Adaptive Learning in Spatial Agent-Based Models for Climate Risk Assessment

A Geospatial Framework with Evolutionary Economic Agents

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The Challenge

Current climate-economy models have critical limitations:

- Static damage functions fail to capture adaptive behaviours
- Absence of spatially-distributed bottom-up heterogeneous agents in economic networks
- No cascading effects through supply chain networks

Gap: Financial institutions and companies need tools to quantify both direct and cascading climate risks

Damage estimates across functions

Study	2°C	3°C
Nordhaus & Boyer (2000)	1%	2%
Tol (2009)	1%	3%
Weitzman (2012)	1%	3%
Dell et al. (2012)	4%	22%
Tol (2014)	1%	2%
Nordhaus (2014)	1%	2%
Dietz & Stern (2015)	2%	13%
Burke et al. (2015)	8%	14%
Howard & Sterner (2017)	3%	8%
Kompas (2018)	1%	2%
Kalkuhl & Wenz (2020)	2%	5%
Kahn et al. (2021)	3%	8%
Waidelich et al. (2024)	4%	8%
Bilal & Känzig (2024)	19%	44%
Kotz et al. (2024)	14%	33%

Source: NGFS v5

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Our Solution: Spatial ABM with Evolutionary Learning

1. Geospatial Integration

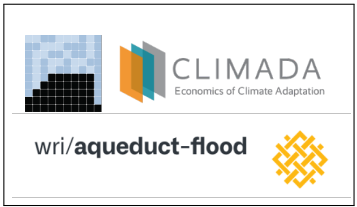
- Mesa framework + CLIMADA impacts
- Flood depth projections under RCP scenarios

2. Economic Agents

- Households: labor, consumption
- Firms: production, supply chains

3. Evolutionary Learning

- Individual adaptation + evolution
- 6 evolving strategy parameters
- Fitness-based selection



Emergent climate risk and adaptation

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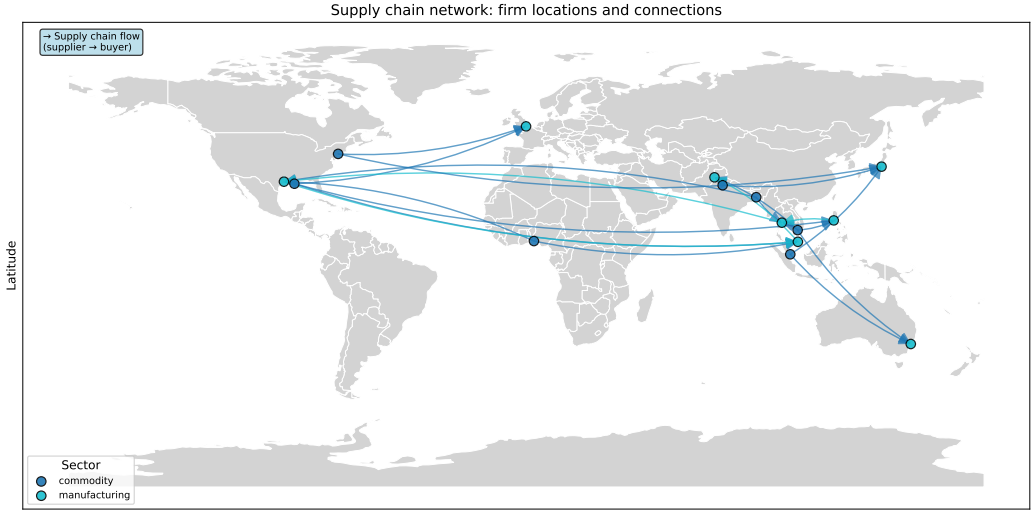
Global Supply Chain Network

15 firms in flood-prone locations with 75 households



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Dual Learning Mechanism

Individual Adaptation

Every 5 steps, each firm:

- Evaluates fitness score (growth, stability, survival, resource balance)
- Mutates strategies with adaptive rates
- Implements hill-climbing optimization

Evolutionary Replacement

Every 10 steps:

- Failed firms replaced (up to 25%)
- Fitness-weighted parent selection
- Offspring inherit + mutate strategies

6 Evolving Parameters: Labor/Input/Capital budget allocation, Risk sensitivity to regional climate events, Price/Wage adjustment sensitivity

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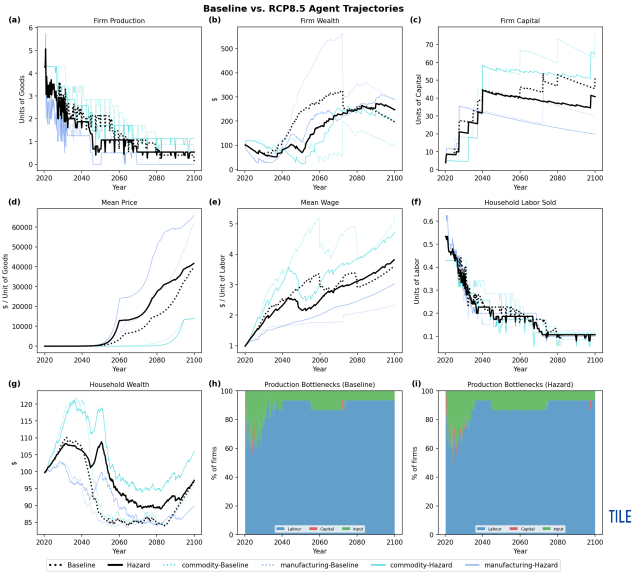
Simulation Results: Baseline Dynamics (2020-2100)

Baseline Trajectory (no hazard):

- Initial disequilibrium: production drops from 4.3 to 0.4 units/firm
- Labor supply falls 80% (0.5 $\rightarrow$ 0.1 units)
- 60-90% of firms are labor-limited
- Emergent inflation: 91% production drop, only 3% household wealth drop
- Wages rise but unemployment increases

See paper for detailed dynamics analysis



Climate Hazards & Evolutionary Adaptation

Impact of RCP8.5 Flooding

Hazards destroy inventory, reduce productivity, and damage capital

Mid-Century Crisis (2050):

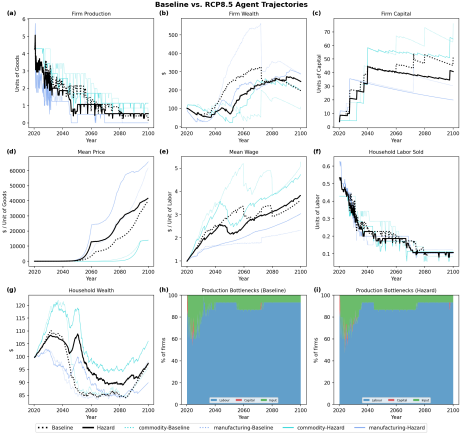
- Production: 0.7 vs 2.1 (baseline)
- More capital-limited firms (acute damage)
- 2× input-limited firms (supply chain disruption)

Evolutionary Recovery (2100):

- Production converges to baseline
- Firms pre-emptively build capital
- Adaptation via budget allocation, pricing, risk sensitivity

Systemic Effects:

- Prices 5.6% higher (supply constraints)
- Household forced savings (limited goods)
- Risks cascade to non-exposed agents



Without evolution:

production drops to 0.1 by 2100

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Practical Applications

For Financial Institutions

- Quantify portfolio climate risks beyond direct exposure
- Assess cascading risks through supply chains
- Improve capital allocation decisions
- Scenario analysis for climate stress testing

For Companies

- Evaluate adaptation strategy effectiveness
- Identify supply chain vulnerabilities
- Cost-benefit analysis of resilience investments
- Optimize climate risk management

Open-source framework: `github.com/yaramohajerani/spatial-climate-ABM`

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Conclusions

- **Network effects amplify risks:** Spatial ABM reveals how climate impacts cascade through supply chains, affecting even non-exposed agents—critical dynamics that aggregate models miss
- **Adaptation is critical:** Evolutionary learning enables resilience and recovery under climate stress
- **Systemic perspective needed:** Direct + indirect impacts must be considered for accurate risk assessment
- **Actionable framework:** Open-source tools bridge climate science and financial/operational decisions

Building climate-resilient economic systems through adaptive agent-based modeling

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Thank You

Questions?

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