Notes on Network Formation

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Resource Sites (Links to Readings/Software):
Trade Network Game (TNG) Lab Home Page
https://www2.econ.iastate.edu/tesfatsi/tnghome.htm

Formation of Economic and Social Networks
https://www2.econ.iastate.edu/tesfatsi/netgroup.htm
Presentation Outline

- Three approaches to the study of network effects
- Two IPD game examples comparing effects of having random vs. preferential partner matching

  - **Preparatory Stuff:** Finite state machine (FSM) representation of IPD player (i.e. strategy) types
  - **Example 1:** IPD game play among *fixed* player types
  - **Example 2:** IPD game play among *evolving* player types
Three Approaches to the Study of Network Effects

- Agents interact with other agents in a **given interaction network**. Agents do not control with whom they interact, or with what regularity (e.g. Axelrod Tournament with round-robin PD play).

- Agents interact with other agents through **given restricted links** but they exert some control over the strength of these interactions (e.g. Electricity Market).

- Agents **preferentially decide** with whom they interact and with what regularity (e.g. Labor Market).
Network Effects vs. Network Formation Effects ...


- **Strong Scaffolding**: *Given* interaction network; or *given* restricted links.

- **Weak Scaffolding**: Agents *preferentially decide* with whom they interact, and with what regularity.

- Scaffolding as a substitute for learning and/or thinking?
Key Question:

What difference does it make if agents can preferentially form their own networks?
Random vs. Preferential Partner Choice: Two Illustrative Examples

Example 1: IPD game play among fixed player types


Example 2: IPD game play among evolving player types

Ref.[2]: Dan Ashlock, Mark Smucker, Anne Stanley, and Leigh Tesfatsion, BioSystems, 1996
Illustrative Finite State Machine Representations for 1-State and 2-State IPD Players

$X/Y \;=:\; \text{“If my rival’s last move was } X, \text{ I will now play } Y.$"
TFTT (Tit-for-Two-Tats) vs. Rip-Off

QUESTIONS:
What happens if TFTT is forced to play Rip-Off?
What happens if two Rip-Offs play each other?

X/Y := “If my rival’s last move was X, I will now play Y.”
Example 1: **Fixed-Player IPD Game with Preferential Partner Choice**

**NOTE:** All Example 1 results are analytically derived

- Fixed Player Population = 3 TFTTs and 2 Rip-Offs
- Players engage in 150 iterations of an Iterated Prisoner’s Dilemma (IPD) Game
- The payoffs for each PD game play are centered about 0, as follows:
  - \( L \) (Lowest = Sucker Payoff) \(<\) \( D \) (Mutual Defection) \(<\) 0 \(<\) \( C \) (Mutual Cooperation) \(<\) \( H \) (Highest=Temptation Payoff)
- In addition, PD payoffs satisfy \([L + H]/2 < C\).
Example 1: Payoffs for Each Play of the Prisoner’s Dilemma (PD) Game

Player 2

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>(C,C)</td>
<td>(L,H)</td>
</tr>
<tr>
<td>D</td>
<td>(H,L)</td>
<td>(D,D)</td>
</tr>
</tbody>
</table>

L (Lowest) < D (Mutual D) < 0 < C (Mutual C) < H (Highest)
Example 1: Expected Payoff Assessments

- Each player A assigns an initial expected payoff $U^o$ to each other player B.

- Expected payoff assessments $U$ are continually updated based on play history (simple averaging).

- Player A finds player B tolerable as long as player A assigns a nonnegative expected payoff $U$ to B.

- Player A stops making play offers to (or accepting play offers from) any player B who becomes intolerable ($U < 0$).
Example 1: Preferential Partner Choice

- At start of each iteration, each player A makes a play offer to a *tolerable* player B he judges to offer the currently highest expected payoff U.

- Player A “flips a coin” to settle ties and goes inactive if he judges every other player to be *intolerable* ($U < 0$).

- If player A has a play offer *refused* by a player B:
  - He suffers a *negative refusal payoff* R (“shame”)
  - He then redirects his offer to a tolerable player B’ he judges to have the next highest expected payoff U
  - If all other players are intolerable, he goes inactive.
Example 1: More on Preferential Partner Choice

- Each player A updates his expected payoff \( U \) for another player B whenever he receives any payoff from interaction with B (either a refusal payoff or a game payoff).

  **Example:** If player A has played B twice in the past and received payoffs \( p_1 \) and \( p_2 \), his current expected payoff \( U' \) for player B is

  \[
  U' = \frac{U^o + p_1 + p_2}{3}
  \]

- If \( U \) falls below 0, player B is deemed *intolerable*.

  ➔ player A will not direct any more play offers to B and player A will refuse any play offers received from B in the future.
Example 1: Key Issues

- Fixed population consisting of two agent types: 3 TFTTs & 2 Rip-Offs
- With random partner choice, Rip-Offs will chew TFTTs to pieces
- How does the introduction of preferential partner choice affect the long-run fitness (accumulated points) of TFTTs vs. RipOffs?
- How does the initial expected payoff level $U^o$ affect long-run fitness outcomes?
Example 1: Visualization of Case Findings

Network Visualization:

- Boxes = Players
- Box size = Long-run fitness level
- Lines = Persistent interactions

Treatment Factor:

Initial expected payoff assessment $U^o$

Stance towards strangers (same for each player)

Four Cases for $U^o$:
very low; low; high; very high
TFTT vs. Rip-Off with Relatively Low $U^\circ$ Values:
$(L < D < 0 < C < H, \text{ and } R < 0)$

**Note:** A larger box indicates a relatively higher long-run fitness.

(a) Case (CP.1)
$0 < U^\circ < -D$

(b) Case (CP.2) or (CP.3)
$(-D \leq U^\circ < -L)$ or $(C < -L \leq U^\circ)$
TFTT vs. Rip-Off with Relatively High $U^0$ Values:
$(L < D < 0 < C < H, \text{ and } R < 0)$

Figure 2: Long-Run Trade Networks Under Assumption (CP) for the Illustrative 5-Tradebot TNG. A relatively larger box indicates a definitely higher fitness score for a sufficiently long trade cycle loop. In case (d), the Rip-TFTT interactions are stochastic if $(H + C)/2 = U^0$ and deterministic if $(H + C)/2 < U^0$. 

(c) Case (CP.4): $-L \leq C$ with 
$-L \leq U^0 < (H + C)/2$

(d) Case (CP.4): $-L \leq C$ with 
$(H + C)/2 \leq U^0$
Example 2: **Evolutionary** IPD Game
with **Preferential** Partner Choice


**Key Issue Studied:**

What happens in an IPD game if *players preferentially choose and refuse their partners* instead of having their interactions exogenously determined by a random matching device *and the players evolve their “types” (game strategies) over time* based on their realized payoff outcomes?
Example 2: Maintained Parameter Specifications

PD Payoffs: Sucker=0, Mutual Defection (MutD) =1,  
Mutual Cooperation (MutC) = 3, Temptation = 5

Initial Expected Payoff: $U^o = 3 = MutC$

Intolerable: $U$ falls below 1.6 (between MutD & MutC)

Refusal Payoff: $R = 1.0$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
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<tbody>
<tr>
<td>Number of Players</td>
<td>$N = 30$</td>
</tr>
<tr>
<td>Number of Generations (Tournaments)</td>
<td>$G \geq 50$</td>
</tr>
<tr>
<td>Number of Iterations per Tournament</td>
<td>$I = 150$</td>
</tr>
<tr>
<td>Initial Expected Payoff:</td>
<td>$\pi_0 = 3.0$</td>
</tr>
<tr>
<td>Minimum Tolerance Level:</td>
<td>$\tau = 1.6$</td>
</tr>
<tr>
<td>Refusal Payoff:</td>
<td>$R = 1.0$</td>
</tr>
<tr>
<td>Wallflower Payoff:</td>
<td>$W = 1.6$</td>
</tr>
<tr>
<td>Memory Weight:</td>
<td>$\omega = 0.7$</td>
</tr>
<tr>
<td>Number of Elite</td>
<td>$X = 20$</td>
</tr>
<tr>
<td>Mutation Probability</td>
<td>$\mu = 5/1000$</td>
</tr>
</tbody>
</table>

Table 3: Parameter Settings for the Standard IPD/CR Scenario
Example 2: **Benchmark Case for Comparison**
Evolutionary IPD Game with **Random Partner Choice**

- **Initial Strategies:** Each player in an initial population of 30 players starts with a *randomly* specified IPD strategy

- **Random Matching:**
  Each player is *randomly* matched in each iteration with another player to play a PD game

  ➔ No choice/refusal of partners is permitted, no refusal payoffs are sustained, and no tolerability assessments are made.
Example 2: **Benchmark Case** ... Continued

- After **150 iterations (= one generation)**, a Genetic Algorithm (GA) is used to construct a **new** set of 30 IPD strategies from players’ current IPD strategy set.

- Players then enter another 150 iterations of PD game play with **random** matching.

- This continues for **500 generations**.

- **Forty runs (500 generations each)** were conducted.
Example 2: Benchmark Case ... Continued

Fig. 3. Random choice evolved for 500 generations. Each player chooses exactly one partner at random on each of the 150 iterations comprising an IPD tournament. (a) The overall average fitness achieved by successive generations across 40 runs. The dashed lines (error bounds) show this overall average fitness plus or minus one standard deviation. (b) Each line shows the average fitness achieved by successive generations during one of the 40 runs. Note the wide spread and the horizontal bands. The bands tend to occur because populations become genetically homogeneous and mutants tend to do poorly.
Example 2: **Evolutionary IPD Game with Preferential Partner Choice**

- Each player in *initial* 30-player population has a *randomly* specified IPD strategy

- **Preferential Partner Choice:** Essentially the same as in Example 1 (*five* players with *fixed* game strategies)

  Players *choose and refuse* game partners on the basis of repeatedly updated expected payoff assessments (using weighted payoff averages), refuse to play with intolerable players, & receive refusal payoffs when their play offers are refused.
Example 2: **Evolutionary IPD Game with Preferential Partner Choice** …

- **Major Contrast with Example 1: Evolution of Strategies**
  - After 150 iterations (= one generation), a Genetic Algorithm (GA) is used to evolve a new set of 30 IPD strategies from players’ existing IPD strategy set.
  - Players then enter another 150 iterations of PD game play with preferential partner choice
  - This continues for 500 generations
  - Forty runs (500 generations each) were conducted
Example 2: **Evolutionary IPD Game with Preferential Partner Choice** ...

Fig. 4. IPD/CR evolved for 500 generations with all parameters at their standard scenario levels. As in Fig. 3, each player chooses at most one partner in each iteration. (a) Overall average fitness across 40 runs and error bounds. (b) Average fitness achieved by successive generations for 40 individual runs. Note how few fitness levels are achieved in comparison to Fig. 3. The jumps in average fitness from the fitness region near 2.69 to a level above the mutual cooperation fitness region at 3.0 are observed frequently, and indicate the Raquel-and-the-Bobs phenomenon discussed in the text.
Example 2: Emergence of “Raquel-and-the-Bobs” Pattern for Evolutionary IPD Game with Preferential Partner Choice

Actual Slice-in-Time Picture:
Inner grouping of 3 “Raquels” playing ≈ C:C (i.e., start with Cooperation (C), then continually play C) with outer grouping of 27 latched “Bobs” playing ≈ D:C (i.e., start with Defection D, then continually play C)

Homogenous population of 30 Bobs → Rise of mutant Raquels until fitness of Bobs > fitness of Raquels → Decimation of Raquels → Back to homogeneous population of 30 Bobs → cycle repeats
Example 2: Summary of Findings for Evolutionary IPD Game with Preferential Partner Choice

Main Conclusions:

➢ Introduction of choice and refusal of partners (in place of random matching) accelerates the emergence of mutual cooperation in the evolutionary IPD game.

➢ However, in general, mutual cooperation can be supported by a wide variety of underlying trade networks (latched, star, recurrent, disconnected, etc.)

Note: Below for illustration are various types of trade networks – evolved using the Trade Network Game (TNG) Lab – that support persistent mutual cooperation among “latched” or “stochastically interacting” subsets of trade partners.
Stochastic All-Dealer Trade Network
Evolved by the Trade Network Game (TNG) Lab
Bi-Lateral (Buyer-Seller) Trade Network
Evolved by the TNG Lab
Tri-Lateral (Buyer-Dealer-Seller) Trade Network
Evolved by the TNG Lab