AGGREGATE DYNAMICS AND MICROECONOMIC HETEROGENEITY: THE ROLE OF VINTAGE TECHNOLOGY

Giuseppe Fiori
Board of Governors

Filippo Scoccianti
Bank of Italy

December 3, 2019

FINPRO Workshop

DISCLAIMER

The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System (or of any other person associated with the Federal Reserve System) or Bank of Italy.

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**

◂ Investment and Productivity Stats

This Paper

Bottom-Up Approach

- **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

THIS PAPER

RESULTS

- **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 $1/3$ 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 $\sim$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**

ik computation More data

Vintage Effects in the Data

Empirical Specification

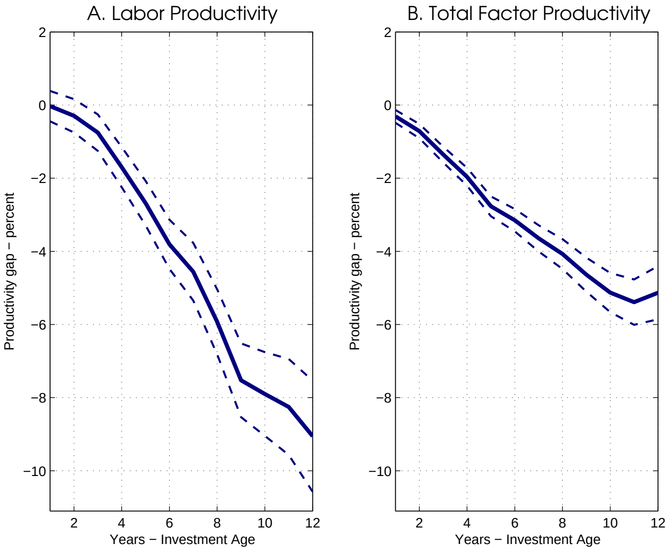
$$log(Productivity_{f,t}) = \alpha + \sum_{j=1}^{12+} \beta_j Inv.Age_{j,f,t} + Controls_{f,t} + \epsilon_{f,t}$$

- **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

Investment Age Productivity Measures

Vintage Effects in the Data

Estimated β_j's



Ruling Out Confounding Factors

- **Results not driven by**
  - Idiosyncratic shocks

    Estimate AR productivity process: ~ 0.4
  - News shocks

    Include expected 2-year ahead growth rate of revenues: β_j's unchanged
  - Innovative firms

    Sample split between firms with high- and low-intensity in intangible capital: β_j's not different

- **Extensive robustness analysis**
  - Spikes definition, sample composition, sectoral analysis

Sectoral Evidence

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, ε, k)**
  - z - permanent productivity vintage
  - ε - 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 γ_A

- **Firms face a non-convex adoption cost ξ**

  ξ 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 $k^* \in \mathbf{R}_+$

- **If firms do not pay the adoption cost (next period)**:
  - Keep current vintage z

    distance from the technological frontier increases at a gross rate γ_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

	Inaction	Positive Spikes	Negative Spikes	Positive Investment	Negative Investment
Data	34.19%	18.81%	3.11%	59.81%	6.00%
Model	36.25%	18.32%	0.15%	60.58%	3.17%

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: $ik \leq 0.05$.

Go Back Go Back

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**: $(1+\lambda_t)i_{f,t}$

  λ_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 λ_t: $Inv.Age_0$ drops as in 2012

Aggregate Shocks

Aggregate Dynamics

Financial Shock

	GDP RBC	GDP VINTAGE	Investment RBC	Investment VINTAGE
Impact	0.00%	0.00%	-4.87%	-4.48%
Period 1	-0.19%	-0.60%	-3.60%	-3.39%
Period 2	-0.31%	-0.85%	-2.66%	-2.83%
Period 3	-0.42%	-0.77%	-1.95%	-2.31%
Period 4	-0.38%	-0.68%	-1.43%	-1.57%

Notes: Each entry is in percent relative from trend values.

Aggregate TFP Response

Financial Shock

	TFP DATA	TFP VINTAGE	TFP RBC
2012	-1.27%	-0.42%	0.00%
2013	-1.08%	-0.57%	0.00%
2014	-1.15%	-0.31%	0.00%
2015	-0.89%	-0.26%	0.00%

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**:
  - Product-level and firm-level: Gordon (AER, 1990), Power (RES, 1998), Sakellaris (JME, 1997)
  - Aggregate-level: Greenwood, Hercowitz, Krusell (AER, 1997), Hulten (1992), Wolff (AER, 1986)
- **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 (ik) as Bloom (2009):
  - $ik_{f,t} = \frac{I_{f,t}}{0.5(K_{f,t-1}+K_{f,t})}$
  - $I_{f,t}$ investment net of disinvestment
  - $I_{f,t}$ includes tangible and intangible investment
  - $K_{f,t}$ capital computed using Perpetual Inventory Method

Go Back

Distribution of Investment Rates

Lumpiness in Capital Accumulation

Investment Rate	Share in Data Set	Share of Investment
$ik \geq 0.20$	18.81%	61.04%
$-0.05 \leq ik \leq 0.05$	34.19%	2.37%
$ik \leq -0.20$	3.11%	-1.74%

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

Go Back

Productivity Measures

- **Labor productivity** $(lp_{f,t})$:
  - $log(lp_{f,t}) = log(v_{f,t}) - log(n_{f,t})$
  - $v_{f,t}$ 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)

Go Back

Sample Statistics

Statistics on Firm's Age

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

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

◂ Dataset

Distribution of Investment Rates

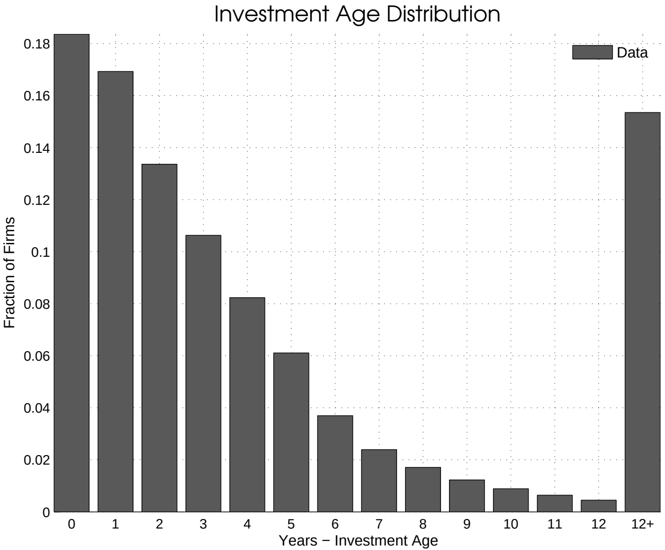
Lumpiness in Capital Accumulation

Investment Rate	Share in Data Set	Share of Output	Share of Investment	Share of Employment
$ik \geq 0.20$	18.81%	26.77%	61.04%	27.52%
$-0.05 \leq ik \leq 0.05$	34.19%	25.67%	2.37%	27.01%
$ik \leq -0.20$	3.11%	1.98%	-1.74%	2.14%

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

Go back

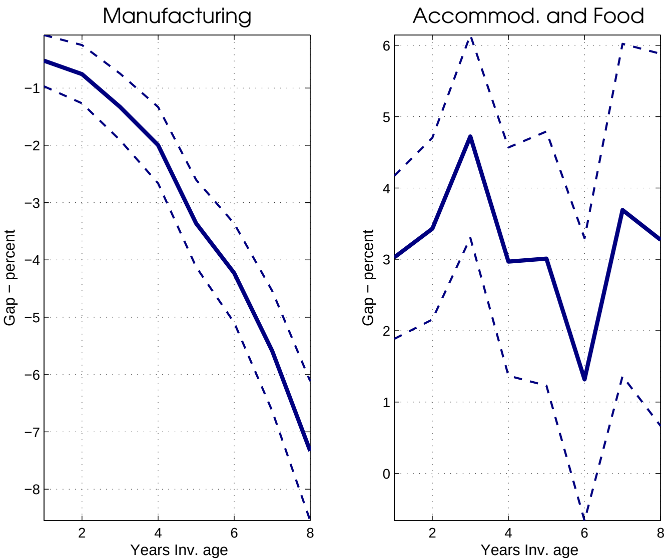
DATA



Investment Age Distribution
Data
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Fraction of Firms
0
1
2
3
4
5
6
7
8
9
10
11
12
12+
Years − Investment Age

Go back

ESTIMATED β_j'S - SECTORAL EVIDENCE



Go back

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

Go back

Financial Shock

Properties of the Stochastic Process

- Financial cost: $(1+\lambda_t)i_{f,t}$

  λ_t follows as AR(1) process

- Process is temporary but persistent

– $\lambda_t = \rho\lambda_{t-1} + \varepsilon_{\lambda_t}$

– In steady state λ_t=0

Go Back

Theoretical Framework

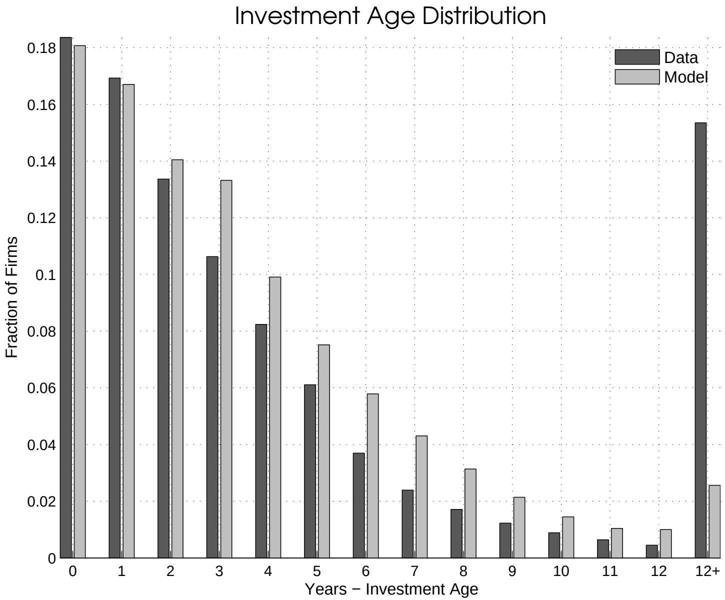
Summary

Firm's Adoption and Investment Decision

	Fixed Cost Paid	Future Technology z'	Future Capital k'	Total Investment
$i \neq 0$	$\xi + \delta_S k$	z_0'	$k' > 0 \in \mathbf{R}_+$	$\gamma k' - (1 - \delta - \delta_S)k$
$i = i^C$	0	z/γ_A	$k' > 0 \in \Omega(k)$	$\gamma k' - (1 - \delta)k$

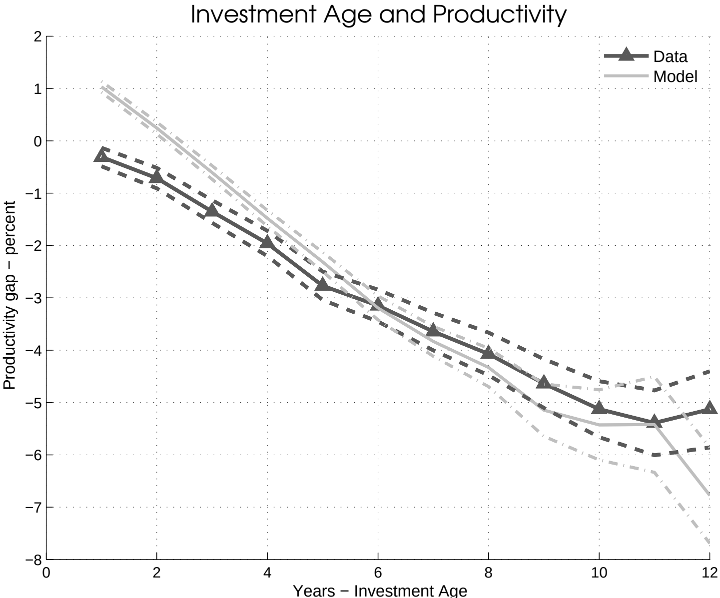
Go Back

Model Validation I



Model Validation II

Estimated Effects with Simulated Data



Technology Shocks

- **Stochastic technological frontier**
  - $\gamma_{A,t}$ follows an AR1 process
  - Trend shocks
  - Model boils down to the RBC when $\xi = 0$

Go Back

Technology Shocks

Business Cycle Moments

	ΔGDP	ΔC	ΔI	LABOR
RBC Model				
σ_X	0.28%	0.27%	3.57%	0.38%
VINTAGE Model				
σ_X	0.42%	0.22%	4.37%	0.41%

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.

Go Back

From Investment to Productivity

Years	Investment	Labor productivity	TFP
1995-2007	3.2%	0.3%	0.2%
2007-2013	-4.6%	-0.9%	-0.9%
2013-2017	1.7%	0.9%	0.6%

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*)

Go Back