))

- Financial Constraints
  - Imperfect information
    (e.g. Evans and Jovanovic, 1989; Fazzari, Hubbard and Petersen, 1996)
Theoretical Roots and Antecedents (2/2)

⇒ Macro theories and Micro models at the root of our model

- Keynesian Theory of Trade Cycles (Keynes, 1936)
  - Investment instability as the main cause of economic fluctuations
  - Income multiplier and Investment accelerator

- Evolutionary model of industry dynamics
  - Silverberg, Dosi and Orsenigo (1988)
  - Chiaromonte and Dosi (1993)
• **The Economy**

  o Two industries

  o $F_1$ consumption-good firms $j = 1, 2, \ldots, F_1$

  o $F_2$ machine-tool firms $i = 1, 2, \ldots, F_2$

  o $N$ consumers/workers

  o Discrete time $t = 0, 1, 2, \ldots, T$
• **Consumption-good firms**
  o invest in machine tools
  o produce homogenous consumption good using capital and labor under constant returns to scale

• **Machine-tool firms**
  o produce heterogeneous capital goods using labor only under constant returns to scale
  o stochastically introduce product and process innovations

• **Consumers/workers**
  o inelastically sell labor to firms
  o fully consume their income
The Model (3/11)

Model Dynamics

- Capital-good firms advertise their machines sending "brochures" to consumption-good firms

- Consumption-good firms decide how much to produce, choose their supplier for next period machines and order them

- Firms hire workers according to their production plans (wages are advanced)

- Production in both sectors begin

- Consumption-good market opens

- Entry, exit and technical change take place

- Consumption-good firms receive the machines they ordered
The Model (4/11)

➢ **Investment**

investment is lumpy and investment decisions are boundedly rational

. Expansion Investment

    • (S,s) Investment Routine:

    - Demand Expectations ($D^e_j$) $\Rightarrow$ Desired Level of Production ($Q^d_j$)
    - Desired Level of Production $\Rightarrow$ Desired Capital Stock ($K^d_j$)
    - Trigger Capital Stock $\Rightarrow$ $K_{j\text{trig}}(t) = K_j(t)\cdot(1 + \alpha)$
    - Expansion Investment $= \begin{cases} 0 & \text{if } K^d_j(t) < K_{j\text{trig}}(t) \\ K_{j\text{trig}}(t) - K_j(t) & \text{if } K^d_j(t) \geq K_{j\text{trig}}(t) \end{cases}$
b) Replacement investment

- Payback period routine:
  - \( c(\tau) \) unit labor cost of an incumbent machine
  - \( p^*, c^* \) average price and unit labor cost of new machines
  - An incumbent machine is scrapped \( \iff \frac{p^*}{c(\tau) - c^*} \leq b \), \( b > 0 \)

- A machine is also replaced if it is older than \( \Lambda_{\text{max}} \) periods
c) Financial structure does matter

- Production and investment decisions of consumption-good firms may be constrained by their financial balances
  
  - Consumption-good firms first rely on their stock of liquid assets and then on more expensive external funds
  
  - Credit ceiling: the stock of debt (\(D_{eb} \)) of consumption-good firms is limited by their gross cash flows (= sales \( S \)):

\[
D_{eb}(t) \leq \kappa S_j(t - 1), \quad \text{with } \kappa \geq 1
\]
The Model (7/11)

**Capital-good market**

- Machines are priced according to their production cost.
- Capital-good firms send a "brochure" with the price and the productivity of their machines to both their historical (HC) and potential (NC) customers:
  \[ NC_i(t) = (1 + \gamma) \cdot HC_i, \quad \text{with } 0 < \gamma < 1 \]
- Consumption-good firms choose their supplier comparing the productivity-price ratios of the machines described in the "brochures".
- Capital-good firms hire workers and start producing according to the orders they receive.
- Time-to build: currently produced machines will be delivered at the end of the period.
The Model (8/11)

- **Consumption-good market**
  - Imperfect competition (prices \( p_j \) \( \rightarrow \) variable mark-up \( m_{ij} \) on unit cost of production \( c_j \))
    \[
    p_j = (1 + m_{ij}(t))c_j
    \]
    \[
    m_{ij}(t) = m_{ij}(t-1) \left( 1 + \frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)} \right), \quad f_j: \text{market share of firm } j
    \]
  - Consumption-good firms **first** produce and **then** try to sell their products
    - Inventories
The Model (9/11)

- Consumption-good market dynamics
  - Market shares evolving according to a quasi replicator dynamics
    \[
    f_j(t) = f_j(t-1) \left( 1 + \chi \frac{E_j(t) - \bar{E}_j(t)}{\bar{E}_j(t)} \right), \quad \text{with } \chi \geq 0
    \]
    
    $E_j$: competitiveness of firm $j$; $\bar{E}$: avg. competitiveness of consumption-good industry;

  - Firm competitiveness ($E_j$) depends on price and unfilled demand

- Entry & Exit
  - Exit $\rightarrow$ (near) zero market share OR negative net worth
  - Entry $\rightarrow$ random copy of an existing firm
Technical Change

- Capital-good firms stochastically search for better machines and for more efficient production techniques

- Product innovation:

  $$A_{i,\text{new}} = A_i(t) \cdot (1 + \epsilon_1), \quad \epsilon_1 \sim U[-uu_1, uu_1], \quad \text{with } 0 < uu_1 < 1;$$

  $A =$ labor productivity associated with machines produced by firm $i$ and used in the consumption-good industry

- Process innovation:

  $$B_{i,\text{new}} = B_i(t) \cdot (1 + \epsilon_2), \quad \epsilon_2 \sim U[-uu_2, uu_2], \quad \text{with } 0 < uu_2 < 1;$$

  $B =$ labor productivity of firm $i$
The Model (11/11)

- **Macro level**
  - Labor market:
    - Exogenous Labor Supply (LS)
    - Wage \( w \) determined by avg. productivity \( \bar{A} \), inflation \( \text{cpi} \) and unemployment \( U \):
      \[
      w(t) = w(t-1) \left( 1 + \psi_1 \frac{\text{cpi}(t) - \text{cpi}(t-1)}{\text{cpi}(t-1)} + \psi_2 \frac{\bar{A}(t) - \bar{A}(t-1)}{\bar{A}(t-1)} - \psi_3 \frac{U(t) - U(t-1)}{U(t-1)} \right),
      \]
      with \( 0 \leq \psi_{1,2,3} \leq 1 \)
    - Involuntary unemployment + possibility of labor rationing
  - Employment, Consumption, Investment, Inventories and GDP \( \rightarrow \) obtained by aggregating micro quantities
Simulation Strategy

• Choose initial conditions and system parameters

• Generate a simulation run for $t = 1, \ldots, T$

  1. Analyze qualitative results

      (e.g. self-sustaining growth, business cycles fluctuations)

  2. Study quantitative results

      (e.g. avg. growth rates, stationarity tests, volatility, correlations, etc.)
No Technical Change

- Consumption-good firms invest only to replace "old" machines
- Economy is always in steady state
- Zero growth
- Firms are all equal and always survive
No Technical Change. GDP, Investment and Consumption (logs)
Technical Change – Qualitative Results

- Self-sustaining growth
- Endogenous business cycles
- Consumption less volatile than GDP (SF2), but also investment less volatile than GDP
- Investment and Consumption procyclical (SF3)
- Expansion investment lumpy and more volatile than replacement investment
Technical Change. GDP, Investment and Consumption (logs)
Technical Change. Bandpass-filtered GDP, Investment and Consumption
Technical Change. Bandpass-filtered Exp. and Repl. Investment
Technical Change – Quantitative Results

- Positive average rates of growth (1.8%)
- Dickey-Fuller test: GDP, Consumption and Investment non-stationary
- Relative standard deviations: consumption is less volatile than GDP (SF2), but also investment is less volatile than GDP
- Cross-correlations: consumption, change in stocks, and net investment are procyclical and coincident variables (SF3). Investment is leading.
- Employment and unemployment rate procyclical and coincident variables
### Technical Change. Output, Investment and Consumption Statistics.

<table>
<thead>
<tr>
<th></th>
<th>GDP</th>
<th>Cons.</th>
<th>Inv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. growth rate (%)</td>
<td>1.8% (0.007)</td>
<td>1.8% (0.006)</td>
<td>1.8% (0.005)</td>
</tr>
<tr>
<td>Dickey-Fuller test (logs)</td>
<td>-0.0988</td>
<td>0.9914</td>
<td>0.3692</td>
</tr>
<tr>
<td>Sign. level</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dickey-Fuller test (bpf 6,32,12)</td>
<td>-5.6450</td>
<td>-4.8685</td>
<td>-6.2572</td>
</tr>
<tr>
<td>Sign. level</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Std. Dev. (bpf 6,32,12)</td>
<td>1.1720</td>
<td>0.6198</td>
<td>0.3306</td>
</tr>
<tr>
<td>Rel. Std. Dev.</td>
<td>1</td>
<td><strong>0.5288</strong></td>
<td>0.2821</td>
</tr>
</tbody>
</table>

Standard deviations in parenthesis

<table>
<thead>
<tr>
<th>Series (bpf 6,32,12)</th>
<th>t-4</th>
<th>t-3</th>
<th>t-2</th>
<th>t-1</th>
<th>t</th>
<th>t+1</th>
<th>t+2</th>
<th>t+3</th>
<th>t+4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>-0.19</td>
<td>0.14</td>
<td>0.54</td>
<td>0.87</td>
<td>1.00</td>
<td>0.87</td>
<td>0.54</td>
<td>0.14</td>
<td>-0.19</td>
</tr>
<tr>
<td>Consumption</td>
<td>-0.09</td>
<td>0.24</td>
<td>0.58</td>
<td>0.85</td>
<td><strong>0.95</strong></td>
<td>0.86</td>
<td>0.59</td>
<td>0.23</td>
<td>-0.12</td>
</tr>
<tr>
<td>Investment</td>
<td>-0.18</td>
<td>-0.17</td>
<td>-0.08</td>
<td>0.11</td>
<td>0.38</td>
<td>0.64</td>
<td>0.78</td>
<td>0.73</td>
<td>0.50</td>
</tr>
<tr>
<td>Change in Inventories</td>
<td>0.03</td>
<td>0.17</td>
<td>0.31</td>
<td><strong>0.40</strong></td>
<td><strong>0.39</strong></td>
<td>0.28</td>
<td>0.10</td>
<td>-0.10</td>
<td>-0.24</td>
</tr>
<tr>
<td>Net Investment</td>
<td>0.06</td>
<td>0.29</td>
<td>0.49</td>
<td>0.63</td>
<td><strong>0.69</strong></td>
<td>0.63</td>
<td>0.46</td>
<td>0.21</td>
<td>-0.07</td>
</tr>
<tr>
<td>Employment</td>
<td>-0.13</td>
<td>0.17</td>
<td>0.52</td>
<td>0.81</td>
<td>0.96</td>
<td>0.89</td>
<td>0.64</td>
<td>0.28</td>
<td>-0.08</td>
</tr>
<tr>
<td>Unemployment rate</td>
<td>-0.01</td>
<td>-0.25</td>
<td>-0.49</td>
<td>-0.67</td>
<td>-0.75</td>
<td>-0.71</td>
<td>-0.53</td>
<td>-0.26</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Endogenous-Component Scenario

- The high volatility of GDP is due to the "wild" fluctuations of the change-in-inventory component.
- The model does not contain any stabilizing component (e.g. service industry, public expenditure, etc.).
- We extend the model allowing unemployed workers to earn a fraction of the market wage ($w^u$):
  \[ w^u(t) = \varphi w(t) U(t) \]
Endogenous-Component Scenario - Simulation Results

- Investment becomes more volatile than GDP (SF1)
- Investment becomes slightly leading, whereas Net investment is still coincident
- The other macro stylized facts are still matched
- Simulated cross-correlations close to “real” cross-correlations (cf. Stock and Watson, 1999)
Endogenous-Component Scenario. GDP, Investment and Consumption (logs)
Endogenous-Component Scenario. Bandpass-filtered GDP, Investment and Consumption
Endogenous-Component Scenario. Bandpass-filtered Exp. and Repl. Investment
### Endogenous-Component Scenario.

#### Output, Investment and Consumption Statistics.

<table>
<thead>
<tr>
<th></th>
<th>GDP</th>
<th>Cons.</th>
<th>Aggr. Inv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. growth rate (%)</td>
<td>1.8% (0.0006)</td>
<td>1.8% (0.0005)</td>
<td>1.8% (0.0017)</td>
</tr>
<tr>
<td>Dickey-Fuller test (logs)</td>
<td>2.6816</td>
<td>5.8739</td>
<td>-0.3739</td>
</tr>
<tr>
<td>Sign. level</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dickey-Fuller test (bpf 6,32,12)</td>
<td>-6.3837</td>
<td>-6.0359</td>
<td>-6.8881</td>
</tr>
<tr>
<td>Sign. level</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Std. Dev. (bpf 6,32,12)</td>
<td>0.1358</td>
<td>0.0946</td>
<td>0.4357</td>
</tr>
<tr>
<td>Rel. Std. Dev.</td>
<td>1.00</td>
<td><strong>0.70</strong></td>
<td><strong>3.21</strong></td>
</tr>
</tbody>
</table>

Standard deviations in parenthesis
Endogenous-Component Scenario. Correlation Structure.

<table>
<thead>
<tr>
<th>Series (bpf 6,32,12)</th>
<th>t-4</th>
<th>t-3</th>
<th>t-2</th>
<th>t-1</th>
<th>t</th>
<th>t+1</th>
<th>t+2</th>
<th>t+3</th>
<th>t+4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>-0.38</td>
<td>-0.03</td>
<td>0.44</td>
<td>0.84</td>
<td>1.00</td>
<td>0.84</td>
<td>0.44</td>
<td>-0.03</td>
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<td>-0.19</td>
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<td>0.41</td>
<td>0.02</td>
<td>-0.28</td>
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<td>-0.91</td>
<td>-0.61</td>
<td>-0.18</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Endogenous-Component Scenario.

Model Generated (M-G) vs. Empirical Data (S-W: Stock and Watson, 1999) Cross-Correlations
Microeconomic Stylized Facts. Firm Size Distribution

- Skewed Size Distribution (SF12)
- Firm Growth Rates exhibit "tent-shaped" patterns with tails fatter than the Gaussian distribution (SF13)
- Strong form of the Gibrat's Law does not hold
Pooled (Year-Standardized) Sales Distributions. Log Rank vs. Log Size Plots.

M-G: Model-Generated Distribution.
Microeconomic Stylized Facts. Firm Productivity Dynamics

- Huge asymmetries in firm productivity (SF10)
- Persistency in inter-firm productivity differentials (SF11)
Standard Deviations of Consumption-Good Firm Productivity
Average Auto-Correlations of Consumption-Good Firm Productivity.

Error Bars: +/- Standard Deviation.
Conclusions (1/3)

- **Business cycles stylized facts**
  - Investment is more volatile than GDP (SF1) whereas consumption is less volatile than GDP (SF2).
  - Investment, consumption and change in stocks procyclical and coincident variables (SF3). Employment and unemployment rate are lagging variables. Employment is procyclical, whereas unemployment is anticyclical (SF4).

- **Investment stylized facts**
  - Investment is lumpy (SF5) and is influenced by firms’ financial structure (SF6).

- **Firm productivity dynamics stylized facts**
  - Firms are extremely heterogeneous in term of productivity (SF10).
  - Inter-firm productivity differentials are persistent over time (SF11).

- **Firm size distribution stylized facts**
  - Firm size distributions tend to be considerably right-skewed (SF12) and firm growth rate can be well proxied by fat-tailed, tent-shaped densities (SF13).
Conclusions (2/3)

- No attempts in providing a model that JOINTLY explains SF1-SF4 and SF10-SF13 starting from SF5 and SF6

- We presented an evolutionary/ACE model
  - Machine-tool and manufacturing industries
  - Routines for expansion and replacement investment
  - Investment lumpiness grounded on bounded rationality
  - Financial structure of firms matters
  - Interactions within- and between-industry
  - Technological progress
  - Keynesian trade cycles

- We find that the model
  - delivers self-sustaining growth patterns
  - endogenously generates business cycles
  - reproduces macro stylized facts (SF1 – SF3)
  - matches micro stylized facts (SF10 – SF13)
Conclusions (3/3)

▪ On our agenda…

  o Microfoundation of consumption and labor markets
  o Different entry/exit rules
  o Introduction of different expectation formation rules