AGGREGATE DYNAMICS AND MICROECONOMIC HETEROGENEITY: THE ROLE OF VINTAGE TECHNOLOGY

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Background/Motivation

- After the Great Recession slow recovery of Southern European countries
  - Prolonged slump in aggregate investment
  - Stagnant aggregate productivity

- Lack of investment often blamed for the poor performance of productivity
  - Logic: technology adoption through investment

- Empirical evidence on vintage technology is scant
We study the role of investment for productivity dynamics

- Microeconomic evidence on heterogeneity and vintage effects
  - Census of incorporated Italian firms
- Macroeconomic implications: structural model
  - Firm heterogeneity à la Khan and Thomas (ECMA, 2008)
  - Technology adoption decision
Investment is a key determinant of productivity dynamics

- Firms with lower investment age have higher productivity
  investment age is the time elapsed since the last large investment episode

- Investment age/vintage effects account for \( \sim 15\% \) of productivity heterogeneity across firms

Macroeconomic relevance of the link investment-productivity

- Vintage technology amplifies dynamics following aggregate shocks

- Investment slowdown accounts for over \( \frac{1}{3} \) of missing productivity growth in the Italian economy
Empirical Analysis

Microeconomic Data

- Census of incorporated Italian firms
  - Balance-sheet data from 1986 to 2015
  - 395,169 different firms and 5,004,894 firm-observations
  - Representative of ~80% of total value-added
Empirical Analysis
Firm-Level Investment Is Lumpy

- Investment is a large and infrequent, or *lumpy*, episode
- Lumpiness in capital accumulation, where 18% of firms
  - Exhibits an investment rate over 20% (spikes)
  - Accounts for 61% of total investment
- Empirics: Spikes as a signal of technology adoption
VINTAGE EFFECTS IN THE DATA

EMPIRICAL SPECIFICATION

\[
\log(\text{Productivity}_{f,t}) = \alpha + \sum_{j=1}^{12+} \beta_j \text{Inv.Age}_{j,f,t} + \text{Controls}_{f,t} + \epsilon_{f,t}
\]

- **Productivity**: labor and total factor productivity
- **Inv.Age_{j,f,t}**: time elapsed since the last investment spike \((ik_{f,t} \geq 0.20)\)
- **Controls**: firm-, industry-, year-effects, firm’s age and size dummies
VINTAGE EFFECTS IN THE DATA

ESTIMATED $\beta_j$’S

A. Labor Productivity

B. Total Factor Productivity
Results not driven by

- Idiosyncratic shocks
  Estimate AR productivity process: $\sim 0.4$

- News shocks
  Include expected 2-year ahead growth rate of revenues: $\beta_j$’s unchanged

- Innovative firms
  Sample split between firms with high- and low-intensity in intangible capital: $\beta_j$’s not different

Extensive robustness analysis

- Spikes definition, sample composition, sectoral analysis
QUANTIFYING AGGREGATE EFFECTS

◇ What is the **Macro** relevance of this **Micro** evidence?

◇ **Reduced-form approach**

  ✓ Industry level, share of lumpy investors predicts future productivity

  ✗ Partial equilibrium analysis

◇ **Structural approach (today)**

  ◦ Aggregate effects from changes in the distribution of firms over investment age

  ◦ Lumpy capital accumulation

  ✓ General equilibrium analysis and transitional dynamics
THEORETICAL FRAMEWORK - AGENTS

◊ Firms
  – Khan and Thomas (ECMA, 2008)
  – Lumpy capital accumulation
  – Technology adoption decision

◊ Representative household
  – Consume
  – Save
Theoretical Framework - Firms

- **A firm is a triplet** $(z, \varepsilon, k)$
  - $z$ - permanent productivity vintage
  - $\varepsilon$ - exogenous temporary idiosyncratic shock
  - $k$ - stock of capital

- **Firms produce output**
  - Cobb-Douglas production function $y = \varepsilon z k^\theta$
  - Perfectly competitive
  - One-sector economy
TECHNOLOGY ADOPTION DECISION

- Technological frontier \( z_0 \) expands over time
  \( z_0 \) evolves at a gross rate \( \gamma_A \)

- Firms face a non-convex adoption cost \( \xi \)
  \( \xi \) is bounded, stochastic, and i.i.d.

- If firms pay the adoption cost (next period):
  - Upgrade to the latest vintage \( z'_0 \)
  - Choose \( k' \) optimally \( k^* \in \mathbb{R}_+ \)

- If firms do not pay the adoption cost (next period):
  - Keep current vintage \( z \)
  - Distance from the technological frontier increases at a gross rate \( \gamma_A \)
  - Choose constrained \( k' \in \Omega(k) \equiv \left[ \frac{1-\delta+a}{\gamma}k, \frac{1-\delta+b}{\gamma}k \right] \)
Model Implications

- Non-convex adoption costs lead to:
  - (S,s) technology adjustment rules - action/inaction region
  - Different vintages z coexist (distribution is non-degenerate)
  - Aggregate TFP is endogenous to firms’ adoption decision

- Model parameterized reproduces
  - The cross-sectional distribution of investment rates (target)
  - The cross-sectional distribution of investment age (validation)
# Cross-Section of Investment Rates

## Model versus Data

<table>
<thead>
<tr>
<th></th>
<th>Inaction</th>
<th>Positive Spikes</th>
<th>Negative Spikes</th>
<th>Positive Investment</th>
<th>Negative Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data</strong></td>
<td>34.19%</td>
<td>18.81%</td>
<td>3.11%</td>
<td>59.81%</td>
<td>6.00%</td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td>36.25%</td>
<td>18.32%</td>
<td>0.15%</td>
<td>60.58%</td>
<td>3.17%</td>
</tr>
</tbody>
</table>

*Notes:* Inaction: $ik \in (-0.05, 0.05)$; Positive spike: $ik \geq 0.20$; Negative spike: $ik \leq 0.20$; Positive investment: $ik \geq 0.05$; Negative investment: $ik \leq 0.05$. 
APPLICATION
FINANCIAL CRISIS IN ITALY

◊ Financial shock (today)
  – Increase in the cost of investing (akin to Italian 2012 recession)
  – Perfect foresight, no aggregate uncertainty

◊ Business cycle/technology shocks
  – Stochastic technological frontier $z_0$
  – Aggregate uncertainty, Krusell-Smith solution method
Properties of the Stochastic Process

Financial Shock

- **Financial cost**: $(1 + \lambda_t) i_f, t$
  
  $\lambda_t$ are AR(1) processes

- **Process is temporary but persistent**
  
  - Time-0 the economy is in steady state
  
  - Time-1 the (temporary) shock hits the economy
  
  - Size of the shock $\lambda_t$: $Inv.Age_0$ drops as in 2012
## Aggregate Dynamics

### Financial Shock

<table>
<thead>
<tr>
<th></th>
<th>GDP RBC</th>
<th>GDP VINTAGE</th>
<th>Investment RBC</th>
<th>Investment VINTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impact</strong></td>
<td>0.00%</td>
<td>0.00%</td>
<td>-4.87%</td>
<td>-4.48%</td>
</tr>
<tr>
<td><strong>Period 1</strong></td>
<td>-0.19%</td>
<td>-0.60%</td>
<td>-3.60%</td>
<td>-3.39%</td>
</tr>
<tr>
<td><strong>Period 2</strong></td>
<td>-0.31%</td>
<td>-0.85%</td>
<td>-2.66%</td>
<td>-2.83%</td>
</tr>
<tr>
<td><strong>Period 3</strong></td>
<td>-0.42%</td>
<td>-0.77%</td>
<td>-1.95%</td>
<td>-2.31%</td>
</tr>
<tr>
<td><strong>Period 4</strong></td>
<td>-0.38%</td>
<td>-0.68%</td>
<td>-1.43%</td>
<td>-1.57%</td>
</tr>
</tbody>
</table>

*Notes: Each entry is in percent relative from trend values.*
# Aggregate TFP Response

## Financial Shock

<table>
<thead>
<tr>
<th></th>
<th>TFP Data</th>
<th>TFP Vintage</th>
<th>TFP RBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>-1.27%</td>
<td>-0.42%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2013</td>
<td>-1.08%</td>
<td>-0.57%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2014</td>
<td>-1.15%</td>
<td>-0.31%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2015</td>
<td>-0.89%</td>
<td>-0.26%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

*Notes:* Each entry is in percent relative from trend values. TFP is computed using a Cobb-Douglas aggregate production function.
CONCLUSION

✓ Investment is a key determinant of productivity dynamics

✓ Vintage technology amplifies the propagation of aggregate shocks

✓ Investment heterogeneity is quantitatively relevant for aggregate dynamics
INVESTMENT AND PRODUCTIVITY

RELATION TO THE LITERATURE

◊ Empirical evidence is mixed:


◊ Theoretical work on vintages and investment:

– Vintage models: Johansen (ECMA, 1959), Solow (1960), Boucekkine, De la Croix, Licandro (2011)

– Firm-level investment: Cooper and Haltiwanger (AER, 1993), Cooper, Haltiwanger and Power (AER, 1999), Cooley, Greenwood, Yorukoglu (JME, 1997), Khan and Thomas (ECMA 2008), Bachmann, Caballero and Engel (AEJ-Macro, 2013), Fiori and Traum (2018)
Firm’s Capital Accumulation

Compute investment rate ($i_k$) as Bloom (2009):

- $i_{kf,t} = \frac{I_{f,t}}{0.5(K_{f,t-1} + K_{f,t})}$

- $I_{f,t}$ investment net of disinvestment

- $I_{f,t}$ includes tangible and intangible investment

- $K_{f,t}$ capital computed using Perpetual Inventory Method
### Distribution of Investment Rates

**Lumpiness in Capital Accumulation**

<table>
<thead>
<tr>
<th>Investment Rate</th>
<th>Share in Data Set</th>
<th>Share of Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i_k \geq 0.20$</td>
<td>18.81%</td>
<td>61.04%</td>
</tr>
<tr>
<td>$-0.05 \leq i_k \leq 0.05$</td>
<td>34.19%</td>
<td>2.37%</td>
</tr>
<tr>
<td>$i_k \leq -0.20$</td>
<td>3.11%</td>
<td>-1.74%</td>
</tr>
</tbody>
</table>

**Notes:** Sample period 1998-2015. Entries are sample averages.
PRODUCTIVITY MEASURES

- **Labor productivity** \((l_{pf,t})\):
  
  \[
  \log(l_{pf,t}) = \log(v_{f,t}) - \log(n_{f,t})
  \]
  
  - \(v_{f,t}\) real value-added and \(n_{f,t}\) labor input

- **Unadjusted total factor productivity** \((tfp_{f,t})\):
  
  \[
  \log(tfp_{f,t}) = \log(v_{f,t}) - \theta\log(k_{f,t}) - \nu\log(n_{f,t})
  \]
  
  - \(k_{f,t}\) real capital stock
  
  - Input elasticities estimated as in Bachmann and Bayer (AER, 2014)
## Sample Statistics

### Statistics on Firm’s Age

<table>
<thead>
<tr>
<th>Firm Age</th>
<th>Share in Data Set (A)</th>
<th>Share of Output (B)</th>
<th>Share of Investment (C)</th>
<th>Share of Employment (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5 years old</td>
<td>29.90</td>
<td>13.90</td>
<td>16.69</td>
<td>15.74</td>
</tr>
<tr>
<td>5 – 10 years old</td>
<td>23.05</td>
<td>17.20</td>
<td>17.81</td>
<td>16.60</td>
</tr>
<tr>
<td>10 – 20 years old</td>
<td>24.97</td>
<td>25.80</td>
<td>24.87</td>
<td>25.04</td>
</tr>
<tr>
<td>20+ years old</td>
<td>22.08</td>
<td>43.10</td>
<td>40.63</td>
<td>42.62</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

*Notes: Sample period 1998-2015. Entries are sample averages.*
## Distribution of Investment Rates

### Lumpiness in Capital Accumulation

<table>
<thead>
<tr>
<th>Investment Rate</th>
<th>Share in Data Set</th>
<th>Share of Output</th>
<th>Share of Investment</th>
<th>Share of Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ik \geq 0.20$</td>
<td>18.81%</td>
<td>26.77%</td>
<td>61.04%</td>
<td>27.52%</td>
</tr>
<tr>
<td>$-0.05 \leq ik \leq 0.05$</td>
<td>34.19%</td>
<td>25.67%</td>
<td>2.37%</td>
<td>27.01%</td>
</tr>
<tr>
<td>$ik \leq -0.20$</td>
<td>3.11%</td>
<td>1.98%</td>
<td>-1.74%</td>
<td>2.14%</td>
</tr>
</tbody>
</table>

*Notes:* Sample period 1998-2015. Entries are sample averages. $ik$ denotes the investment rate.
Investment Age Distribution

Years − Investment Age

Fraction of Firms

Data
Estimated $\beta_j$’s - Sectoral Evidence

**Manufacturing**

- Gap - percent
  - Years Inv. age

**Accommod. and Food**

- Gap - percent
  - Years Inv. age
Marginal Estimated Effects

- One standard deviation shock to the share of lumpy investors
  - Between 0.8 and 1.1 percent to LP
  - Between 0.7 and 1.1 percent to TFP
  - **Caveat:** General equilibrium effects are ignored
**Financial Shock**

*Properties of the Stochastic Process*

- Financial cost: \((1+\lambda_t) i_{f,t}\)
  
  \(\lambda_t\) follows as AR(1) process

- Process is temporary but persistent

  - \(\lambda_t = \rho \lambda_{t-1} + \varepsilon_{\lambda_t}\)

  - In steady state \(\lambda_t=0\)
**Theoretical Framework**

**Summary**

Firm’s Adoption and Investment Decision

<table>
<thead>
<tr>
<th>Fixed Cost Paid</th>
<th>Future Technology</th>
<th>Future Capital</th>
<th>Total Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i \neq 0 )</td>
<td>( \xi + \delta_{S}k )</td>
<td>( z' )</td>
<td>( k' &gt; 0 \in \mathbb{R}_+ )</td>
</tr>
<tr>
<td>( i = i^C )</td>
<td>0</td>
<td>( z/\gamma_{A} )</td>
<td>( k' &gt; 0 \in \Omega(k) )</td>
</tr>
</tbody>
</table>
Model Validation I

Investment Age Distribution

Comparison between the empirical and the model-based Investment Age distribution.
MODEL VALIDATION II
ESTIMATED EFFECTS WITH SIMULATED DATA

Investment Age and Productivity

Data
Model

Regressions with actual versus simulated data.
Technology Shocks

- Stochastic technological frontier

  - $\gamma_{A,t}$ follows an AR1 process
  
  - Trend shocks
  
  - Model boils down to the RBC when $\xi = 0$
## Technology Shocks

### Business Cycle Moments

<table>
<thead>
<tr>
<th></th>
<th>ΔGDP</th>
<th>ΔC</th>
<th>ΔI</th>
<th>LABOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RBC Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_X$</td>
<td>0.28%</td>
<td>0.27%</td>
<td>3.57%</td>
<td>0.38%</td>
</tr>
<tr>
<td><strong>VINTAGE Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_X$</td>
<td>0.42%</td>
<td>0.22%</td>
<td>4.37%</td>
<td>0.41%</td>
</tr>
</tbody>
</table>

**Notes:** Each entry represents the volatility of the respective variable. Δ we indicate the growth rate. C, I and L refer to consumption, investment, and labor, respectively.
FROM INVESTMENT TO PRODUCTIVITY

<table>
<thead>
<tr>
<th>Years</th>
<th>Investment</th>
<th>Labor productivity</th>
<th>TFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995-2007</td>
<td>3.2%</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>2007-2013</td>
<td>-4.6%</td>
<td>-0.9%</td>
<td>-0.9%</td>
</tr>
<tr>
<td>2013-2017</td>
<td>1.7%</td>
<td>0.9%</td>
<td>0.6%</td>
</tr>
</tbody>
</table>

Note: all figures are averages of yearly growth rates.

A prolonged fall in investment negatively affects productivity:

1. temporarily (cyclical component of TFP)
2. maybe also structurally (trend TFP)