How firms choose their partners in the Japanese production network?

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1. Literature review and research topic
   - Systemic risk and firms' bounded rationality
   - Research topic
2. Exponential Random Graph Model
   - Modeling formalism
   - The proposed algorithm (Python algorithm from scratch)
3. Data and modeling assumptions
   - Production network
   - Endogenous and exogenous attributes
4. Results and discussion
5. Conclusion and research opening

Theoretical works

Systemic risk:

- Loretan (1996): Non-rational behavior of economic agents is necessary to understand the systemic crisis.
- Marbukh (2016): Bounded rationality and high complex inter-connectivity are in the origins of both economic performance and systemic risk.

Bounded rationality of economic agents:

- Simon (1982): In an environment characterized by incomplete information, economic agents take decision under uncertainty which characterize their bounded rationality.
- Fagiolo and Valente (2005): Economic systems are composed by many bounded rational agents who interact and compete over time.

Empirical works

Gulati and Gargiulo (1999):

Data: 166 business organizations; Industries (new materials (62), automotive products (52), industrial automation (52)); Countries (Japan (66), USA (54), Europe (46)) - 9 years observation.

Methodology: Formation of alliance is predicted as a function of the intensity of transactions between organizations.

Results: The probability of cooperation between two organizations increases by their endogenous interdependence as mutual alliance (reciprocity), common third part (transitivity). . .

Lomi and Pattison (2006):

Data: supplier-customer network; size 106 firms; sector: production of the means of transportation in Italy.

Methodology: Exponential Random Graph Model (ERGM), p* model - Snjiders (2002).

Results: Ties between firms are formed based on endogenous (network topology) and exogenous attributes (firm characteristics).

Firms choice are based on both strategic and irrational decisions: bounded rationality.

Limits of existent works and research contribution

Limits and critics:

Up to our knowledge, no existent work explains the links formation between firms in the whole economy: Absence of a large view on the macroeconomic dynamic.

Why? Non-Ability of ERGM in its standard form to analyze a large scale network: Very high computational time consumption.

Consequence Absence of a quantification of the firms decision strategy which is essential in the calibration of economic simulation problems.

Research Objective

Exploit recent developments in ERGM literature to construct a **fast** ERG model able to estimate a **large scale network** of the most important firms in the Japanese economy based on a **large set of endogenous and exogenous variables**. Conclude about the ***rationality level*** of the way of how Japanese firms decide about there investment strategies.

ERGM or extended logistic regression

X: Adjacency matrix of unweighted network (directed or undirected). How to explain the existent ties based on multiple attributes $\Omega = \{\omega^1, ..., \omega^K\}$, e.g. age, sex...

Logit model: $\mathrm{Logit}[\Pr(X_{ij} = 1|\theta)] = \log\left(\frac{\Pr(X_{ij}=1|\theta)}{\Pr(X_{ij}=0|\theta)}\right) = \sum_{k=1}^{K} \theta_k \cdot \omega_{ij}^k$: Independence of observations.

Strauss and Ikeda (1990): Logistic regression of network-ties suffers from endogeneity problem: The probability depends on network statistics, e.g. mutuality, transitivity...
$\Rightarrow$ ERGM

To extended the logit model, the probability of ties formation is conditioned to the past network states: $\log\left(\frac{\Pr(X_{ij}=1|X_{-ij}=x_{-ij},\theta)}{\Pr(X_{ij}=0|X_{-ij}=x_{-ij},\theta)}\right) = \sum_{k=1}^{K} \theta_k \cdot \delta_{ij}^k$: endogenous and exogenous attributes.

Canonical form of ERGM: $\Pr(X = x|\theta) = \frac{1}{\kappa(\theta)} \cdot \exp\left(\sum_{k=1}^{K} \theta_k \cdot z_k(x)\right)$; **Objective:** estimation of $\Theta = (\theta_1, ..., \theta_k)$

Endogenous attributes, Snijders et al. (2006) and Hunter (2007)

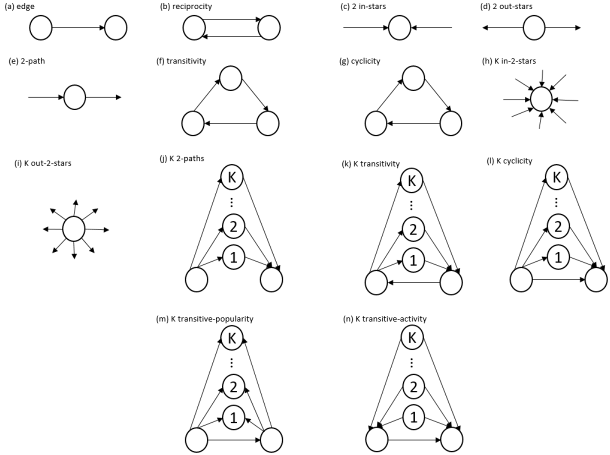

Figure: (a) Bernoulli model, Frank and Strauss (1986); (a) + (b) + ... + (g) Markov model, Snijders (2002); (a) + (b) + ... + (n) Social circuit model, Hunter (2007)

Stochastic Approximation (SA), Robins-Monro algorithm, Snijders (2002)

Phase 1: Initialization

1- Generate M_1 samples of network with configurations $(z_1, \ldots, z_{M_1})$.

2- z the configuration of the real network; $\bar{z}_s$ and D_s are the mean and covariance matrix of the sampled configurations.

3- Update: $\theta_0 = \tilde{\theta} - a \times D_0^{-1} \times (\bar{z}_s - z)$, $D_0 = diag(D_s)$.

Phase 2: Stochastic update

Repeat this process until convergence

Loop 1: r from 1 to max-phases

Loop 2: r_{sub} from 1 to max-sub-phases

1- Generate one sample of network with configuration z_s

2- Update: $\theta_t = \theta_{t-1} - a \times D_0^{-1} \times (z_s - z)$

End Loop 2, $a = a/2$, and correlation test: **If** $(z_s - z) \times (z - z_s^{-1}) < 0$, Go to phase 3, **Else** Continue Loop 1

End Loop 1

Phase 3: Convergence test

1- Calculate the $t-ratio$ for all attributes j

2- **If** $\max_j(t - ratio_j) \leq 0.10$ Convergence, **Else:** Go to phase 2

Fast sampling algorithm: Improved Fixed Density MCMC, Byshkin et al. (2016)

Objective: With the current value of θ, generate based on an MCMC sampling a network with average total edges $= \pm$ to the average observable edges $\Rightarrow$ Make the convergence of the SA method much faster with less iterations.

Loop 1: r from 1 to IFD-max

$N_A = 0, N_D = 0$ (A: Add, D: Delete)

While $N_A + N_D < m$

Step 1: $N_A+ = 1$; add one edge randomly to the network; calculate the change statistics z^+; calculate the probability $P = \exp(\sum \theta_i \cdot z_i^+)$

if $P \geq RN$ go to step 2, **Else** repeat Step 1, without keeping the new change

Step 2: $N_D+ = 1$; delete one edge randomly to the network; calculate the change statistics z^+; calculate the probability $P = \exp(\sum \theta_i \cdot z_i^+)$

if $P \geq RN$ go to Step 1, **Else** repeat Step 2, without keeping the new change

Supplier-customer network of firms in the Tokyo Stock Exchange

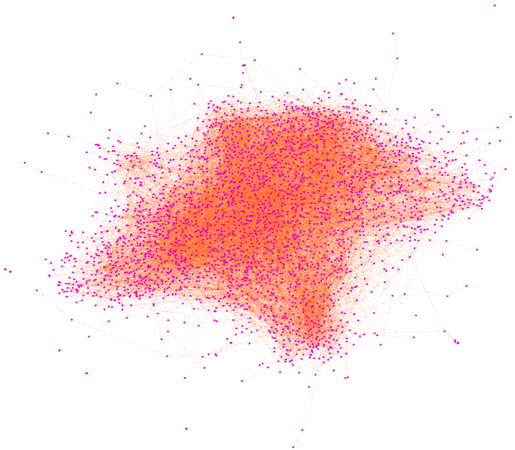

Figure: A sub-production network of firms belong to the Tokyo Stock Exchange: 3.198 firms with 20.514 links.

Economic assumptions and model attributes

Firms may make trading connection based on their **social attributes (network specificity)**[a] and **economic attributes**[b].

a: We consider a social circuit model of curved ERGM, Hunter (2007), (details in Slide 9): 9 endogenous attributes are considered.

b: Three economic attributes are considered:

1. Sector (sector homophily) and Location (location homophily): works as Chakraborty et al. (2017) and Krichene et al. (2017) showed the economic role of sectors and locations in explained the production network structure. Homophily of an attribute y: $\sum_{i,j} x_{ij} y_i y_j$.

2. Profit (profit sender, profit receiver and profit heterophily effects): significant influence of profit on the production network structure is showed in Krichene et al. (2017). For an attribute y, sender effect: $\sum_{i,j} x_{ij} y_i$, receiver effect: $\sum_{i,j} x_{ij} y_i$, heterophily effect: $\sum_{i,j} x_{ij} |y_i - y_j|$.

Model validation (GoF): reproduction of some stylized facts (1/2)

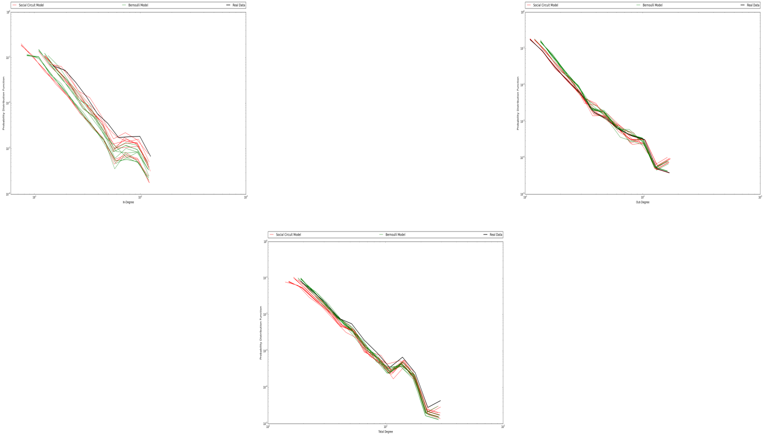

Figure: Reproduction of the network degrees stylized facts. Following the GoF ratio proposed in Hunter al. (2008), **all degrees attributes have ratio less than 2: high Goodness of Fit**. Black line: real network, Red lines: 20 simulated networks based on **Metropolis MCMC sampling**.

Model validation (GoF): reproduction of some stylized facts (2/2)

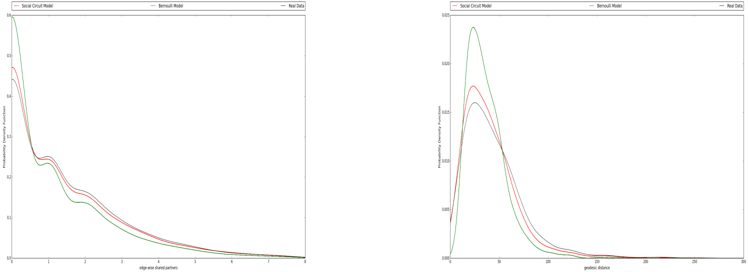

Figure: Reproduction of the network transitivity stylized facts. Following the GoF ratio proposed in Hunter al. (2008), **all transitivity attributes have ratio less than 2: high Goodness of Fit**. Black line: real network, Red lines: 20 simulated networks based on **Metropolis MCMC sampling**.

Estimation results

Table 2. Estimation results of ERG model applied on production network of firms belong to the Tokyo Stock Exchange. All endogenous and exogenous attributes are highly significant based on the p-value.

Attributes	$\hat{\theta}_{MLE}$	$s.e(\hat{\theta}_{MLE})$	p-value	Attributes	$\hat{\theta}_{MLE}$	$s.e(\hat{\theta}_{MLE})$	p-value
Degree	-4.05	0.01	≤ 0.01	Profit Sender	$2.31 \cdot 10^{-07}$	$9.61 \cdot 10^{-10}$	≤ 0.01
Reciprocity	1.15	0.004	≤ 0.01	Profit Receiver	$1.02 \cdot 10^{-07}$	$4.10 \cdot 10^{-10}$	≤ 0.01
In-Stars	2.01	0.004	≤ 0.01	Out-Stars	2.04	0.005	≤ 0.01
Sector Homophily	0.59	0.005	≤ 0.01	Location Homophily	0.16	0.002	≤ 0.01
Two-Path	-0.02	$9.08 \cdot 10^{-05}$	≤ 0.01	Profit Heterophily	$8.37 \cdot 10^{-08}$	$4.43 \cdot 10^{-10}$	≤ 0.01
AT-T	0.06	0.0007	≤ 0.01	AT-U	0.17	0.0005	≤ 0.01
AT-C	0.13	0.002	≤ 0.01	AT-D	0.20	0.0008	≤ 0.01

Economic interpretation: how firms make their relationships?

General observation: Both endogenous and exogenous attributes are significant is the production network ties formation. Firms take their investment decisions based on both economic and relational (mutuality, common partners...) reasons. We cannot say that the firm decision is completely rational or completely irrational $\Rightarrow$ Firms is the Japanese economy behave with a bounded rationality strategy.

Relational strategy (endogenous attributes):

- Negative degree: low network density; Positive reciprocity: significant presence of mutual trading aspect; Negative two-path: presence of disassortative mixing.
- Positive in-stars: higher activity of active firms; Positive out-stars: higher popularity of popular firms.
- Positive triangulation: for all configurations (transitivity or cyclicity) common commercial links are probable.

Economic strategy (exogenous attributes):

- Sector: firms with similar sector have more chance to establish a trading relationship.
- Location: firms trading choice is significantly based on geographic location.
- Profit: with the sender and receiver effects, firms with more activity and more popularity will have more trading connections. With the profit heterophily, firms with low profit tend to establish relationships with firms with high profit (disassortative mixing).

Conclusion

- Japanese production network is characterized by significant boost and bust period (see Krichene et al. (2017) about the business cycles correlation in the production network).
- These economic performance and contractions were explained by the bounded rationality of economic agents (see literature in the introduction).
- A production network of biggest firms was considered to verify the assumption of bounded rationality.
- Application of a fast ERGM algorithm: firms choice their strategies based on both social and economic decisions: firms in the production network have a bounded rationality which explain the economic fluctuations, the period of expansions and the period of crisis.
- Other results concerning each attributes have been shown.

Further research

- Apply this model for multiple communities ($\approx$ 1000 communities) of medium sizes ($\approx$ 500 firms) in order to have a significant representation of the production network in terms of firms heterogeneity: Apply this ERGM in parallel using K computer.
- Decompose the production network using a sampling technique (e.g. snowball sampling) and try an estimation of the whole production network based on 20.000 samples of average size of 500 firms. Estimation in parallel using K computer.
- Extend the current ERGM model to a bipartite ERGM model to explain the dynamic of the Bank-Firms network.