Credit and Endogenous Growth in an Agent-Based Model with Locally Interacting Agents

Panaro D.\textsuperscript{1}, Mastrorillo M.\textsuperscript{2}, Ferraresi T.\textsuperscript{1}, Fagiolo G.\textsuperscript{3} and Roventini A.\textsuperscript{3,4,5,6}

\textsuperscript{1}University of Pisa, \textsuperscript{2}University of Foggia, \textsuperscript{3}Sant’Anna School of Advanced Studies, \textsuperscript{4}University Paris Ouest Nanterre La Defense, \textsuperscript{5}OFCE, Sciences Po, \textsuperscript{6}University of Verona

2012 Latsis Symposium Satellite Workshop
Sept. 11\textsuperscript{th}, ETH Zurich
Motivations

- Research questions:
  1. Does finance promote or hinder long-run economic growth?
  2. Do alternative credit-market structures lead to more or less growth?
  3. Credit markets and the trade off between growth and volatility

- Mainstream literature (Aghion and Howitt [2009]; Levine [2005]; Freixas and Rochet [2008]):
  1. Finance appears to foster growth
  2. No deep investigation of the relation between different markets structures and growth
  3. Mixed results on the growth-volatility

- Agent-based models (ABMs) provide a promising framework to address the link between finance and growth (interactions, bounded rationality, disequilibrium; e.g. Dosi, Fagiolo, Napoletano and Roventini [2012])
Aims

- Extend the "island" (endogenous-growth) model in Fagiolo and Dosi (2003) to allow for credit;
- Analyzing whether the exploration-exploitation trade-off is still present in the credit-augmented "island" model;
- Investigating how credit markets affect firm innovation and imitation patterns and in turn long-run growth;
- Studying how different hypotheses about credit market structure, attitudes towards risk and credit constraints affect output growth and volatility;
Related Literature

- **Early contributions:**
  - Gurley and Shaw (1955); Goldsmith (1969)

- **"Classical" literature:**
  - Greenwood and Jovanovic (1990); King and Levine (1993); Galor and Zeira (1993); Aghion, Banerjee and Piketty (1999)

- **Multisector Schumpeterian endogenous growth models with financial constraints (Aghion and Howitt [2009], ch. 6):**
  - Ex ante screening
  - Ex post monitoring and moral hazard
  - Inequality
  - Productivity differences

- **Agent-based models of growth and business cycles:**
  - Dosi, Fagiolo, Napoletano and Roventini (2012);
  - Gaffeo, Delli Gatti, Gallegati, Desiderio and Cirillo (2011)
Basic Model: The island model (Fagiolo and Dosi, 2003)

- Endogenous growth model in which heterogeneous firms are modeled as boundedly-rational, locally interacting agents.
- Technologies ("islands") are located in an open-ended technological space (2-dim lattice).
- Each node of the lattice can be empty or contain an island.
- Firms may produce a homogeneous good (GDP), imitate other technologies or move across the technological space (explore).
- Firms constantly look for better technologies under strong uncertainty and direct spillovers.
What firms do

- **Production:** agents (miners) settle on an island and produce the homogenous good according to:
  \[ q_{j,t}^i = s(x_j, y_j) \left[ m_t(x_j, y_j) \right]^{\alpha-1} \]

- **Exploration (R&D activity):** agents become explorers with probability \( \varepsilon \) and they stop when they find an "island".

- **Innovation:** the productivity of a newly discovered island is:
  \[ s^* = s(x^*, y^*) = (1 + W)(|x^*| + |y^*| + \varphi q_{i,t} + \xi) \]

- **Imitation:** Each island \( j \) sends a signal about its productivity. The agents around can receive the signal with probability proportional to the intensity of the signal and decreasing with source-receiver distance:
  \[ \omega_t(x_j, y_j; x, y) = \frac{m_t(x_j, y_j)}{m_t} \exp\{-\rho[|x - x_j| + |y - y_j|]\}, \rho \geq 0, \]
  and decide whether to become imitators.
Beyond the basic model I

- Introduction of consumption and savings
- Introduction of costs of R&D and imitation activities
- Introduction of credit market with different specifications about credit-market structure, credit constraints and banks’ attitudes towards risk
- In particular, to account for heterogeneity of credit markets, three different versions of the model have been explored:
  1. Autarchy
  2. Many saving banks (one for each island)
  3. Monopolistic bank
Beyond the basic model II

- At each time $t$, all miners consume a fraction $c$ of their own output $q_{j,t}$
- Banks collect miners savings
- The cost of sailing activities (R&D and imitation) is $s_j m_{t,j}^{\eta+(\alpha-1)}$, where $\eta$ governs agglomeration economies, i.e. how the number of miners on the island affects the cost of exploration/imitation
- Agents finance their exploration activities using their own savings or (if necessary) apply for a loan to the bank
- Under different pecking-order rules, the bank allocates credit to agents:
  - the imitation projects are risk-free and the amount of loan needed is known
  - Innovation is uncertain because they can fail during the research. The expected research time for new island is: $\tau = 1/\pi$
- When and if the agents reach the (imitated or new) island, they pay back their debts
We employ empirical evidence to microfound bank decision rules, in particular:

1. Theoretical justification of credit multiplier (Aghion, Banerjee and Piketty [1999])
2. Empirical evidence about credit constraints and R&D decisions (Hall [2002])
Bank decisions rules II

- At time $t$, bank deposits are equal to:

$$L_{j,t} = \sum_{i \in J_t} (1 - c) y_{i,t}^j + \sum_{i \in J_t} R_{i,t}^j$$

where $y_{i,t}^j$ is agent $i$ output at time $t$, $R_{i,t}^j$ is the amount of agent $i$ savings and $J_t$ is the set of agents currently on island $j$.

- Banks lend to each borrower up to

$$(1 - \Delta) y_{i,t}^j$$

where $(1 - \Delta)$ is a credit multiplier à la Aghion, Banerjee and Piketty (1999).

- In line with the credit multiplier, banks hold precautionary reserves.
Bank decisions rules III

- Banks employ different pecking-order rules
- Debtors must refund their loans plus an interest rate
- If an explorer runs out of resources during the exploration, she goes bankrupt and she is replaced by a new agent on the island from which she started and the bank loses the capital lent
- If a bank goes bankrupt, the agents on the island divide equally the savings left and a new bank is immediately recreated
Financial and R&D scenarios:

- We compare three different financial setups:
  1. Autarchy
  2. Many saving banks (one for each island)
  3. Monopolistic bank

- We analyze three different pecking order rules:
  1. Risk-averse banks prefer imitator to explorer
  2. Risk-lover banks finance before explorers then imitators in decreasing order according to their savings
  3. Risk-neutral banks finance agents according to their savings

- We compare two different R&D setups for different returns-to-scale ($\alpha$) regimes:
  1. Exploration-oriented (low R&D costs and high willingness to explore)
  2. Imitation-oriented (high R&D costs and low willingness to explore)
Parameters:

- \( N = 100 \)  
  number of agents

- \( T = 1000 \)  
  length of simulations

- \( \alpha = 1.5, 2, 2.5 \)  
  returns to scale

- \( \epsilon = 0.1, 0.4 \)  
  willingness to explore

- \( \eta = -0.5, 0.5 \)  
  agglomeration economies

- \( \rho = 0.01 \)  
  degree of local interactions

- \( \varphi = 0.4 \)  
  degree of knowledge accumulation

- \( \lambda = 5 \)  
  likelihood of radical innovation

- \( \pi = 0.4 \)  
  technological opportunities

- \( s = 0.3 \)  
  propensity to save

- \( 1 - \Delta = 3 \)  
  credit multiplier

- \( \chi = 0.3 \)  
  precautionary reserves coefficient

- \( \mu = 0.01; \nu = 0.05 \)  
  imitators and explorers interest rates
Preliminary results I

Does the exploitation-exploration trade-off emerge also in the credit-augmented "island model"?

- As in the basic "island" model, also in the credit-augmented model there exists an "optimal" level of exploration.

Note: Many saving banks scenario with risk-neutral banks; $\alpha = 2, \eta = -0.1$. 95% confidence MC intervals shown.
Preliminary results II

Does finance promote long-run economic growth?

- Setups with banks perform better than 'autarchy' set up
- Growth-rate differences between bank and autarchy scenarios are significantly positive under different parameterizations

<table>
<thead>
<tr>
<th>$(\alpha, \epsilon, \eta)$</th>
<th>$agr_{many} - agr_{aut}$</th>
<th>$agr_1 - agr_{aut}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(1.5, 0.1, -0.1)$</td>
<td>0.0106**</td>
<td>0.0050</td>
</tr>
<tr>
<td>$(1.5, 0.4, 0.1)$</td>
<td>0.0044</td>
<td>0.0434**</td>
</tr>
<tr>
<td>$(2.0, 0.1, -0.1)$</td>
<td>0.0734**</td>
<td>0.0886**</td>
</tr>
<tr>
<td>$(2.0, 0.4, 0.1)$</td>
<td>0.0396**</td>
<td>0.0283**</td>
</tr>
<tr>
<td>$(2.5, 0.1, -0.1)$</td>
<td>0.0887**</td>
<td>0.0831**</td>
</tr>
<tr>
<td>$(2.5, 0.4, 0.1)$</td>
<td>0.0233**</td>
<td>-0.0215</td>
</tr>
</tbody>
</table>

Note: **= significant at 5% using Montecarlo standard errors

- Results are robust to the risk-attitude of banks
Preliminary results III

Does higher average long-run growth imply more volatility?
► Strong positive correlation between growth and volatility

Note: MC AGR; colors represent different parameterizations for \((\alpha, \epsilon, \eta)\) within each scenario
Preliminary results IV

Does credit-market structure affect growth?

- In general, long-run average-growth rates are not statistically different in the "many saving banks" (many) and "monopolistic bank" (1) scenarios.

<table>
<thead>
<tr>
<th>$(\alpha, \epsilon, \eta)$</th>
<th>Adverse Banks $agr_1 - agr_{many}$</th>
<th>Neutral Banks $agr_1 - agr_{many}$</th>
<th>Risky Banks $agr_1 - agr_{many}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1.5, 0.1, -0.1)</td>
<td>0.0004</td>
<td>-0.0084</td>
<td>-0.0056</td>
</tr>
<tr>
<td>(1.5, 0.4, 0.1)</td>
<td>0.0477**</td>
<td>0.0215**</td>
<td>0.0390**</td>
</tr>
<tr>
<td>(2.0, 1, -0.1)</td>
<td>-0.0117</td>
<td>-0.0154</td>
<td>0.0152</td>
</tr>
<tr>
<td>(2.0, 0.4, 0.1)</td>
<td>0.0028</td>
<td>0.0117</td>
<td>-0.0113</td>
</tr>
<tr>
<td>(2.5, 0.1, -0.1)</td>
<td>-0.0433</td>
<td>-0.0394</td>
<td>-0.0056</td>
</tr>
<tr>
<td>(2.5, 0.4, 0.1)</td>
<td>-0.0481</td>
<td>-0.0661**</td>
<td>-0.0448**</td>
</tr>
</tbody>
</table>

- Significant differences do not appear to be systematic.
- Exploring more realistic credit-market structures...
Further Work

- Exploring setups similar to those studied in Diamond (1984), wherein banks are given the choice to monitor R&D activity to avoid free-rider problems
- Allowing for bank heterogeneity in their pecking order rules
- Introducing time lag for the creation of a new bank after a bankruptcy episode
- Introducing bankruptcy costs as in Greenwald and Stiglitz (1993)