Information Acquisition and Response in Peer-Effects Networks

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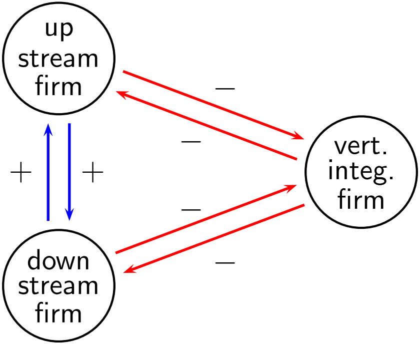
1. infer the state of the world,
2. in equilibrium, infer the observations and subsequent actions of neighbors.

Peer-effects networks with incomplete information

$$u_i\left(x_1,\ldots,x_N\right)=\underbrace{\left(a_i+\omega+\sum_{k\neq i}\sigma_{ik}x_k\right)}_{\text{marginal value to } x_i}x_i\;-\;\underbrace{\frac{1}{2}\sigma_{ii}x_i^2}_{\text{O.C. to } x_i}$$

$$u_i(x_1, \ldots, x_N) = \left(a_i + \omega + \sum_{k \neq i} \sigma_{ik} x_k\right) x_i - \frac{1}{2}\sigma_{ii} x_i^2$$

A competitive supply chain



ω : demand for novel product

x_{firm} : production

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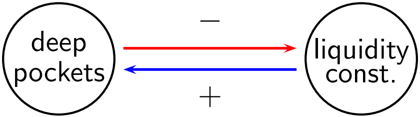
Traders with heterogeneous funding constraints



ω : long term asset value

x_{trader} : market order/inventory

Basic questions

(1) How does heterogeneity in strategic positioning influence the incentives to acquire information?

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(2) Who over and who under acquires information?
Who gains to influence others' beliefs?

Positive results

Information response game $\xrightarrow{EQ}$ value to information.

Equilibrium properties:

a. game on correlation-adjusted network (second stage),

b. negative responses (second stage),

c. multiple information acquisition equilibria (first stage).

Welfare results

1. Extent of symmetry among pair-wise peer effects drives direction of two inefficiencies:
   a. informational externalities (network charact.: in-walks),
   b. strategic value to information acquisition
   (network charact.: closed-walks).

2. Symmetric networks (for e.g.)
   a. "*bunching*" for moderate peer effects:
   equilibrium information asymmetries *inefficiently low*,
   b. significant strategic substitutes:
   acquisition of negative responders *inefficiently low*,
   c. positive strategic distortion $\propto$ *connectedness* in network.

3. "Antisymmetric" networks: inefficiencies reverse.

Policy implications

Transparency-based policy:
targeted certification of information investments.

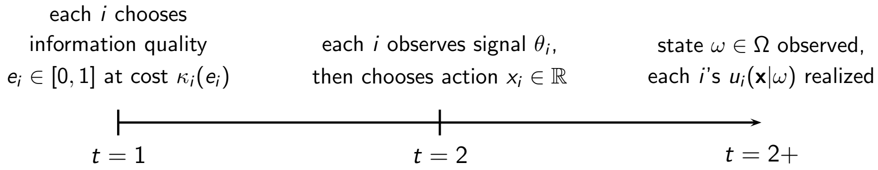
Literature

- Network games with incomplete information:
  Calvó-Armengol & de Martí (2007,2009), Calvó-Armengol, de Martí, Prat (2015), de Martí & Zenou (2015).

- Coordination games with endogenous information:
  - Novshek & Sonnenschein (1983,1988), Vives (1988,2008), Hauk & Hurkens (2007).
  - Morris & Shin (2002), Hellwig & Veldkamp (2009), Myatt & Wallace (2012,2013), Colombo, Femminis, & Pavan (2014).

- Finance:
  Grossman & Stiglitz (1980), Kyle (1985,1989), Babus & Kondor (2013).

Timeline of the game



Model primitives: second stage ($t = 2$)

- Each i chooses $x_i \in \mathbb{R}$, yielding i's payoffs ($t = 2$):

$$u_i(\mathbf{x}|\omega) = \left(\omega + \rho \sum_{k \neq i} \sigma_{ik} x_k\right) x_i - \frac{1}{2} x_i^2,$$

where $\omega \in \Omega \subseteq \mathbb{R}$, $\sigma_{ij} \in \mathbb{R}$ for each i, j, and $\rho \in [0, 1]$,

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Assumption 1

$(\mathbf{I} - [s_{ij}\sigma_{ij}])^{-1}$ *is well defined for every* $\mathbf{s} \in [0, 1]^{N(N-1)}$.

Model primitives: first stage ($t = 1$)

- Each $i = 1, \ldots, N$ privately invests in information quality $e_i \in [0, 1]$.
- i's cost of information quality $\kappa_i(\cdot) \in C^2$ satisfies $\kappa_i(0), \kappa_i'(0) = 0$, with non-decreasing $\kappa_i''(e_i) \geq 0$.

Assumption 2

For $v_0 > 0$, there exists an unique $e_i^\dagger \in (0, 1)$ solving $v_0 e_i^\dagger = \kappa_i'(e_i^\dagger)$.

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All conditions satisfied for normal state and signals case.

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- E1.

$$\mathbb{E}_i\left[\omega\right] = \mathbb{E}_i\left[\theta_i\right] = 0,$$
$$v_0 := \mathbb{E}_i\left[\omega^2\right] = \mathbb{E}_i\left[\theta_i^2 | e_i\right],$$

E2.

$$\mathbb{E}_i\left[\omega | \theta_i, e_i\right] = e_i \theta_i,$$

E3.

$$\mathbb{E}_i\left[\theta_j | \theta_i, e_i, e_j\right] = e_i e_j \theta_i,$$

for each $e_i \in [0,1]$.

Equilibrium facts

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3. Significant peer effects required for 1. or 2. to obtain.

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1. Multiple IAE $\mathbf{e}^*$ may exist even with a unique IRE $\boldsymbol{\beta}^*$ for each $\mathbf{e}$.
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Proposition

Under Assumptions 1 and 2, there exists a $\bar{\rho} > 0$ such that for $\rho \in [0, \bar{\rho})$, a unique IAE $\mathbf{e}^*$ with $\beta_i^* > 0$ for all i obtains.

Welfare

Welfare

For any $\mathbf{e}$, giving $\mathbf{X}^*$:

$$\nu_i(\mathbf{X}^*|\mathbf{e}) := \mathbb{E}_i[u_i(\mathbf{X}^*|\theta_i, e_i, \mu_i^*)|e_i, \mu_i^*] - \kappa_i(e_i)$$

$$\vdots$$

$$= \frac{1}{2}v_0\beta_i^{*2} - \kappa_i(e_i).$$

Welfare: marginal inefficiencies

Define the utilitarian problem:

$$\max_{\mathbf{e}\in[0,1]^N} \sum_k \nu_k \left(\mathbf{X}^* | \mathbf{e}\right).$$

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$$= \left.\frac{\partial \nu_i \left(\mathbf{X}^*|\mathbf{e}\right)}{\partial e_i}\right|_{\beta_k^*, k\neq i} + \sum_{k\neq i} \frac{\partial \nu_i \left(\mathbf{X}^*|\mathbf{e}\right)}{\partial \beta_k^*} \frac{\partial \beta_k^*}{\partial e_i} + \sum_{k\neq i} \frac{\partial \nu_k \left(\mathbf{X}^*|\mathbf{e}\right)}{\partial \beta_k^*} \frac{\partial \beta_k^*}{\partial e_i}.$$

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$$= \underbrace{\underbrace{\underbrace{\left(v_0 \frac{\beta_i^{*2}}{e_i} - \kappa'\left(e_i\right)\right)}_{=0 \text{ in IAE } \mathbf{e}^* \text{ f.o.c.}} + v_0 \beta_i^* \sum_{k\neq i} e_i \rho \sigma_{ik} e_k \frac{\partial}{\partial e_i} \beta_k^*}_{=0 \text{ in public acquisition eq. } \mathbf{e}^{pb} \text{ f.o.c.}} + \quad v_0 \sum_{k\neq i} \beta_k^* \frac{\partial}{\partial e_i} \beta_k^*}_{=0 \text{ in planner's solution } \mathbf{e}^{pl} \text{ f.o.c.}}.$$

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$$= \left(v_0 \frac{\beta_i^{*2}}{e_i} - \kappa'\left(e_i\right) \right) + \underbrace{v_0 \beta_i^* \sum_{k \neq i} e_i \rho \sigma_{ik} e_k \frac{\partial}{\partial e_i} \beta_k^*}_{\text{(marginal) strategic value}} + \underbrace{v_0 \sum_{k \neq i} \beta_k^* \frac{\partial}{\partial e_i} \beta_k^*}_{\text{(marginal) externalities}}.$$

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$$= \left(v_0\frac{\beta_i^{*2}}{e_i} - \kappa'\left(e_i\right)\right) + \underbrace{v_0\beta_i^*\sum_{k\neq i} e_i\rho\sigma_{ik}e_k\frac{\partial}{\partial e_i}\beta_k^* + \quad v_0\sum_{k\neq i}\beta_k^*\frac{\partial}{\partial e_i}\beta_k^*}_{\text{(marginal) public-value}}.$$

Welfare: marginal inefficiencies

Theorem (marginal inefficiencies)

For information qualities $\mathbf{e}$, *consistent beliefs* $\boldsymbol{\mu}$ *and IRE* $\mathbf{X}^*$*:*

$$\begin{aligned} \xi_i^{st}(\mathbf{e}, \mathbf{X}^*) &= 2v_0 \frac{\beta_i^{*2}}{e_i^*} \mathbf{1}_i' \mathbf{I_e} \Sigma \mathbf{I_e} \left(\mathbf{I} - \mathbf{I_e} \Sigma \mathbf{I_e}\right)^{-1} \mathbf{I_e} \Sigma \mathbf{I_e} \mathbf{1}_i, \\ \xi_i^{ex}(\mathbf{e}, \mathbf{X}^*) &= 2v_0 \frac{\beta_i^*}{e_i^*} \left(\boldsymbol{\beta}^* - \beta_i^* \mathbf{1}_i\right)' \mathbf{I_e} \Sigma \mathbf{I_e} \left(\mathbf{I} - \mathbf{I_e} \Sigma \mathbf{I_e}\right)^{-1} \mathbf{1}_i. \end{aligned}$$

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$$\xi_i^{ex}(\mathbf{e},\mathbf{X}^*) = 2v_0\frac{\beta_i^{*}}{e_i^*}\left(\boldsymbol{\beta}^*-\beta_i^*\mathbf{1}_i\right)'\mathbf{I_e}\Sigma\mathbf{I_e}\left(\mathbf{I}-\mathbf{I_e}\Sigma\mathbf{I_e}\right)^{-1}\mathbf{1}_i.$$

- $$\xi_i^{st}(\mathbf{e},\mathbf{X}^*) \propto \mathbf{1}_i'\left(\sum_{\tau=2}^{\infty}\left([e_ie_j\rho\sigma_{ij}]_{i\neq j}\right)^{\tau}\right)\mathbf{1}_i :$$

  summation of closed walks on $[e_ie_j\rho\sigma_{ij}]_{i\neq j}$ beginning and ending on i.

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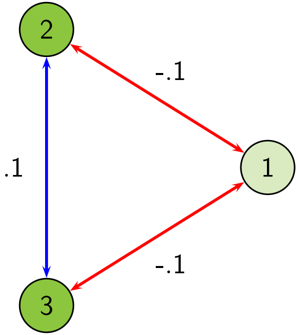
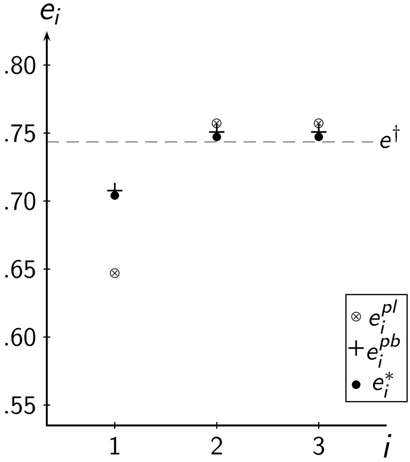
- $$\xi_i^{ex}(\mathbf{e}, \mathbf{X}^*) \propto \left(\boldsymbol{\beta}^* - \beta_i^* \mathbf{1}_i\right)' \left(\sum_{\tau=1}^{\infty} ([e_i e_j \rho \sigma_{ij}]_{i \neq j})^{\tau} \right) \mathbf{1}_i :$$

  summation of walks on $[e_i e_j \rho \sigma_{ij}]_{i \neq j}$ beginning with j and ending on i, weighted by β_j and aggregate over $j \neq i$.

Example: three-player symmetric network, common κ





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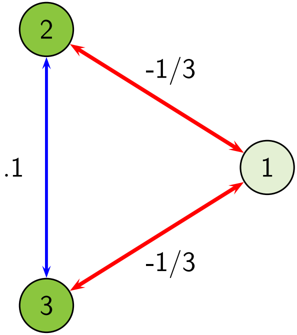

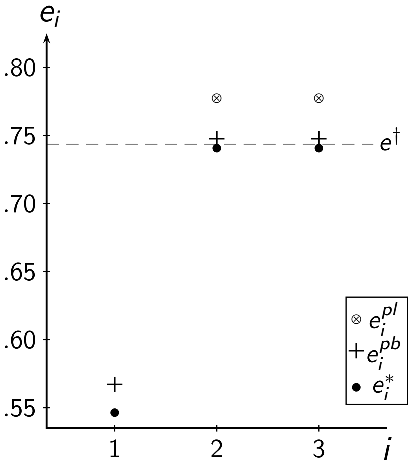

$e_1^{pl} = 0$

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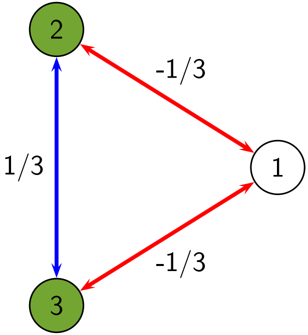
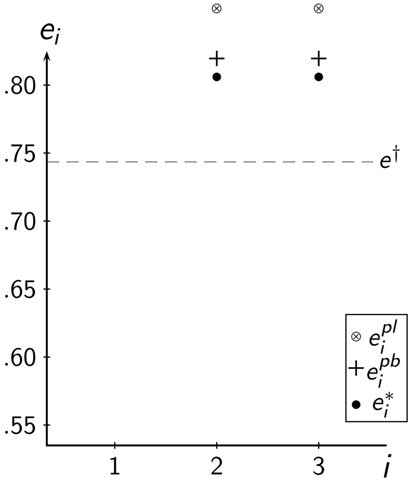
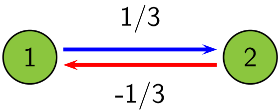
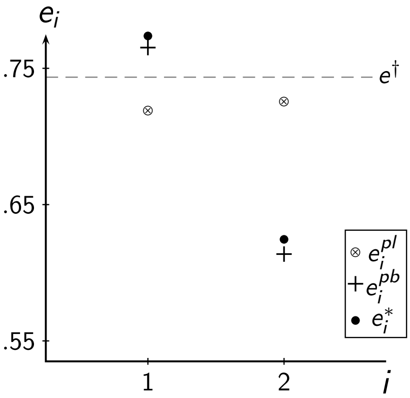




$e_1^{pl} = e_1^{pb} = e_1^* = 0$

Example: two-player antisymmetric network, common κ

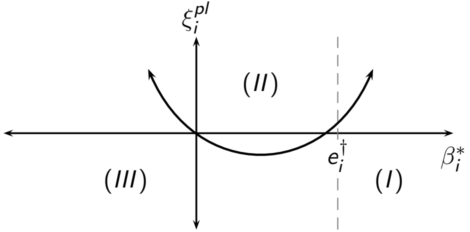




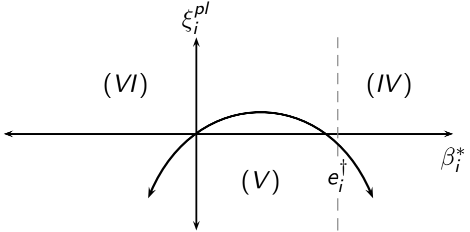
Welfare and policy design

Welfare and the neutral player

symmetric networks



antisymmetric networks



Market efficiency in liquidity crises

conclusion

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- ω: risky asset's long term value.
- $t = 2$ payoffs:

$$\begin{aligned} u_i(\mathbf{x}|\omega) &= (\omega + p_i\phi(\bar{x}))\, x_i - x_i^2 \\ &= \left(\omega + p_i A + p_i B \sum_{k \neq i} x_k\right) x_i - (1 - p_i B)\, x_i^2. \end{aligned}$$

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Liquidity flush market:

- $p_i < 0$ for each unconstrained i.
- Market *crowding* in information acquisition.
- Traders set $e_i^*, \beta_i^* < e^\dagger$ (region (II)): *over*-acquire; over exertion in informationally inefficient markets.

Market efficiency in liquidity crises

Liquidity crises:

- Liquidity spirals à la Brunnermeier and Pedersen (2009) $\rightarrow$ upward sloping demand.

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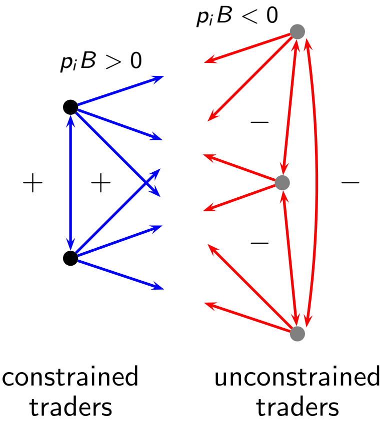
- $p_i > 0$ for liquidity-constrained trader i.

Market efficiency in liquidity crises

Market structure:



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Liquidity crisis paradigm shift:

- Constrained traders set $e_i^*, \beta_i^* > e^\dagger$
  1. Flush market: antisymmetric relationships $\rightarrow$ over-acquire.
  2. Crisis: symmetric relationships $\rightarrow$ *under*-acquire.

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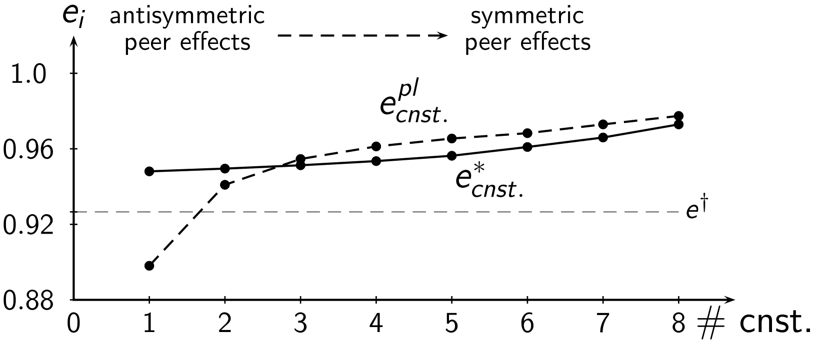

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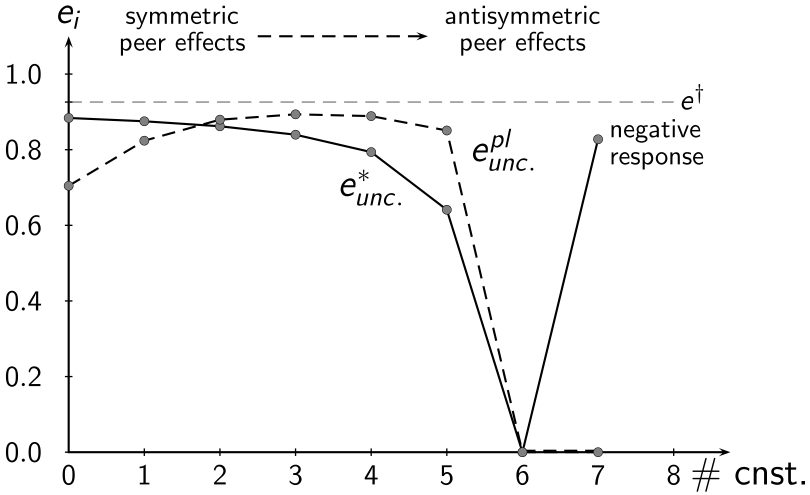
- Unconstrained traders set $e_i^*, \beta_i^* < e^\dagger$
  1. Flush market: symmetric relationships $\rightarrow$ over-acquire.
  2. Crisis: antisymmetric relationships $\rightarrow$ *under*-acquire.
  3. Extreme crisis: few unconstrained traders set $e_i^*, \beta_i^* < 0$.

Market efficiency in liquidity crises



Policy suggestion in liquidity crises

- Constrained traders impose symmetric, positive informational externalities on each other: under acquire, with positive strategic values...

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  Couple stress-tests with certification of information investments of constrained traders.

Conclusions

1. Introduce problem of costly information acquisition into new context: *general network of peer effects*.
2. Symmetric networks:
   a. Equilibrium information inefficiently *symmetric*.
   b. Players moving against their information do so *too little*.
   c. Strategic values to information are *positive*.
3. Direction of welfare and strategic motives determined by network "*position*" and extent of *symmetry* in relationships: direction of inefficiencies *reverse* in antisymmetric networks.
4. Information externalities and "position": β_i^* w.r.t. $e_i^\dagger$ and origin, Strategic values and "position": *connectedness*.

Conclusions II

1. Liquidity crisis *paradigm shift*: over acquisition of information in liquid markets, under acquisition in constrained markets.
2. Unconstrained "*shorters*" in crisis: inefficient.
3. Transparency-based policy intervention: stress test *with* information investment certification.

Equilibrium characterization

Equilibrium characterization

Theorem ($t = 2$ information-response equilibrium (IRE))

Under Assumption 1, for any $\mathbf{e}$ *and consistent* $\boldsymbol{\mu}$ *there exists a unique linear IRE of the form:*

$$\mathbf{X}^* = [X_i^*(\theta_i|e_i)] \quad = \quad [\beta_i^* \theta_i],$$

where each β_i^* *solves* $\beta_i^* = e_i + \sum_{k \neq i} e_i e_k \rho \sigma_{ik} \beta_k^*$:

$$\begin{aligned} \boldsymbol{\beta}^* \quad &:= \quad \left(\mathbf{I} - [e_i e_j \rho \sigma_{ij}]_{i \neq j}\right)^{-1} \mathbf{e} \\ &= \quad \sum_{\tau=0}^{\infty} \left([e_i e_j \rho \sigma_{ij}]_{i \neq j}\right)^{\tau} \mathbf{e}. \end{aligned}$$

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β_i^*: i's "informational centrality" (weighted Bonacich centrality).

Equilibrium characterization

Back

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Under Assumption 1, for IRE $\mathbf{X}^*$ and consistent beliefs $\boldsymbol{\mu}$ there exists a (generically unique) IAE $\mathbf{e}^*$. For any such IAE, and $\forall\ i$ with $e_i^* \in (0,1)$:*

$$v_0 \frac{\beta_i^{*2}}{e_i^*} = \kappa_i'\left(e_i^*\right).$$

Equilibrium characterization

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