Criminal Network Formation and Optimal Detection Policy: The Role of Cascade of Detection

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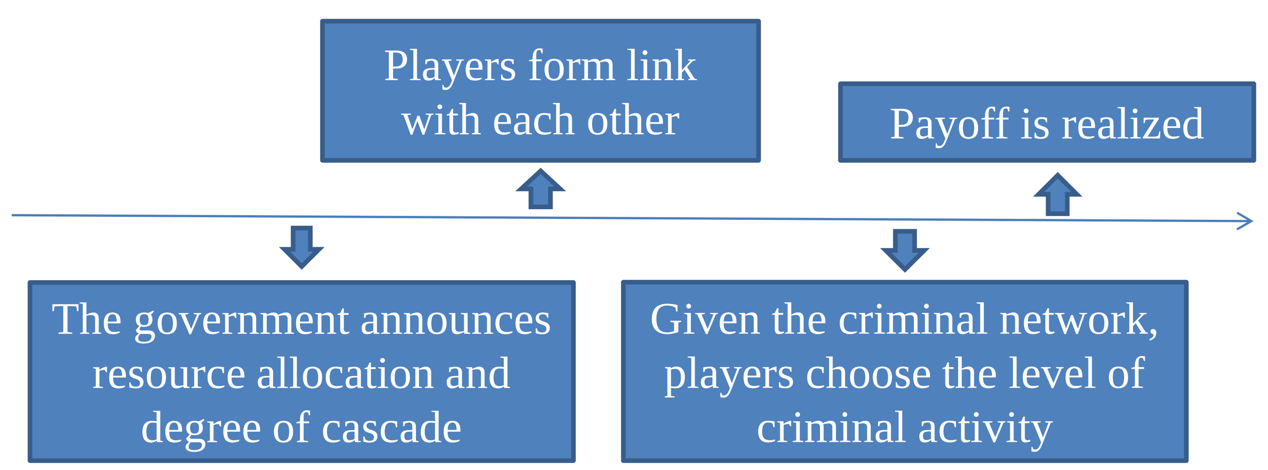
Abstract

This paper investigates the effect of cascade of detection, that is, how detection of a criminal triggers detection of his network neighbors, on criminal network formation. We develop a model in which criminals choose both links and actions. We show that the degree of cascade of detection plays an important role in shaping equilibrium criminal networks. *Surprisingly, greater cascade of detection could reduce ex ante social welfare*. In particular, we prove that full cascade of detection yields a weakly denser criminal network than that under partial cascade of detection. We further characterize the optimal allocation of the detection resource and demonstrate that it should be highly asymmetric among ex ante identical agents.

Model

- Time Line (Baccara and Bar-Isaac, 2008)



- The government announces detection resource allocation, β, and degree of cascade of detection, d.
  - Full cascade ($d = n$) versus partial cascade ($d = 1$)
- Players propose link to each other and link formation requires bilateral consent.
- Given the undirected network g, players choose their effort level.
- The stage game is modeled as Ballester, *et al.* (2006), with a quadratic payoff function ($0 < \lambda < \frac{1}{n-1}$).

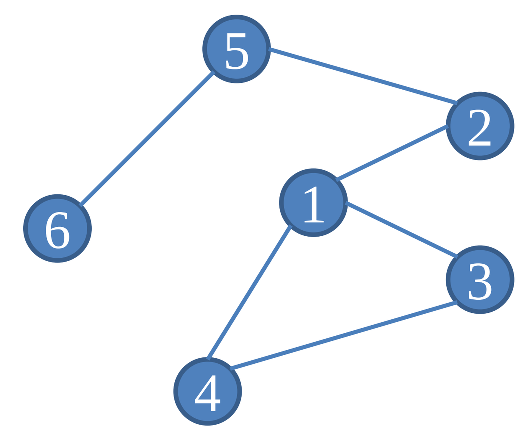
$$\pi_i(x, g) = x_i - \frac{1}{2}x_i^2 + \lambda \Sigma_{j=1}^{n} g_{ij} x_i x_j$$

- The total payoff is $p_i(g; \beta, d)\pi_i(x, g)$, where $p_i(g; \beta, d)$ is the probability of not being detected.

An Illustration of Model and Results

- Probability of not being detected

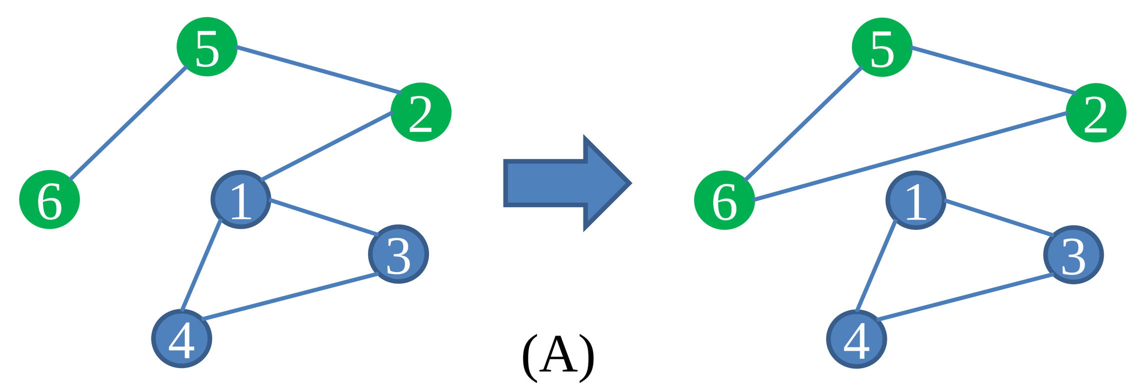
$$p_i(g; \beta, d) = \Pi_{d_{ij} \le d}(1 - \beta_j)$$



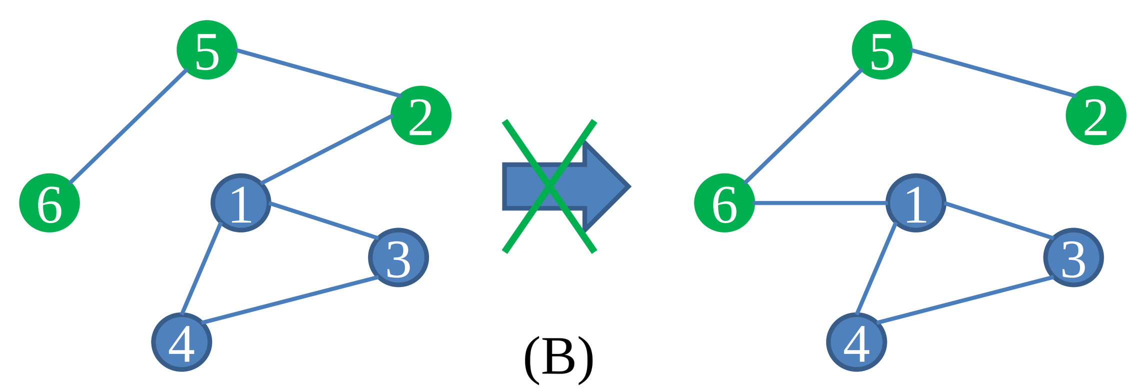
- No cascade ($d = 0$)
  $p_1(g; \beta, 0) = 1 - \beta_1$
- Partial cascade ($d = 1$)
  $p_1(g; \beta, 1) = \Pi_{i=1}^{4}(1 - \beta_i)$
- Full cascade ($d = n$)
  $p_1(g; \beta, 6) = \Pi_{i=1}^{6}(1 - \beta_i)$

- Multilateral coordination of link formation: both partners of a newly added link have to be group members; at least one partner of a newly deleted link has to be a group member.

Example: coordination among players 2, 5, 6



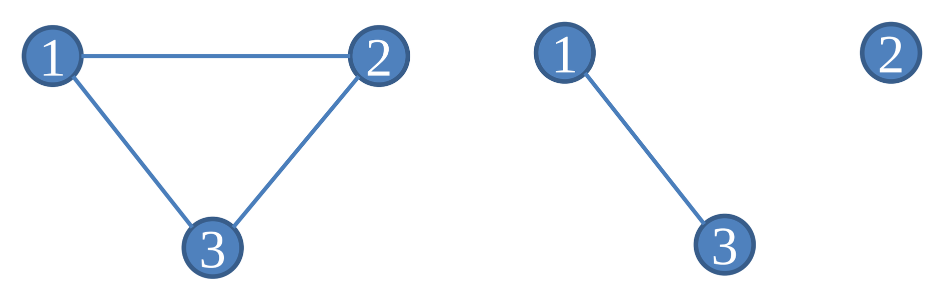
(A)



(B)

- Multiple pairwise stable Nash equilibria

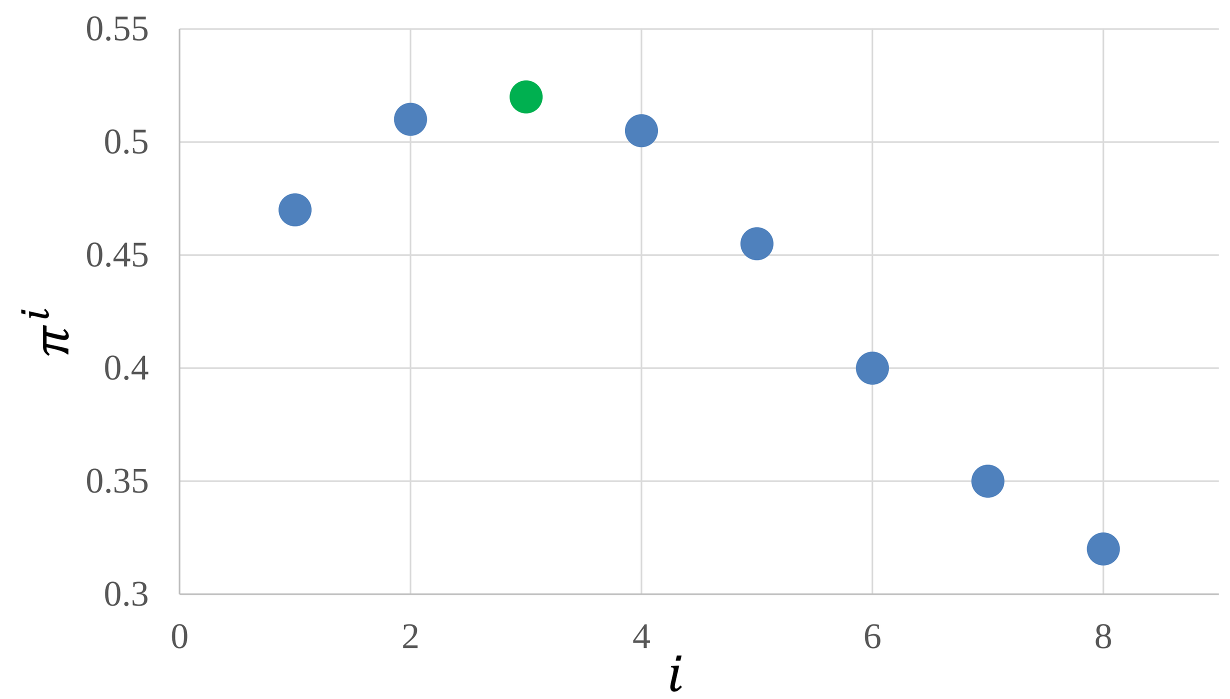
Example: $\beta_1 = \beta_2 = \beta_3 = 0.18,\ \lambda = 0.1)$

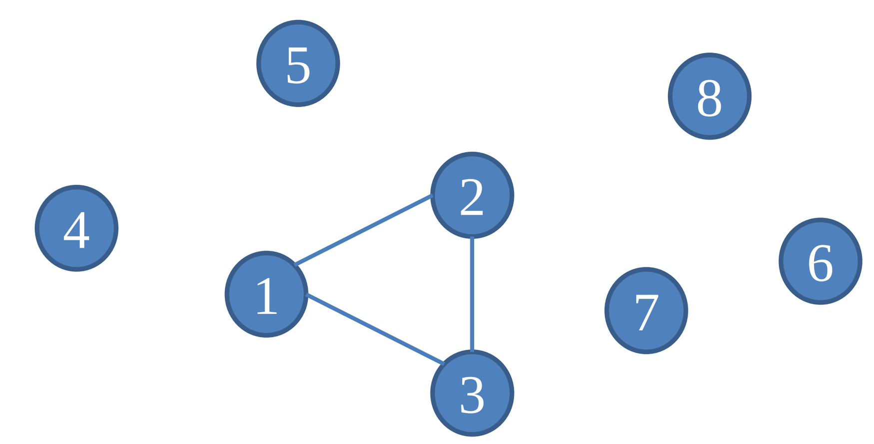


- The unique strongly stable Nash equilibrium under full cascade consists of a set of isolated agents and a complete component of size $n_0 \equiv max\{argmax_i \pi^i\}$

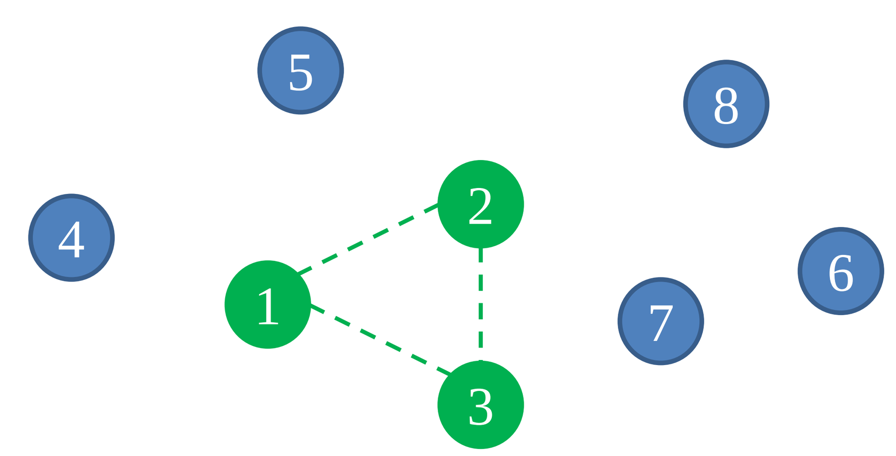
where $\pi^i = \frac{1}{2}\left(\frac{1}{1-(i-1)\lambda}\right)^2 \Pi_{k=1}^{i}(1 - \beta_k)$.

Example: $n = 10, \beta_i = \frac{i}{20}, \lambda = 0.08$.





- The equilibrium network above imposes an "upper bound" on the criminal network of any pairwise stable Nash equilibrium under partial cascade



Equilibrium

- **Pairwise stable Nash equilibrium - PSNE** (Hiller, 2014) is a subgame perfect Nash equilibrium robust against bilateral coordination of link formation.
- **Strongly stable Nash equilibrium – SSNE** (Jackson and van den Nouweland, 2005) further requires that the equilibrium is robust against multilateral coordination of link formation.

Results

Theorem 1. Under full cascade of detection ($d = n$), the network in each pairwise stable Nash equilibrium is component-wise complete.

Theorem 2. There exists a unique strongly stable Nash equilibrium under full cascade of detection. The equilibrium network consists of a complete component and a set of isolated nodes.

Theorem 3. Those players who are isolated in the strongly stable Nash equilibrium under full cascade of detection ($d = n$) remain isolated in any pairwise stable Nash equilibrium, including strongly stable Nash equilibrium, under partial cascade of detection ($d = 1$).

Theorem 4. Those players who are isolated in the strongly stable Nash equilibrium under full cascade of detection ($d = n$) remain isolated in any strongly stable Nash equilibrium under positive degree of cascade.

Theorem 5. Under full cascade of detection, the optimal allocation of detection budget is asymmetric across agents and admits a closed-form solution. The result continues to hold in the presence of outside options.

Reference

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