Games on Networks.
Rationality, Dynamics and Interactions

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May 2007

Research Areas

- **Agent-Based Computational Economics (ACE)**
  - Methodology: Empirical validation in ACE models
  - Applications: ACE models and policy
- **Networks**
  - Game-theoretic models of strategic network formation
  - Empirical properties of economic networks
- **Industrial dynamics: models and empirical evidence**
  - Firm locational choices and the geography of industrial agglomeration
  - Firm size and growth dynamics: the role of financial constraints
- **Statistical properties of micro/macro dynamics**
  - Statistical properties of household consumption patterns
  - Statistical properties of country-output growth

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My Homepage

https://mail.sssup.it/~fagiolo/welcome.html

Background

Open Issues in Dynamic Game Theory

- **Pros and Cons**
  - Sharp and powerful models addressing strategic setups
  - Based on two over-simplifying assumptions
    - hyper-rational players w/o computational bounds
    - everyone always plays with everyone else

- **Why such assumptions?**
  - Underlying philosophy: Razor of Occam
  - Allow for analytical solutions and sharp implications
  - Extensions are very difficult (time, agents, etc.)
    - loosing analytical tractability
    - getting anything-goes type of results

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Empirical Plausibility

- **Hyper-rationality vs. experimental economics**
  - Persistent and predictable violations of rationality and decision-theory axioms
  - Bounded-rationality theory closer to reality than hyper-rationality
- **Interactions vs. real-world networks**
  - Economic agents typically interact (e.g. play games) locally
  - Examples: imitation, adoption, cooperation, . . .
  - Keywords: neighborhood, relevant others, interaction group
- **Endogenous interactions**
  - Economic agents choose whom they interact with along the process: set of opponents in the game might endogenously evolve
  - Whom one plays the game with becomes a strategic variable
  - Strategies in the game (e.g., cooperate or not) co-evolve with set of players with whom one plays the game

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A meta model (1/3)

- **Demographics and Time**
  - Agents: $I = \{1, 2, \ldots, N\}$
  - Time: $t = 1, 2, \ldots$
- **Strategic Setup**
  - 2-person stage-game payoff matrix $\Pi = \{\pi(\cdot, \cdot)\}$
  - Suppose agents play 2×2 bilateral games at each t
  - Current strategy of agent i at time t: $s_{i,t}$
  - Strategies can be repeatedly revised
  - $s_{i,t} \in \{-1, +1\}$
- **Initial Interaction Structure**
  - Agents are located on nodes of a network/graph
  - Links between agents mean playing games
  - Each agent $i \in I$ plays the game with $V_{i,0} \subseteq I$ at time $t = 0$
  - $V_{i,0}$: neighborhoods or interaction groups

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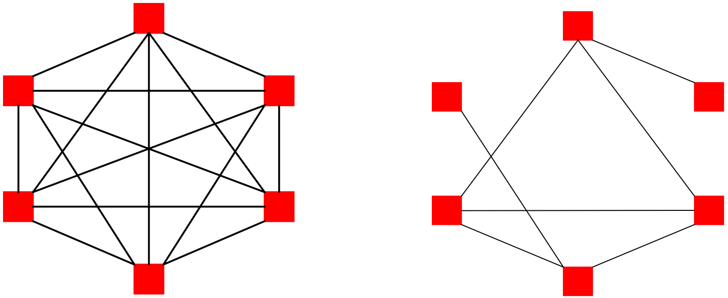
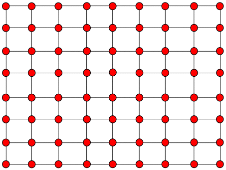
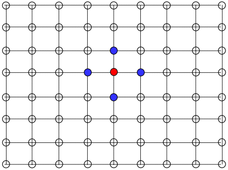
Initial Interaction Structures: Global vs. Local

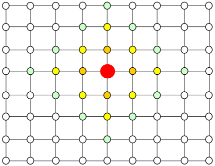


Global Local

Initial Interaction Structures: 2-Dimensional Lattices







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- **Dynamics ($t > 0$)**
  - One or more agent(s) are chosen (at random)
  - They are allowed to update their state $(s_{i,t}, V_{i,t})$
  - With probability
    - $p \in (0, 1]$ change $s_{i,t}$ given $V_{i,t}$
    - $1 - p \in [0, 1)$ change both $s_{i,t}$ and $V_{i,t}$
- **Choice**
  - Agents employ myopic best-reply rules
  - Maximizing current total payoff

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Best-Reply Rules: Examples

- **Strategy updating (given interaction structure)**

$$s_{i,t+1} = \arg\max_{s \in \{-1,+1\}} \sum_{j \in V_{i,t}} \pi(s; s_{j,t})$$

- **Strategy and interaction structure updating**

$$(s_{i,t+1}, V_{i,t+1}) = \arg\max_{(s,V) \in \{-1,+1\} \times \Gamma_t} \sum_{j \in V} \pi(s; s_{j,t})$$

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A meta model (3/3)

- **Constraining Endogenous Network Formation: Γ_t**
  - Agents always choose from the set of all possible networks
  - Agents can only add/delete one link per period
  - Enlarging/shrinking interaction window
- **We are interested in**
  - Dynamics of $\{(s_{i,t}, V_{i,t}), i \in I\}$ and statistics thereof
  - Existence and stability of equilibria (if any)
  - Equilibria: steady-states, ergodic distributions, etc.
  - Analytical solutions vs. simulations
- **Remark: Extensions of the meta-model**
  - More complicated strategic games
  - More complicated interaction setups

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Three Classes of Models

- **Bounded-Rationality Games**
  - Interaction structure frozen ($p = 1$) and global
  - Study dynamic games where agents are myopic
  - Evolutionary-games literature (Samuelson, Vega-Redondo, Young)
- **Local-Interaction Games**
  - Interaction structure frozen ($p = 1$) but local
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1. **Common issue: Equilibrium selection**
   - Can these models provide a robust equilibrium selection criterion? Cf. evolutionary games
2. **Local-Interaction Games**
   - How do different networks affect equilibrium selection?
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Applications

Related Papers

- Fagiolo, G., Valente, M. and Vriend, N. (2007), "Segregation in Networks", *Journal of Economic Behavior and Organization*, forthcoming.
- Fagiolo, G. and Valente, M. (2005), "Minority Games, Local Interactions, and Endogenous Networks", *Computational Economics*, 25:41-57.
- Fagiolo, G. (2005), "Endogenous Neighborhood Formation in a Local Coordination Model with Negative Network Externalities", *Journal of Economic Dynamics and Control*, 29: 297-319.
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- **Revisiting Schelling spatial-segregation model**
  - Standard Schelling lattice setup
  - Agents are now located on generic networks
  - Interaction structure is frozen ($p = 1$)
  - Agents employ best-reply dynamics
  - They possibly move to empty nodes where they get more utility

- **Main Question**
  - Do different network structures lead to less segregation?
  - Does segregation emerge even if the underlying interaction structure is not geographically constrained?

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Segregation in Networks (2/3)

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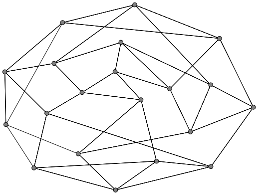

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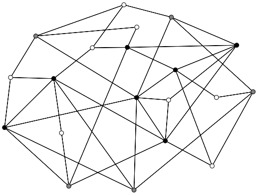
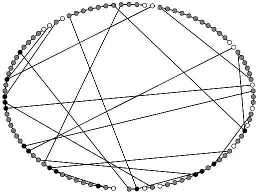
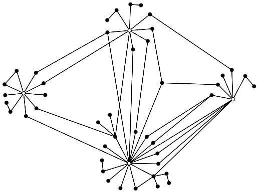


Segregation in Networks (2/3)

Small-World



Scale-Free



Segregation in Networks (3/3)

- **Main results**
  - Segregation levels are always very high
  - Network structure does not affect segregation levels
  - Schelling results are very robust!!
  - But agents do not move along paths...

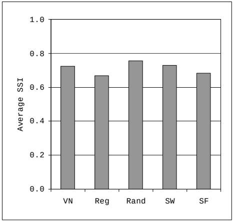


Figure 8: Average Spectral Segregation Index (SSI) v. Network Classes. Average Degree $d = 4$. Parameters: $M = 100$, $\theta = 0.3$. MC Sample Size $= 1000$.

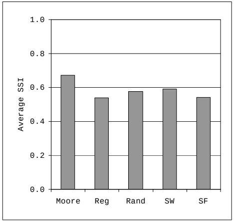


Figure 9: Average Spectral Segregation Index (SSI) v. Network Classes. Average Degree $d = 8$. Parameters: $M = 100$, $\theta = 0.3$. MC Sample Size $= 1000$.

Coordination Games with Endogenous Networks (1/3)

- **Standard** 2×2 **Symmetric Coordination Games**
  - Agents placed on 1- or 2-dimensional lattices
  - Play coordination games with their r-nearest neighbors
  - In each period agents can either:
    - Play a coordination game given current neighborhood structure; or
    - Simultaneously choose strategy and neighborhood radius (r)
  - Neighborhood adjustment is sticky and costly
  - Network externalities may become negative (congestion effects)
- **Main Questions**
  - Frozen networks: Previous results show
    - Low coordination levels
    - Risk-efficient equilibria
  - Does endogenous neighborhood adjustment favors higher coordination levels?
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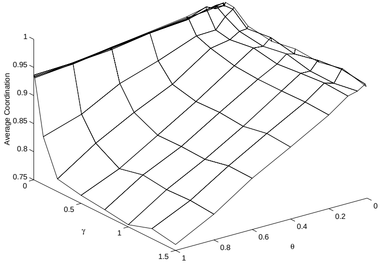
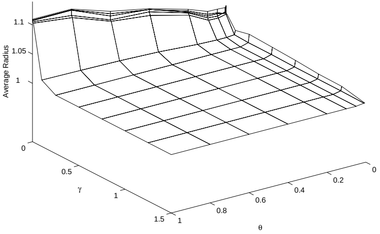
Coordination Games with Endogenous Networks (2/3)

- **Results: Coordination Levels**
  - Multiple equilibria (strategy and neighborhood structure)
  - Endogenous neighborhoods formation does have an impact on equilibrium selection
  - Higher coordination than in the “frozen interactions” case (but it must not be too fast, i.e. high *p*)



Coordination



Radius

Coordination Games with Endogenous Networks (3/3)

- **Results: Equilibrium Selection and Efficiency**
  - Risk-efficiency is confirmed to be a robust equilibrium-selection criterion

		Average Strategy			Average Radius		
$N = 51$		$c = 0.00$	$c = 1.00$	$c = 1.99$	$c = 0.00$	$c = 1.00$	$c = 1.99$
$\beta = 10^{-6}$	$\theta = 1.0$	1.00	0.18	-1.00	1.00	1.13	1.00
	$\theta = 0.1$	0.84	-0.03	-1.00	1.00	1.01	1.00
$\beta = 1.5$	$\theta = 1.0$	1.00	0.01	-1.00	1.00	1.00	1.00
	$\theta = 0.1$	1.00	-0.05	-1.00	1.00	1.00	1.00

Table 2: MC Means of Average Strategy ($\overline{s}_m$) and Average Radius when the underlying stage-game is a generic coordination game. The parameter c measures the risk-efficiency of (-1,-1). Parameter Setup: $c = 0$: (+1,+1) PE and RD; $c = 1$: (+1,+1) and (-1,-1) risk equivalent; $c = 1.99$: (-1,-1) is RD. MC Sample Size $M = 1000$.

Minority Games with Endogenous Networks (1/2)

- **Local Minority Game**
  - Agents placed on random networks
  - They care about being in the minority of their neighborhood
  - Applications: Speculation, market-entry games
  - Three setups:
    - Networks are frozen
    - Networks are frozen but link weights can be updated on the basis of past payoffs
    - Networks are endogenous: links can be both updated and deleted on the basis of past payoffs

- **Main Questions**
  - Comparing frozen vs. endogenous networks in terms of average payoffs
  - Does endogenous network allow for more efficiency?
  - Global efficiency vs. local information

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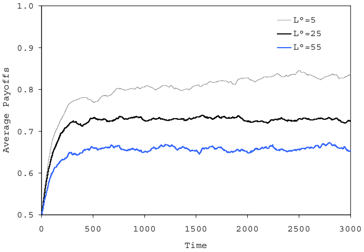
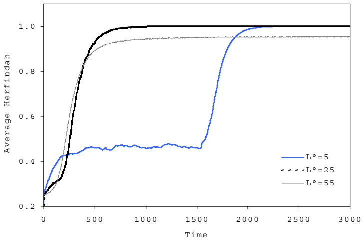
Minority Games with Endogenous Networks (2/2)

- **Main Results**
  - In a frozen-network setup agents attain lower payoffs
  - When agents can add/discard links, population learns to “globally” win the local Minority Game
  - Population splits into two stable (almost) equally-sized groups (+1 and -1)
  - Agents in one group only select agents in the other group



Frozen Nets



Endo Nets

Conclusions

A Class of Population Games

- **Bounded Rationality and Dynamics**
  - Agents behave myopically
  - Markovian dynamics
- **Local Interactions**
  - Agents are located on the nodes of generic networks
  - They hold a limited knowledge of the world
  - They play games with their neighbors only
- **Endogenous Networks**
  - Agents are able to choose whom to play with
  - Strategies and interaction structure endogenously co-evolve
  - Window of observation adapts over time
- **Trade-off between**
  - Analytical tractability
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Applications and Results

- **Alternative strategic setups**
  - Schelling segregation game
  - Coordination
  - Minority
  - ...and many more in the literature
- **Equilibrium selection**
  - Network endogeneity does have a huge impact on both the set of equilibria and on the selection process
  - The system attains higher efficiency levels
  - Population learning given and/or about networks
  - Risk-efficiency is confirmed to be a robust selection principle
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  - Network structure does not always affect equilibrium selection
  - Still an open issue
  - Answer depends on whether network topological properties affect agents decisions!

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Thanks!

`https://mail.sssup.it/~fagiolo/welcome.html`