Navigating Climate-Induced Systemic Risk: Insights from an Agent-based Integrated Assessment Model

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Introduction & Motivation

Motivation

- Financial crisis, sudden stops, supply-chain disruptions, **climate-induced damages** highlight the perils of systemic risk build up in robust-yet-fragile financial systems (Haldane, 2013)
- Climate change is a *macro-financial* threat: physical shocks deteriorate balance sheets, and propagate across economic and financial networks, possibly reinforcing.
- Despite efforts to reduce CO2 emissions, lack of strong commitment has raised concerns that climate targets will not be met in time (IPCC, 2023).
- Prudential frameworks must enhance resilience to *systemic* effects from physical risk, while avoiding unintended *transition-risk* consequences (European Systemic Risk Board., 2023).
- **Challenge:** Can micro- and macro-prudential frameworks contain financial instability in a warming world?

Our Contribution

- Extend the established *Schumpeter meeting Keynes* Agent-based model (Dosi et al., 2010a, 2013a, 2015a)
- with a financial network explicitly modeled (Pallante et al., 2025)
- into the *Dystopian Schumpeter meeting Keynes* Agent-based Integrated assessment model (Lamperti et al., 2018a, 2019, 2021)
- Test the resilience of a Basel-III like framework coupled with a "network-consistent" micro-prudential tool *(Barucca et al., 2020a)* under increasing physical climate risk.

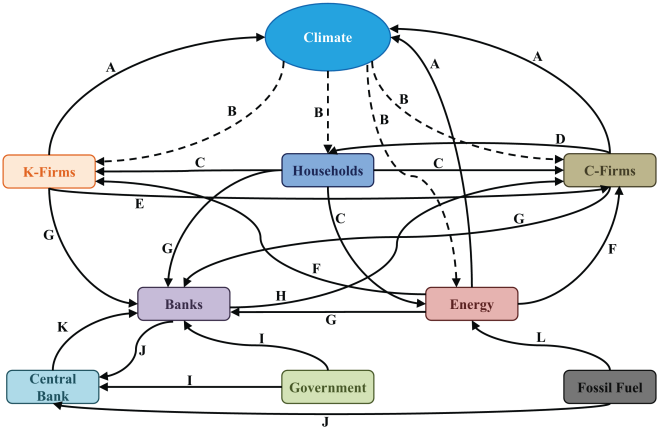
Literature Highlights

- **Channels of contagion**
  - Balance-sheet contagion (Allen and Gale, 2000); Financial-to-real (Laeven and Valencia, 2012; Gross et al., 2018); Real-to-financial (Battiston et al., 2007)
- **Interbank Networks**:
  - Initial focus on direct transactions (Angelini et al., 1996; Iori et al., 2008; Gai et al., 2011)
  - Recent shift towards multi-layer perspective (Huang et al., 2013; Luu et al., 2021; Aldasoro et al., 2022)
- **Agent-Based Models (ABMs)**:
  - Suited for modeling interactions among heterogeneous agents (LeBaron and Tesfatsion, 2008; Farmer and Foley, 2009).
  - Study macro behaviors as emergent phenomena and suitable laboratory for policy testing (Dosi and Roventini, 2019; Axtell and Farmer, 2025; Borsos et al., 2025).
- **Macro-financial climate risk**
  - Physical and Transition risk undermine economic and financial stability, with non-trivial self-reinforcing mechanisms (Battiston et al., 2017; Monasterolo, 2020; Roncoroni et al., 2021; Semieniuk et al., 2021; Lamperti and Roventini, 2022)

The Model

The K+S model with an interbank network

More detail

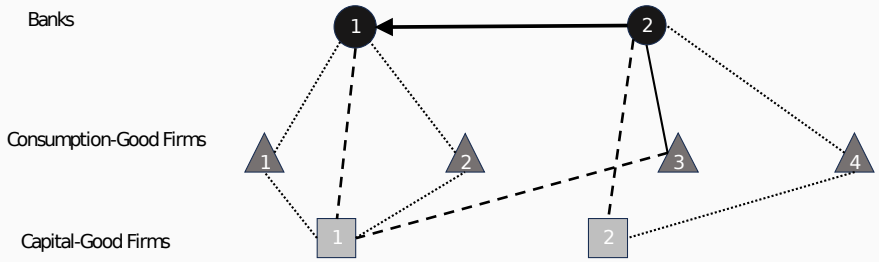


Core K+S Model (Dosi et al., 2010b, 2013b, 2015b; Lamperti et al., 2018b; Pallante et al., 2025)

- Heterogeneous capital-good and consumption-good firms.
- Endogenous technical change.
- Keynesian demand-driven business cycles.
- Boundedly rational agents adopting simple heuristics.
- Banks grant loans, hold bonds and interbank claims
- Climate-box interacts with the economic system

The DSK model with an interbank network

- **Endogenous Interbank Network**
  - Banks manage payments between firms (C-good firms buying machines from K-good firms).
  - This creates an endogenous network of interbank linkages.



Interbank Network Emergence

Link Creation

- If a consumption-good firm (client of Bank A) pays a capital-good firm (client of Bank B), a temporary link A $\rightarrow$ B occurs.

Link Disappearance

- Consumption-good firm collect enough funds to repay the external debt.
- The bank can clear the position immediately

Link Persistence

- Consumption-good firm **does not** collect enough funds
- External debt cannot be repaid entirely
- The loss corresponding to the payment for the machinery is an interbank position that cannot be cleared immediately, unless banks use their own reserves.

Interbank Network Evolution

Link Destruction

- Creditor bank k decides to close/rollover interbank asset towards bank b
- using a relatively simple heuristic that involves the opportunity cost of holding the interbank asset for another period.

The creditor bank will close the interbank position if

- default probability of the borrower ($p_{b,t}$) is too large to compensate the spread between the returns on the interbank position (r_t^{IB}) and on the central bank deposits (r_t^{res})
- the creditor bank k is relatively more exposed on the interbank network.

More details

Bank Equity & Credit Supply

Taking into account interbank exposures, Bank Equity reads:

$$E_{k,t} = \Theta_{k,t} + IB^{A}_{k,t} - IB^{L}_{k,t} = \Theta_{k,t} + \sum_{b=1}^{B} \ell_{k,b,t} - \sum_{b=1}^{B} \ell_{b,k,t} \tag{1}$$

- $\Theta_{k,t}$: Net external assets of bank k
- We assume that credit Supply $TC_{k,t}$ is determined as follows:

$$TC_{k,t} = \frac{E_{k,t-1}}{\tau^{B}(1 + CCB_t + \beta Bda_{k,t-1})} \tag{2}$$

- Capital requirements τ^{B}
- Counter-cyclical capital buffers CCB_t
- Additional prudential buffer based on a bank-fragility indicator BDa

Bank Fragility depends on the relative importance of NPL (BadDebt)

$$Bda_{k,t} = \frac{\gamma_{BD} BadDebt_{k,t}}{Ext.Assets + \sum_{b=1}^{B} \ell_{k,b,t}} \tag{3}$$

Network Valuation (NEVA, Barucca et al., 2020b)

- Network Valuation used as a micro-prudential tool for valuing interbank claims $IB^{A}_{k,t}$.
- Generalizing Eisenberg and Noe (2001)'s results, NEVA provides a balance-sheet consistent clearing vector of financial network inter-dependencies that minimizes the losses due to contagion
- **Micro-prudential Policy scope**: institutions perform collectively the valuation
- **Feasibility**: banks are assumed to need knowledge of their own interbank assets only.
- Replaces the historical book valuation

$$E^{NEVA}_{k,t} = \Theta_{k,t} + IB^{A,NEVA}_{k,t} - IB^{L}_{k,t} = \Theta_{k,t} + \sum_{b=1}^{B} \ell_{k,b,t} V^{NEVA}_{k,b,t} - \sum_{b=1}^{B} \ell_{b,k,t} \tag{4}$$

Network Valuation implementation

$$E_{k,t}^{NEVA} = \Theta_{k,t} + \sum_{b=1}^{B} \ell_{k,b,t} V_{k,b,t}^{NEVA} - \sum_{b=1}^{B} \ell_{b,k,t} = \Theta_{k,t} + IB_{k,t}^{A,NEVA} - IB_{k,t}^{L} \tag{5}$$

- $V_{k,b,t}^{NEVA}$ is the Network Valuation vector of bank k towards other b banks.
- $V_{k,b,t}^{NEVA}$ implies an endogenously determined probability of default $p_{b,t}^{NEVA}$ $\forall k$ (counterparty risk)

Scenario	Probability of default $p_{b,t}$	Valuation of Interbank Claims
BASE	exogenous	✗
NEVA	$p_{b,t}^{NEVA}$	✗
NEVA^2	$p_{b,t}^{NEVA}$	$\sum_{b=1}^{B} \ell_{k,b,t} V_{k,b,t}^{NEVA}$

Table 1: Interbank valuation scenarios.

Climate module at a Glance

Physical core (simple climate box)

- *Carbon cycle*: biosphere uptake via Net Primary Production (NPP) and ocean exchange. Climate-box as in Lamperti et al. (2018a), drawn from Sterman et al. (2012)
- *Temperatures*: two-layer energy balance; radiative forcing; dynamics from the exchange of mixed/deep layers.

Emissions link

- Emissions are directly generated by the *endogenous* energy sector (dirty vs. green technologies); technology draws affect efficiency/emission intensity

Validation / benchmarks

- Baseline *industrial* CO_2 trajectories and Temperature Anomalies in line with a *Hot house world* / *Too little, too late* NGFS Long-term Climate Scenarios assuming a late and uncontrolled transition, where global efforts are insufficient to halt significant global warming.

Timeline of Events

1. Policy variables (capital requirement, tax rate, CB interest rate, etc.) are fixed.
2. Banks determine their credity supply
3. Capital-good firms perform R&D, discover new products/more efficient production techniques. Imitation takes place.
4. Production plans are undertaken.
5. Consumption good firms receive the "brochures" of machineries produced by upstream firms and buy the most convenient. **Banks settle the payments**.
6. *Firms in both sectors compute their profits. If profits are positive, firms pay back their loans to their bank and deposit their net savings, if any.*
7. *If consumption-good firms does not pay back the loan, banks involved in the payment system have an open interbank position.*
8. *Banks evaluate their interbank exposures via Network Evaluation and decide whether to close their interbank claims.*
9. Profits are collected and taxed. Under the NEVA algorithm, if banks are still largely exposed to contagion risk, they would adjust their leverage decision, so to constrain the credit supply in the following period.
10. Entry and exit take places.
11. Machines ordered at the beginning of the period are delivered and become part of the capital stock at time $t + 1$.
12. Aggregate variables are calculated.
13. **Climate Box is updated and climate-induced damages may occurr**

Validation - Stylized facts replication

- **Micro/Macro empirical regularities**: Firm size distribution, Lumpy investment rates, business cycle dynamic cross-correlations, low unemployment, stable inflation (Dosi et al., 2010a; Lamperti et al., 2018a).
- **Financial Aggregates**: dynamic cross-correlations. Higher growth & volatility in financial variables vs. real variables (Jakab and Kumhof, 2015).
- **Bank Balance Sheets**:
  - Debt highly elastic to assets; Equity inelastic. (Adrian et al., 2013)
- **Financial Network Properties**
  - Disassortativity, core-periphery structure, relatively low density (Soramäki et al., 2007; Cocco et al., 2009; Alves et al., 2013; Aldasoro and Alves, 2018)
  - Centrality-size relation (large banks more central, net borrowers). (Craig and von Peter, 2014; Fricke and Lux, 2015; Müller, 2006; Liu et al., 2020)

Results

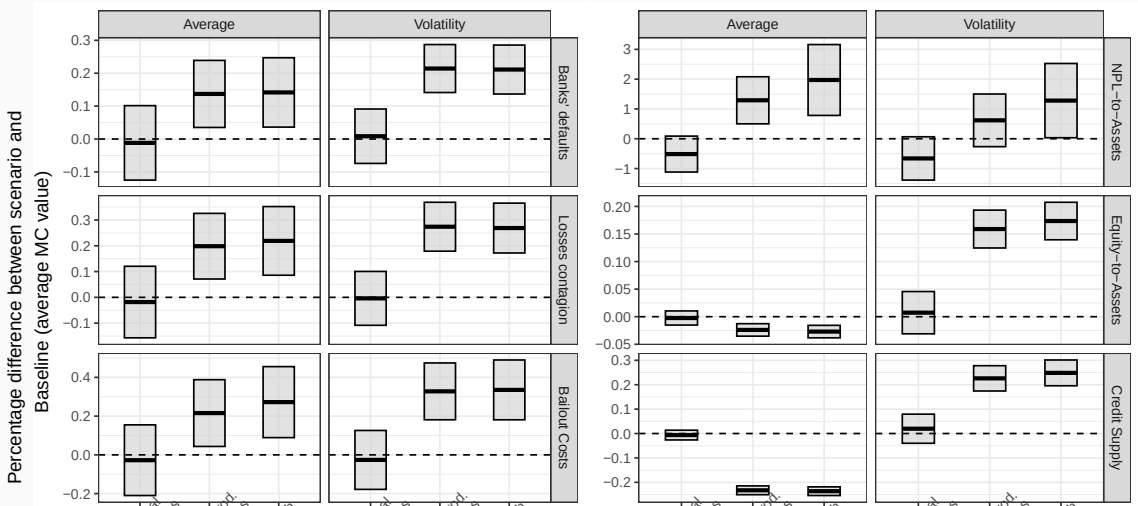
Baseline Properties

- Realistic GDP, Consumption, Investment growth rates & volatility hierarchy. Low unemployment, stable inflation.
- Functioning economy with endogenous growth and business cycles.
- Episodic episodic bank defaults with sizable interbank exposures and losses due to contagion.

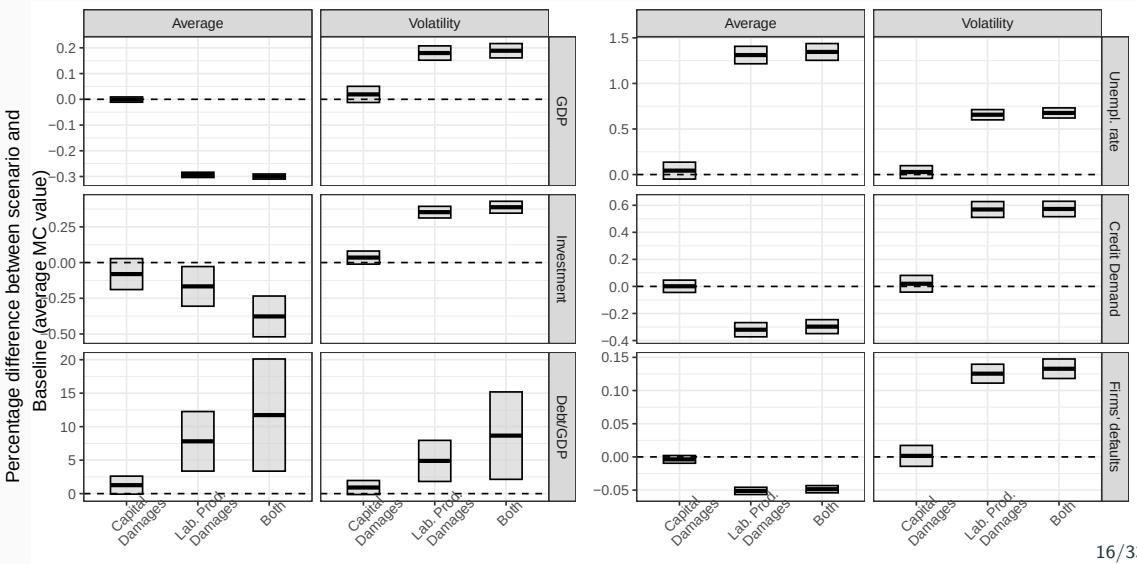
	$\bar{\mu}$	σ		$\bar{\mu}$	σ
GDP	0.013	0.001	*Bank defaults per 10y*	11.400	9.700
Consumption	0.013	0.001	*Bad Debt*	0.037	0.007
Investment	0.010	0.008	*Interbank Exposure*	0.045	0.007
Unempl. rate	0.056	0.038	*Total Credit*	0.040	0.014
Inflation	0.038	0.004	*Losses due to contagion*[a]	0.025	0.025
Firm defaults %	11.837	0.511	*Bank Equity*	0.043	0.006

[a] Interbank losses over interbank claims. 300 Monte Carlo runs.

Climate-induced systemic and macro-financial risk



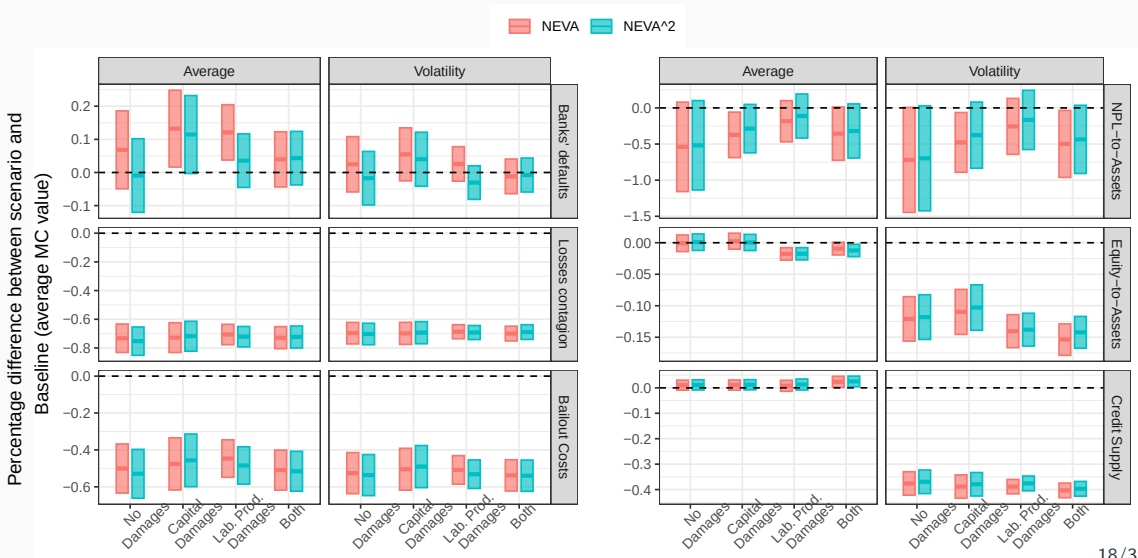
Climate-induced macroeconomic risk



Climate-induced Damages: Mechanisms

- **Capital damages:** Slightly higher turbulence as firms can renovate damaged machineries with new ones which are likely to be upgraded. However, imperfect information reverberates along the supply chain.
- **Labor damages:** economic growth is lower and demand is weaker, with $\nearrow$ unemployment. Macro outlook deteriorates with broad consequences on the financial system. Higher bank defaults trigger financial contagion.
- **Joint damages:** *self-reinforcing*— mechanism which bring systemic risk to rise; largest rise in credit/investment volatility, public costs.

Policy: NEVA under Climate Stress



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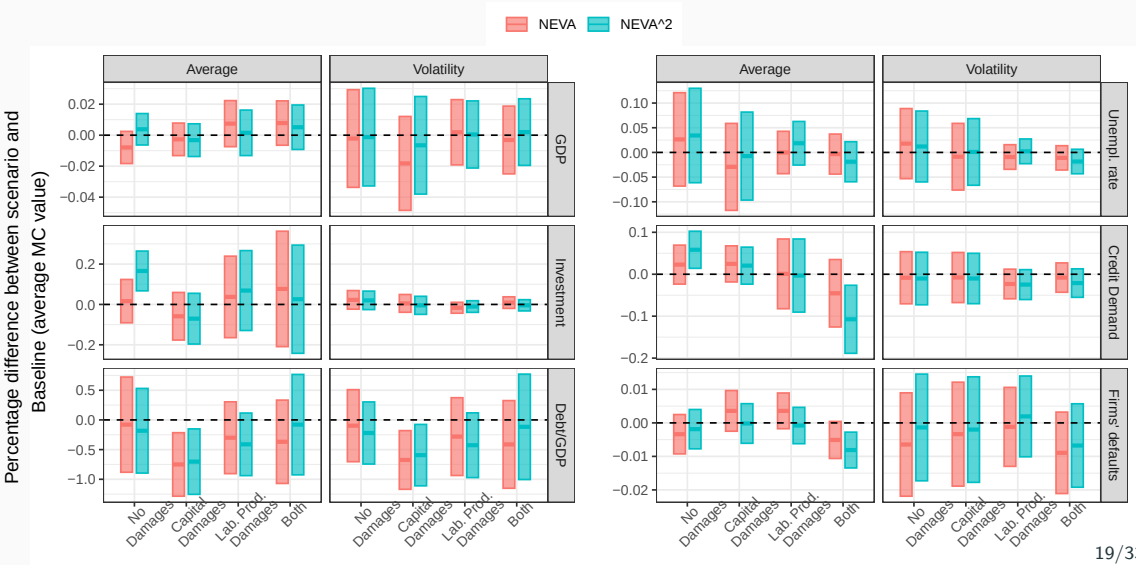

Policy: NEVA under Climate Stress

- **Systemic risk mitigated:** $\searrow$ losses due to contagion and Bailout Costs (% of overall IB exposure) across damage scenarios.
  Bank defaults not statistically lower, but volatility declines. Damages are strong and defaults still occur. Cascades don't.
- **Financial Stability:** NPL/assets down; equity/assets lower and less volatile; in joint-damage, slightly higher average credit and markedly lower credit volatility. **NEVA improves financial conditions.**
- **Real side:** no adverse average effect on GDP/investment/unemployment; suggestive lower macro volatility in joint-damages scenario, i.e., when turbulence is higher.

Concluding Remarks

Concluding Remarks — Main Messages

- **Macro–financial amplification of climate shocks.** The model reproduces a functioning economy with endogenous growth and crises, and shows that climate damages propagate from the real side to bank balance sheets and the interbank network, magnifying downturns.
- **Damage channels matter.** Capital losses mainly operate via capacity constraints; labour-productivity losses depress growth and trigger stagnation; *joint* damages are self-reinforcing, delivering the largest increase in credit and investment volatility, firm/bank defaults, and public costs.
- **Network-based prudential tool works under climate stress.** NEVA curbs contagion mechanisms: losses due to interbank cascades and bailout costs fall across all damage scenarios. Bank default *counts* do not drop dramatically, but their *volatility* does — failures occur with less system-wide cascades.
- **Financial stability improves without macroeconomic penalties.** NPL/Assets declines; Equity/Assets becomes lower and less volatile; credit supply is slightly higher in joint-damage scenarios and decisively *more stable*. Average macro outcomes (GDP, unemployment, investment) are not adversely affected; macro volatility tends to be lower in the most adverse case.

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Policy Implications

- **Complement, don't substitute:** As in Pallante et al. (2025), NEVA is a *complement* to Basel III-style macro-prudential framework, targeting contagion externalities without harming real activity. Relevant also for climate risks and climate induced instability.
- **Stress-testing and supervision:** Climate stress tests should embed network-aware valuation.
- Theoretical and policy-friendly approach to study the macro-financial consequences of
  - Multi-layered contagion
  - The network diffusion of economic and environmental shocks
    - Wealth-debt destruction
    - Climate-induced damages
    - Environmental degradation

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    - Liquidity shocks (fire-sales)
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    - supply chain disruptions
    - climate-induced damages
    - environmental degradation

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Limitations & Next Steps

- **Policy Mix:** How does NEVA interact with coordinated macro-prudential policy? (*in progress*)
- **Transition risk:** Does NEVA introduce transition risk?
- **Other Climate scenarios:** How does NEVA interact with other IPCC/NGFS scenarios (*Middle of the Road* / *(Dis)Orderly transition*).

Thanks!!

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Background Slides

Behavioral rule for closing Interbank Position

Back

Based on a simple endogenous profitability rule, the bank k closes her interbank position towards bank b when

$$\Pr\left(\text{CLOSE}_{k,b,t}=1\right)=\Pr\left(r_t^{\text{res}}-r_t^{IB}\left(1-p_t^b\right)>\xi_{k,b,t}\right) \tag{6}$$

$$\xi_{k,b,t}=\begin{cases}1 & \text{if } IB_k^A/\left(\sum_k IB_k^A\right)\leq\Upsilon\\ 0 & \text{otherwise}\end{cases} \tag{7}$$

- r^{CB}: interest rate paid on deposits at central bank facilities
- r^{IB}: interbank interest rate
- $\Upsilon\sim\mathcal{U}[m_t,n_t]$, where m_t and n_t are the min/max interbank exposures
- $p_{b,t}$: exogenous probability of default of bank b drawn from a uniformly distributed r.v. $\mathcal{U}(0,2h_0)$ whose expected value $h_0\in(0,0.5]$ can be interpreted as the haircut rate, defined as the percentage deduction from the value of the collateral required to obtain financing. $\mathcal{U}(0,2h_0)$ reflect idiosyncratic shocks to the perceived underlying risk of the interbank debtor.

Schumpeter meeting Keynes (Dosi et al., 2015b; Lamperti et al., 2018b) Back

KG-Firms (upstream)

Upstream firms invest in R&D and produce heterogeneous machineries.

CG-Firms (downstream)

Produce and invest (buy machineries) to meet expected demand.

Banks

Manage payments between agents and provide loans to CG-Firms

- are also subject to a fix capital requirement;
- base the credit decision upon the financial conditions of clients.

Central Bank

Fixes the baseline interest rate in the economy.

Government

Levies taxes on profits and pays unemployment benefits.