



Early-warning Signals in Interbank Transactions: Evidence from Japan

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Outline

1. Motivation
2. Data
3. Methodology
4. Results
5. Preliminary Conclusions and Next Steps

1. Motivation

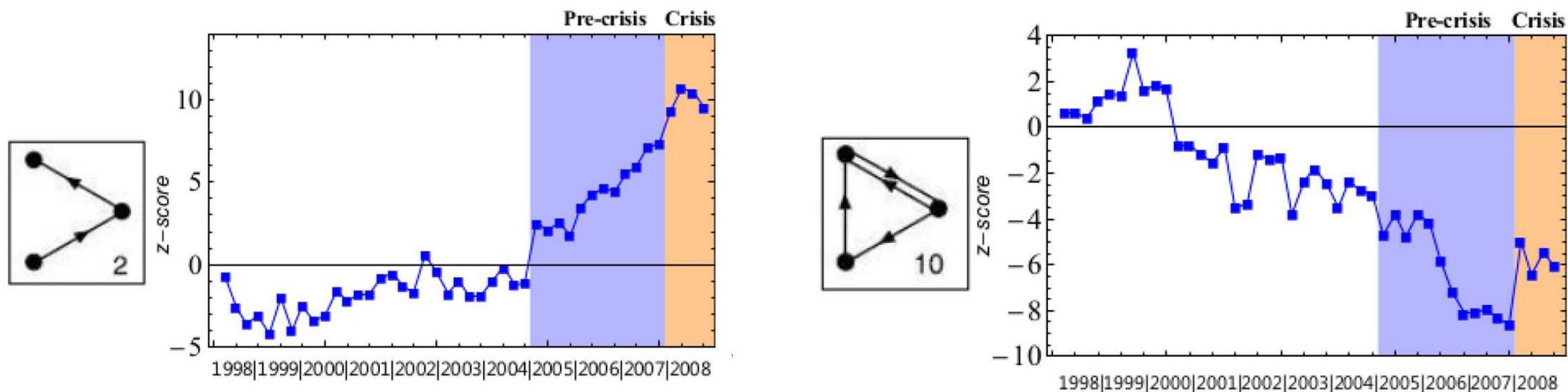
- The global financial crisis has led to much effort to analyze the stability of interbank markets.
- The stability of markets highly depends on the network structure as distress is not independent.
- Previous studies around the propagation of contagion risk mainly have focused on **a given and static topology**.
- Topologies of interbank networks are highly dynamic.



Little is known about **the interplay between exogenous shocks and topological changes.**

1. Motivation

- Squartini, et al. (2013) showed that higher-order local topological properties of the interbank network (= “network motifs”) can help us **see the changes 3 years in advance of the crisis.**



- They analyzed the Dutch interbank network based on the prudential reports.
 - ✓ The existence of **exposures of more than 1.5 million euros** with maturity shorter than 1 year.

Squartini, T., van Lelyveld, I. and Garlaschelli, D. (2013), “Early-warning signals of topological collapse in interbank networks”. Sci. Rep., 3, 3357.

1. Motivation

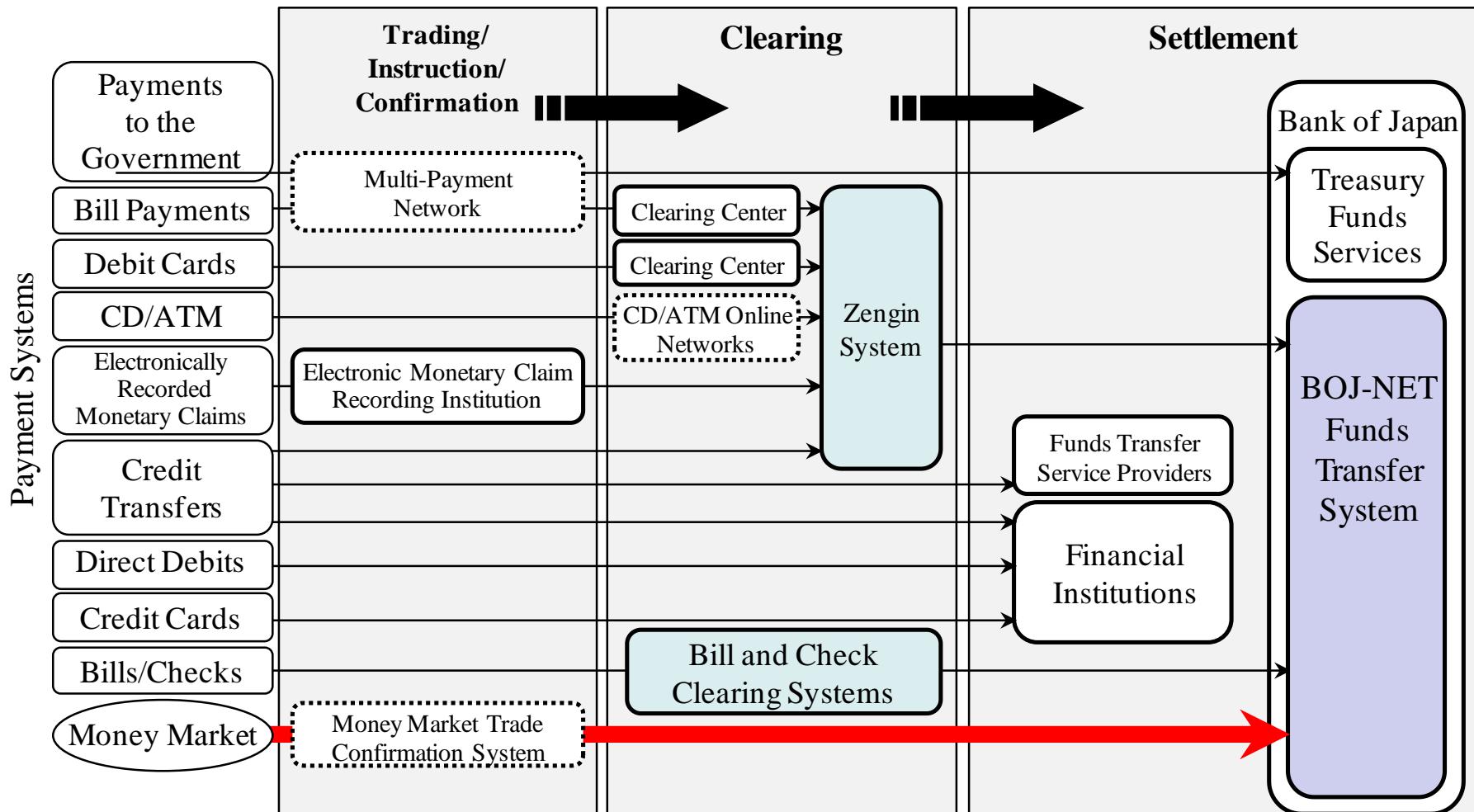
- Two main questions;
 - ✓ **Can we get any topological precursors from the transaction data?**
 - NOT a liability network which is constructed from estimated bilateral exposures (Furfine method (1999))
 - All the payment behaviors of FMIs participants
 - ✓ **If so, how can these topological changes affect the stability of the markets?**
 - The economic functions of network motifs
- Contributions;
 - ✓ Participants' behaviors before/after crisis
 - ✓ The economics of network formation

Outline

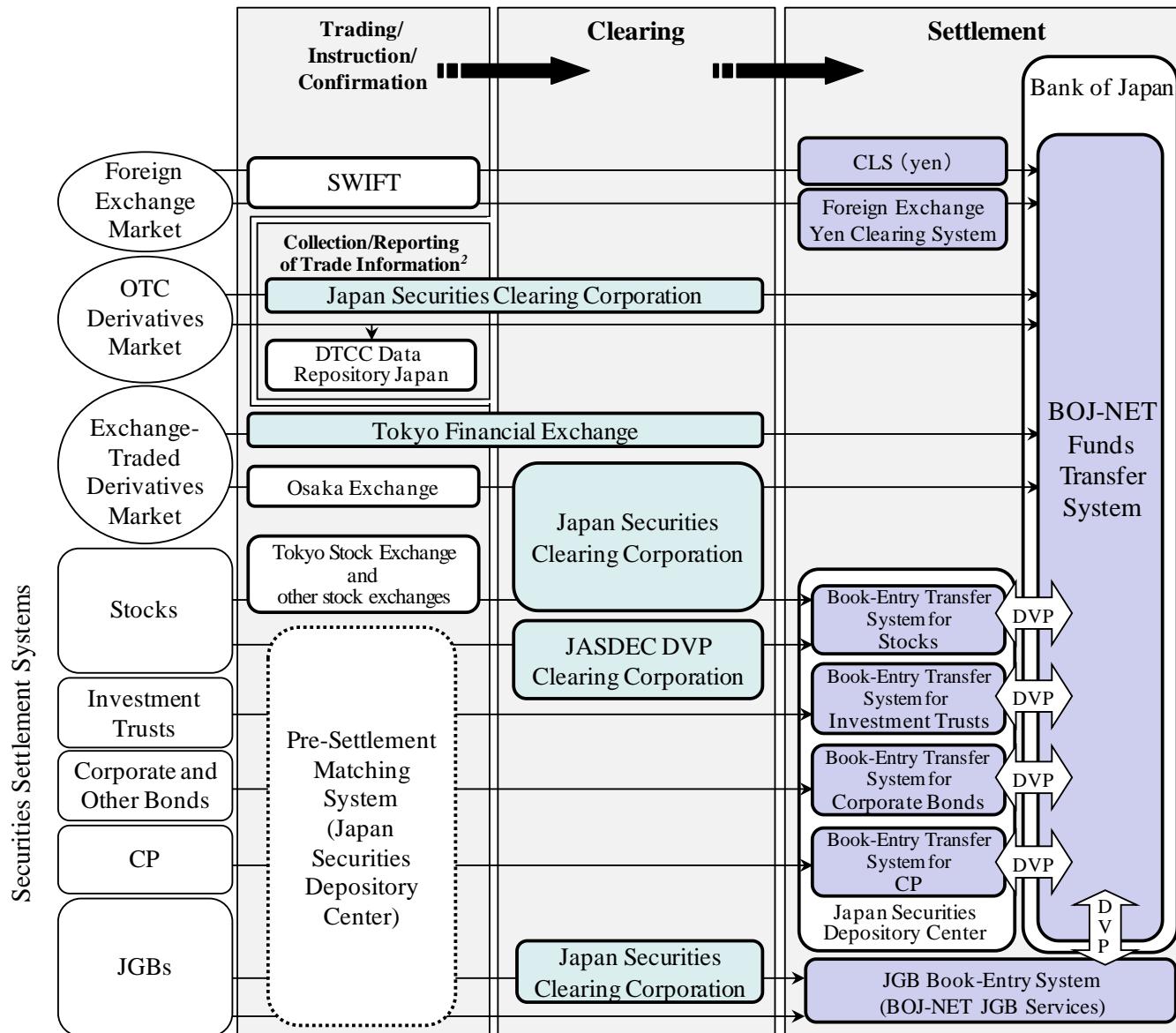
1. Motivation
2. **Data**
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2. Data – Japan Payment Landscape

- The BOJ-NET, the core payment and settlement system among Japan's FMIs.



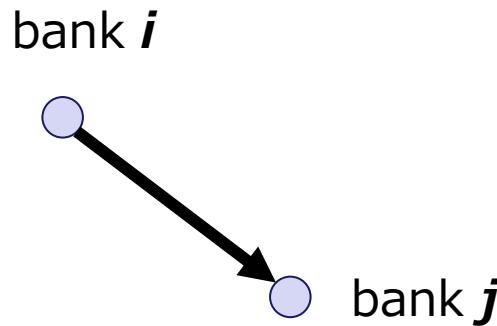
2. Data – Japan Payment Landscape



2. Data

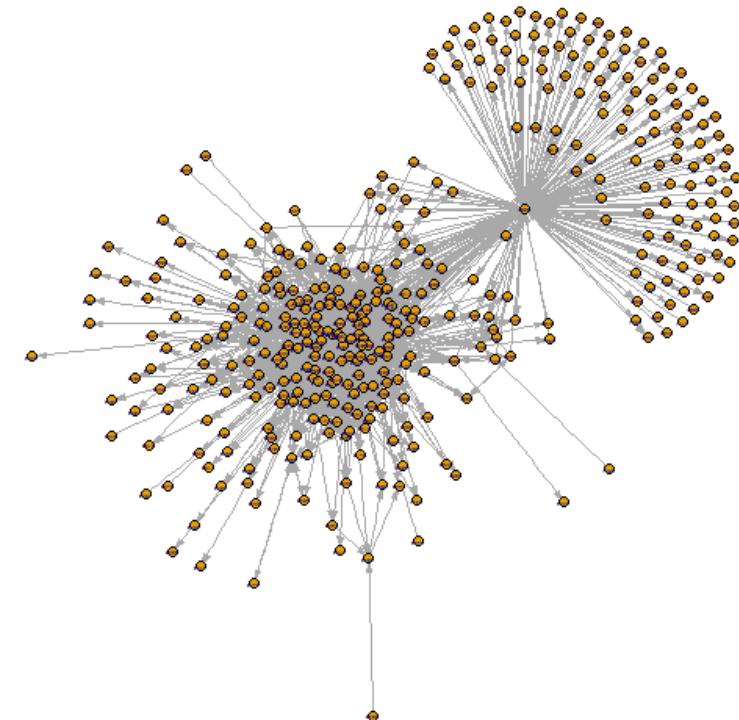
- Transaction-level settlement data for 3,619 business days.
(June 1, 2001 to March 31, 2016)
- “Binary” directed network for each day.

【binary directed representation】



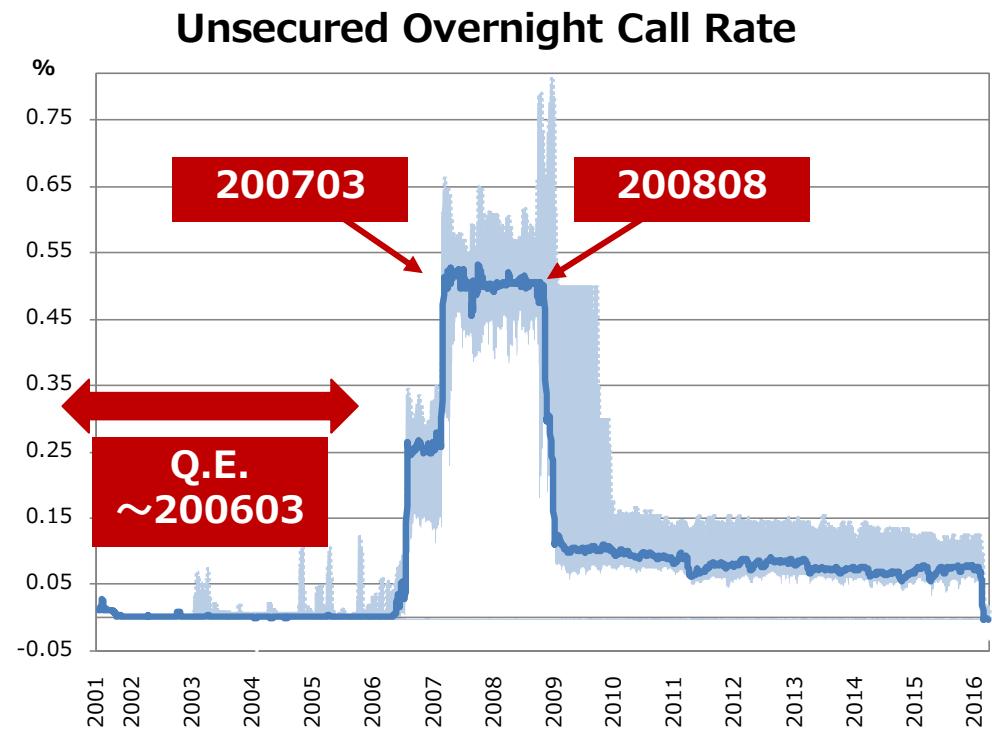
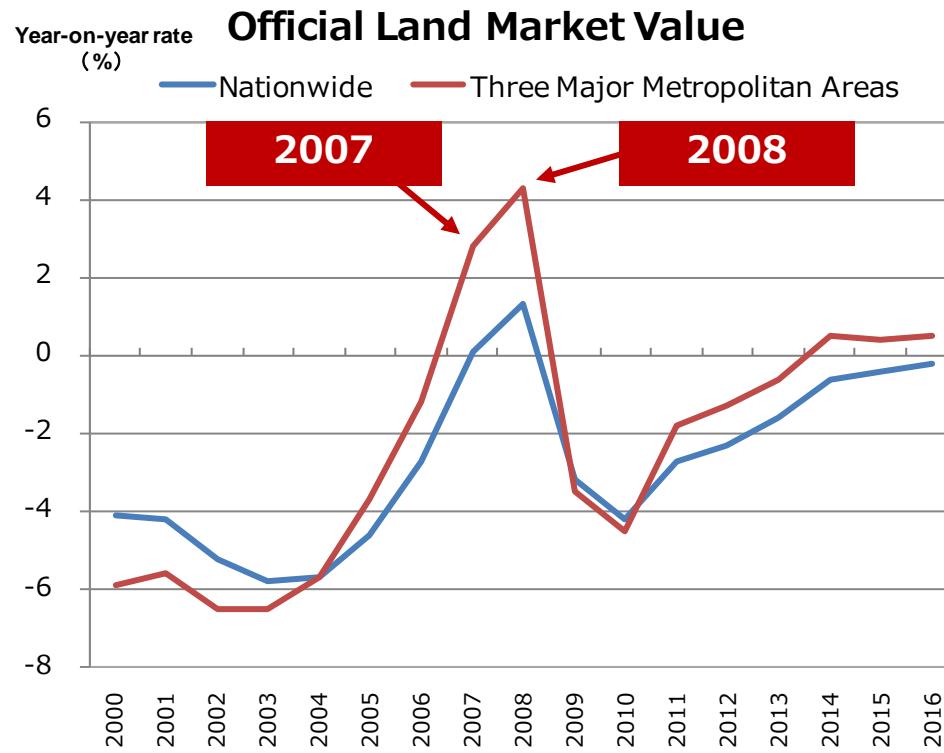
bank *i* sends the money
to bank *j* on the day

【snapshot on March 31, 2016】



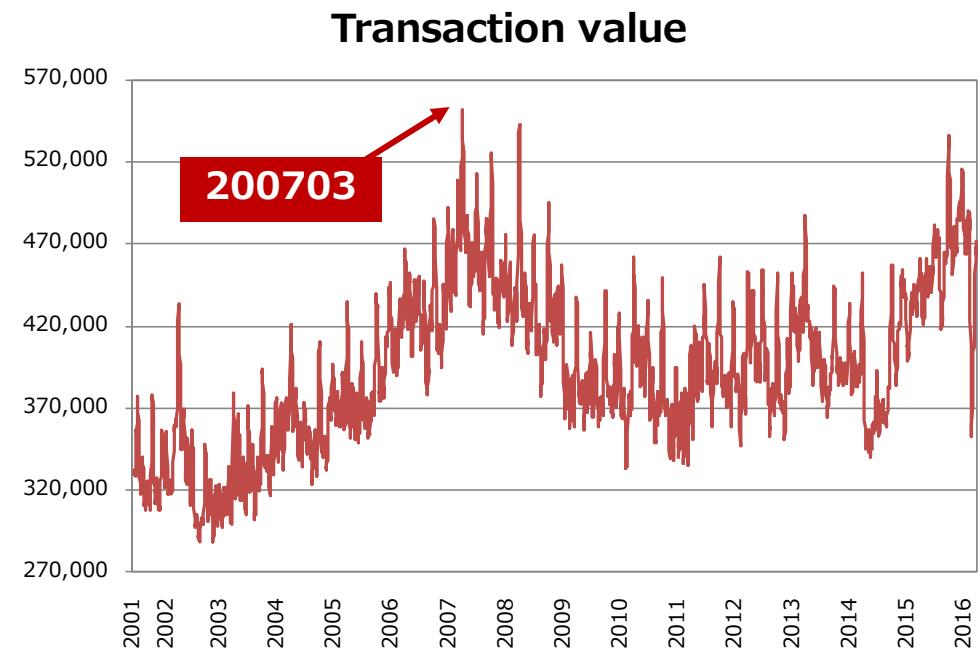
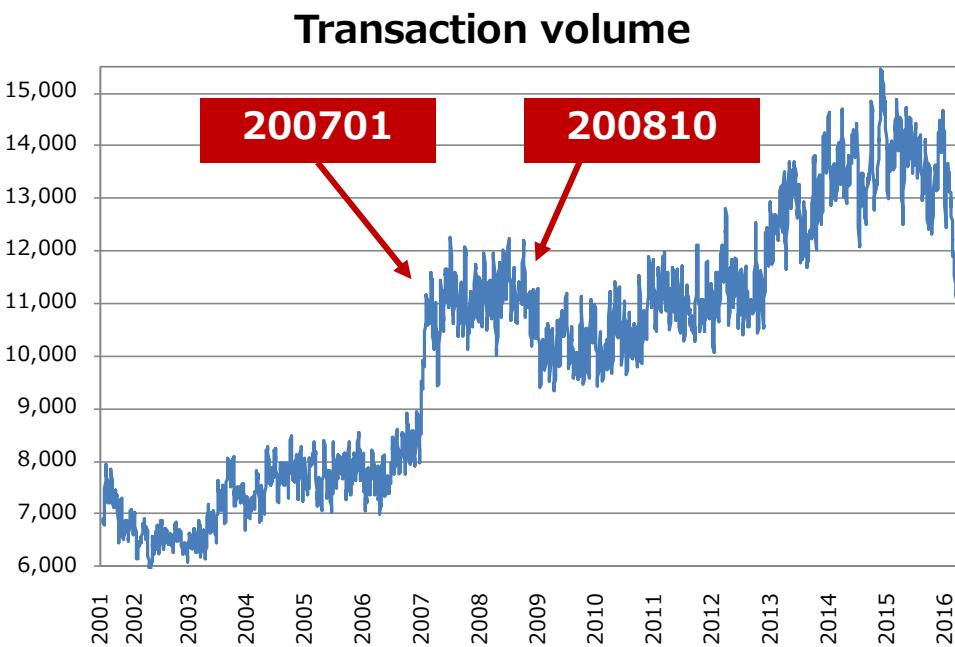
2. Data – Before The Global Financial Crisis

- Gradual recovery phase from 2002 to 2008.
- The increase of O/N call rate after the BOJ lifted;
 - ✓ The quantitative easing policy (March, 2006)
 - ✓ The zero-interest-rate policy (July, 2006)



2. Data – Observed Values

- Visible change in the basic properties (transaction volume/value) due to “Mini-bubble economy” / the BOJ monetary policy.

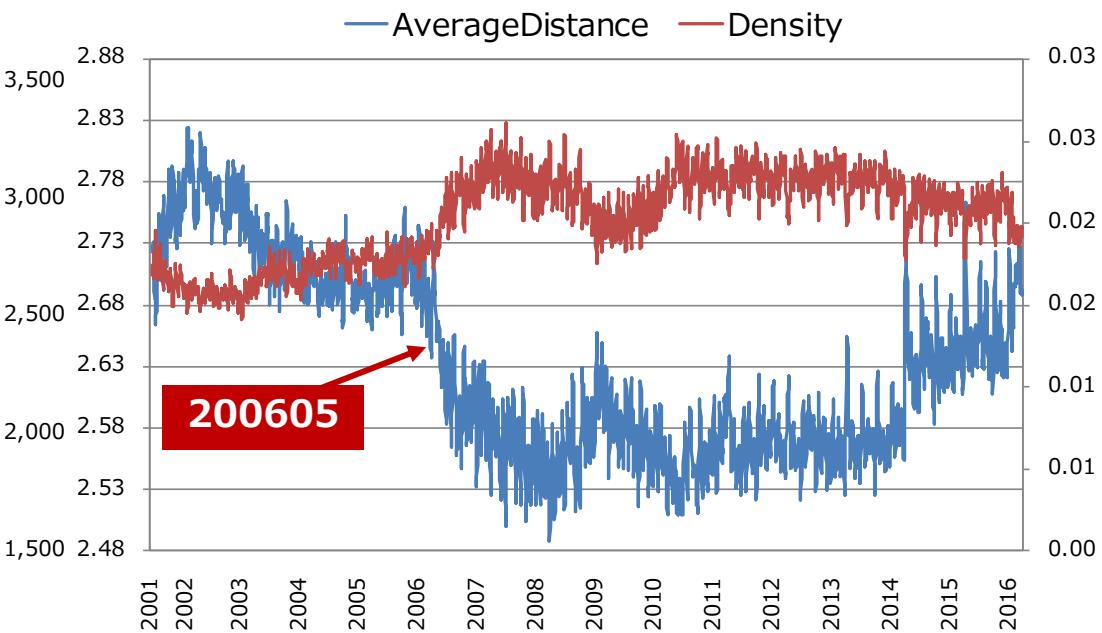
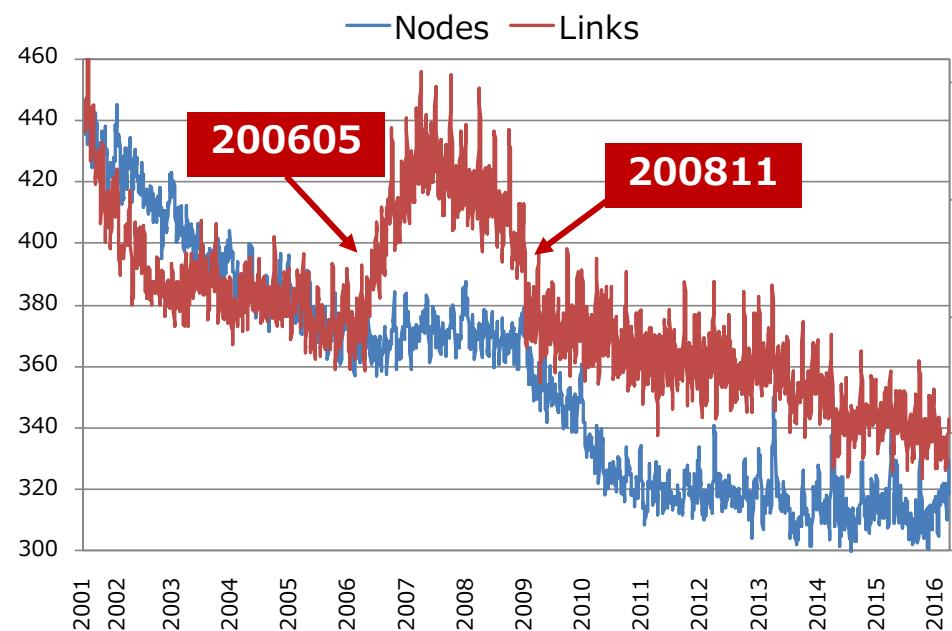


10-day moving averages are plotted.

2. Data – Observed Values

- Similar changes in the global and local topological properties of the interbank network.

【global properties】

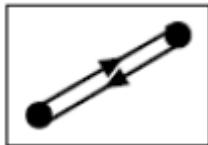


2. Data – Observed Values

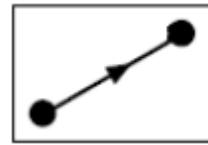
- To assess the statistical significance of the observed values, **a model of comparison (= “null model”)** is needed.

【local properties (dyadic-motifs)】

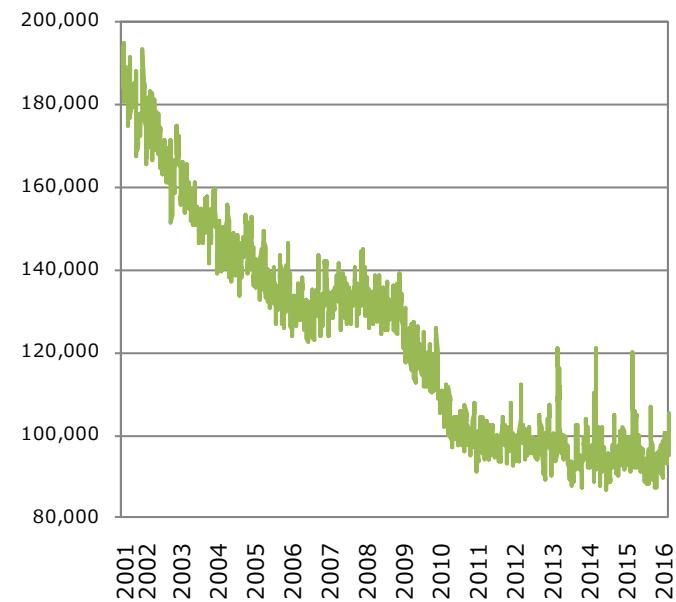
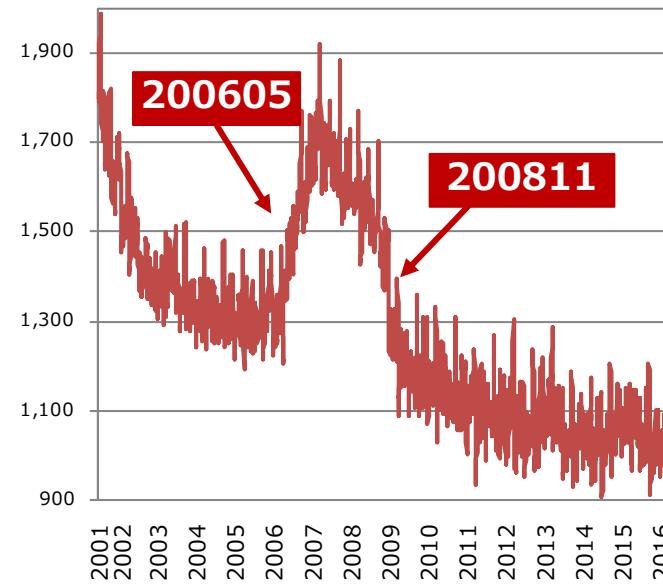
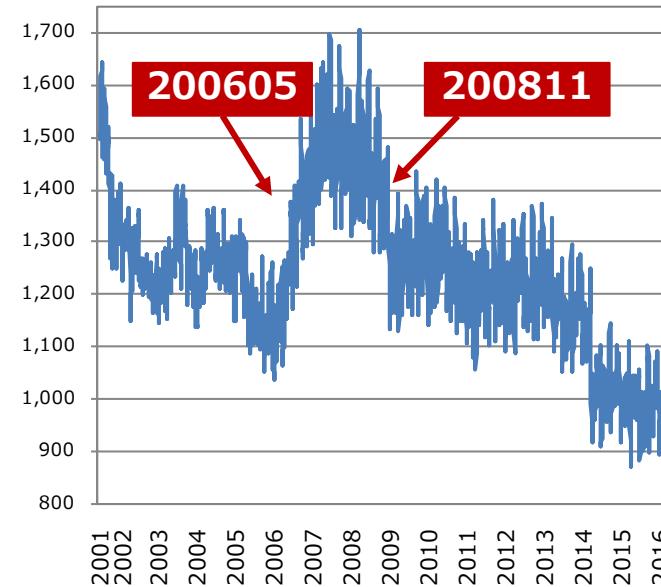
Full dyads
(reciprocated)



Single dyads
(non-reciprocated)



Empty dyads
(disconnected)

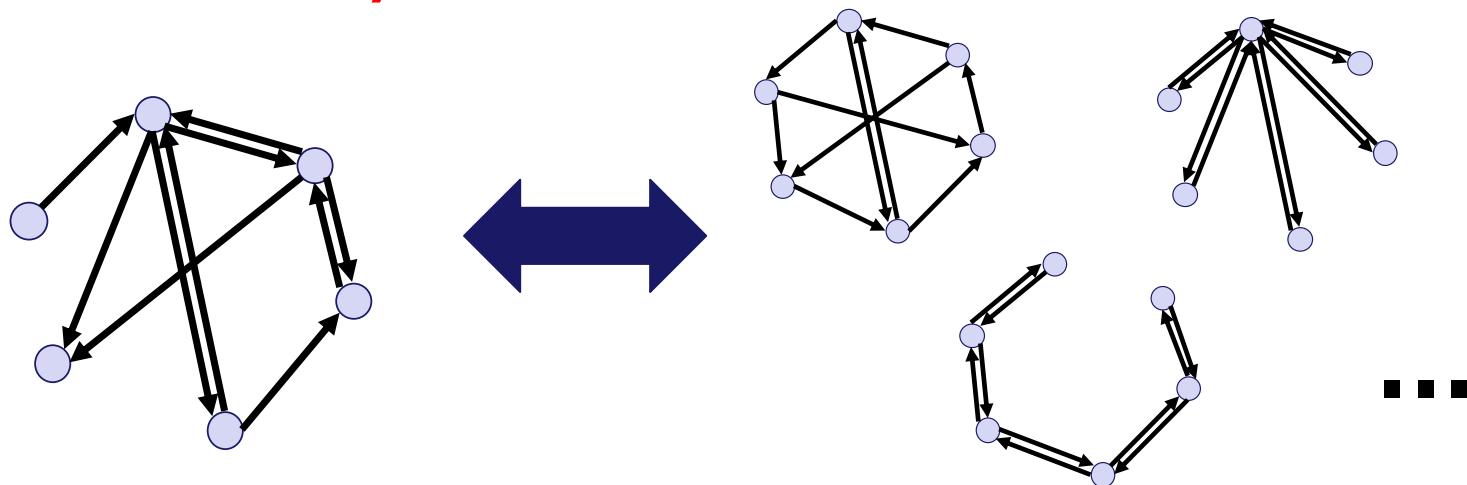


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2. Data
- 3. Methodology**
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3. Methodology - Overview

1. Choosing some observed topological quantities as constraints.
 - ✓ # of links, degree distribution, strength distribution etc.
2. Defining **an ensemble of networks** with the chosen constraints.
 - ✓ **This ensemble preserves chosen constraints, and is otherwise fully random.**



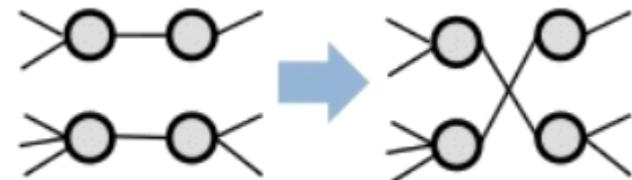
3. Comparing the observed values with the ensemble averages.
 - ✓ z-score/p-value is used to quantify the deviation between the data and the null model.

3. Methodology – Null Model

A) Computational – microcannocial ensemble

- ✓ Many randomized variants.
- ✓ Chosen constraints are met exactly by each variant.
 - time-consuming
 - biased
 - inflexible

[local rewiring algorithm (2002)]



B) Analytical - (grand)cannocial ensemble

- ✓ Mathematical expressions.
- ✓ Chosen constraints are met on average.
 - **fast**
 - **unbiased** (uniformly)
 - **versatile** (directed/undirected, binary/weighted)

3. Methodology – Null Model

- Maximum-likelihood estimation of Maximum-entropy models
 - ✓ Maximum-entropy (unbiased)

$$\text{maximize} \quad S = - \sum_G P(G) \ln P(G)$$

$$\text{subject to} \quad \sum_G P(G) = 1, \quad \langle \vec{C} \rangle = \vec{C}(G)$$

$$\rightarrow P(G | \vec{\theta}) = \frac{e^{-H(G, \vec{\theta})}}{Z} = \frac{e^{-\vec{\theta} \cdot \vec{C}(G)}}{Z}$$

a probability distribution over a grandcannocial ensemble of networks

Park, J., Newman, M.E.J. (2004), "Statistical mechanics of networks". Phys. Rev. E, 70, 066117

3. Methodology – Null Model

- ✓ Maximum-likelihood estimation of Θ (fast/versatile)

$$\text{maximize } L(\vec{\theta}) \equiv \ln P(G^* | \vec{\theta}) = -H(G^*, \vec{\theta}) - \ln Z(\vec{\theta})$$

where G^* is a real network

$$\rightarrow \langle \vec{C} \rangle_{\vec{\theta}^*} = \sum_G \vec{C}(G) P(G | \vec{\theta}^*) = \vec{C}(G^*)$$

$$\left\{ \begin{array}{l} \langle X \rangle^* = \langle X \rangle_{\vec{\theta}^*} = \sum_G X(G) P(G | \vec{\theta}^*) \\ \sigma[X] = \left\langle [X(G^*) - \langle X \rangle^*]^2 \right\rangle = \sum_{i,j} \sum_{t,s} \sigma[g_{ij}, g_{ts}] \left(\frac{\partial X}{\partial g_{ij}} \frac{\partial X}{\partial g_{ts}} \right) \end{array} \right.$$

Squartini, T., Garlaschelli, D. (2011), "Analytical maximum-likelihood method to detect patterns in real networks". New J. Phys., 13, 083001.

3. Methodology – Null Model

- The deviation is measured by significance profile.

$$SP_m = \frac{z_m}{\sqrt{\sum_m z_m^2}}$$

Relative importance of each motif with respect to others.

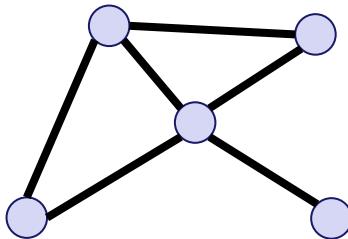
- **positive = over-represented**
- **negative = under-represented**

where $z_m = \frac{X_m - \langle X_m \rangle}{\sigma[X_m]}$

$$X = X(G^*), \quad \langle X \rangle^* = \langle X \rangle_{\vec{\theta}^*}, \quad \sigma[X] = \left\langle [X(G^*) - \langle X \rangle^*]^2 \right\rangle$$

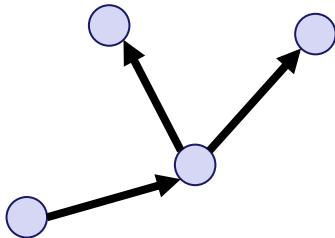
3. Methodology – Constraints

- **Directed Random Graph (DRG)**



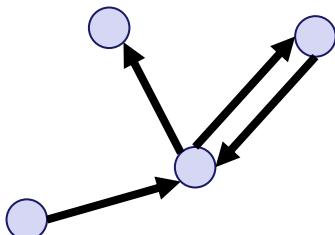
$$C = L \quad \text{total number of links}$$

- **Directed Configuration Model (DCM)**



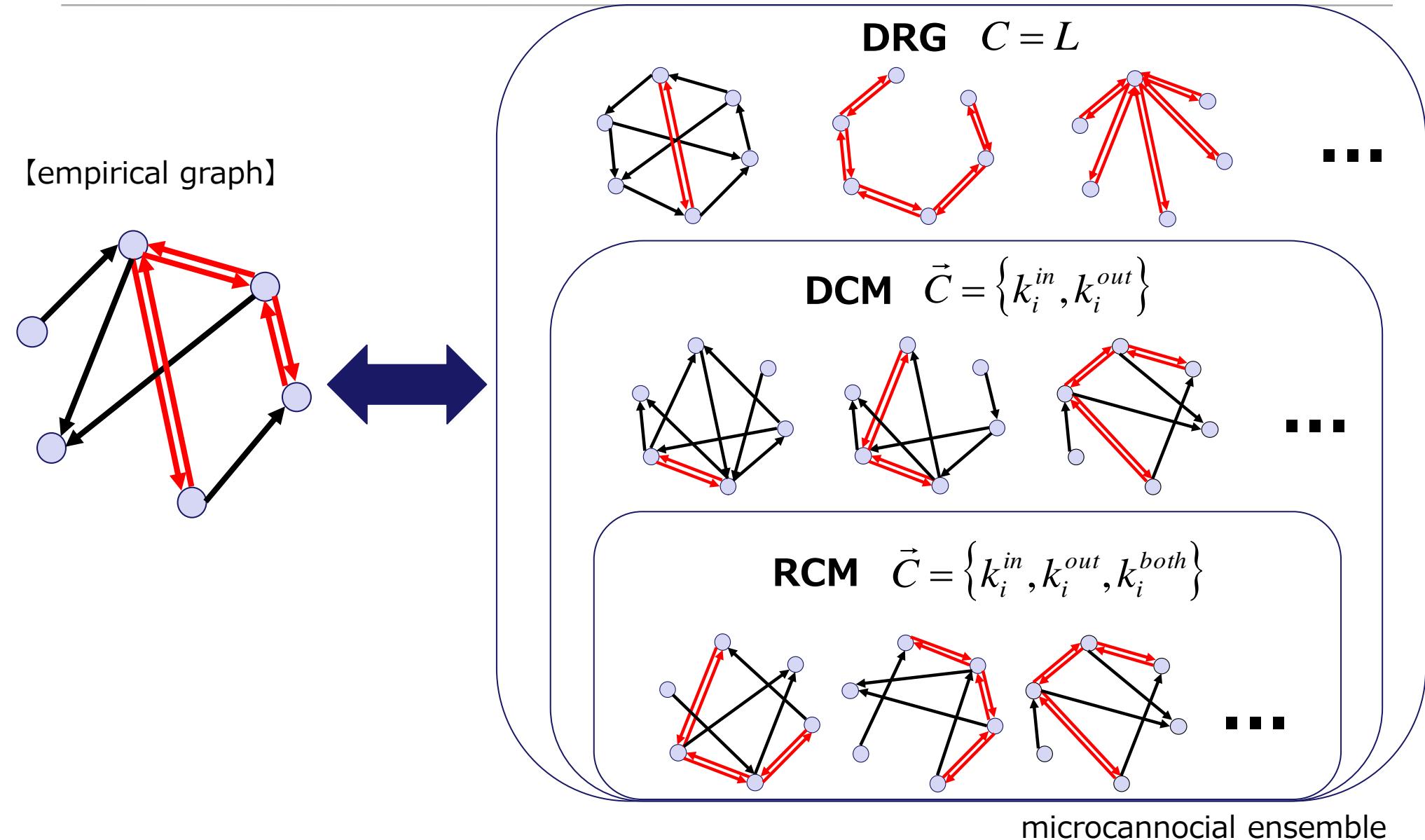
$$\vec{C} = \left\{ k_i^{in}, k_i^{out} \right\} \quad \text{in-degree & out-degree}$$

- **Reciprocal Configuration Model (RCM)**



$$\vec{C} = \left\{ k_i^{in}, k_i^{out}, k_i^{both} \right\} \quad \text{in-degree & out-degree & reciprocal degree}$$

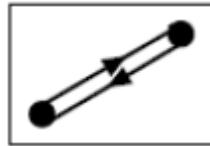
3. Methodology – Constraints



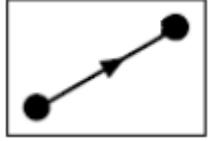
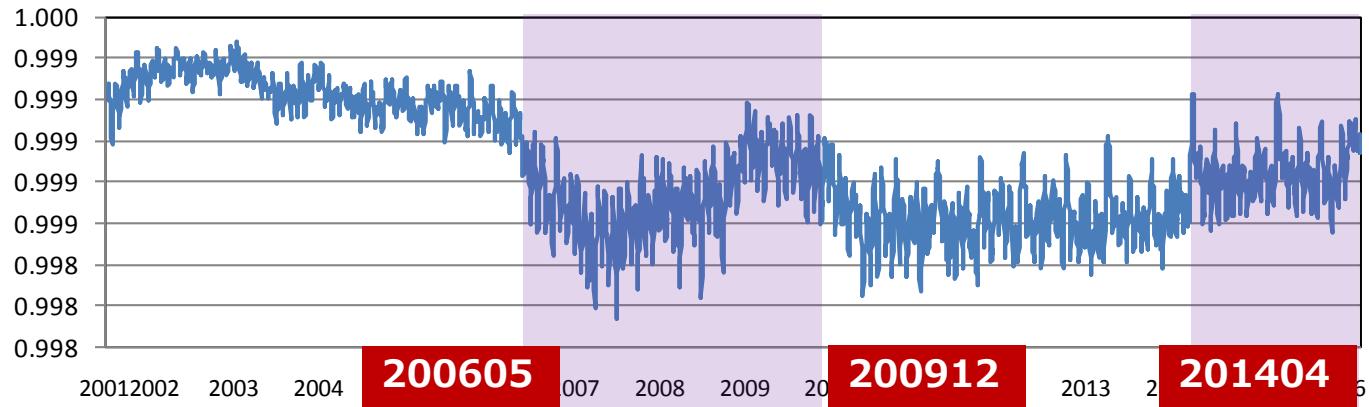
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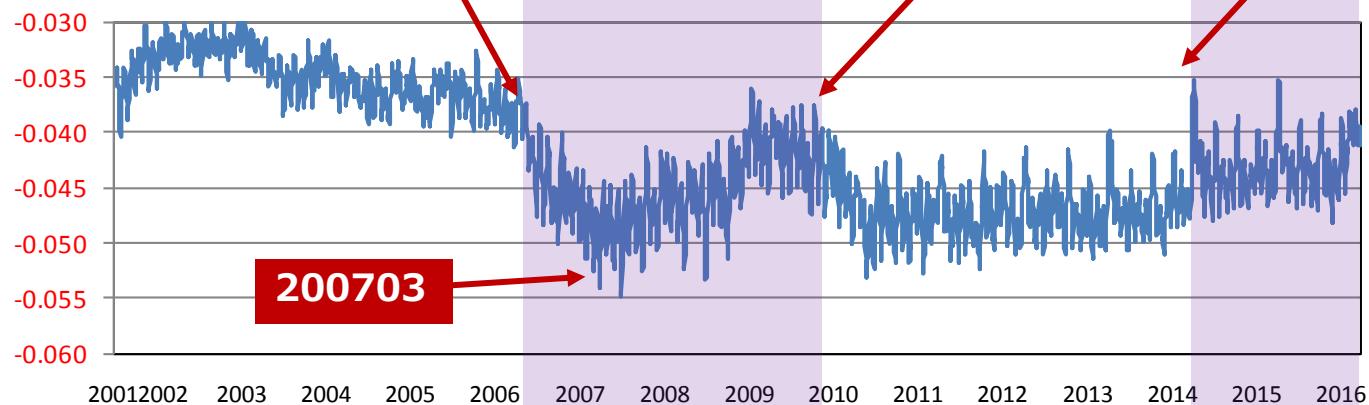
DRG ($C = L$)



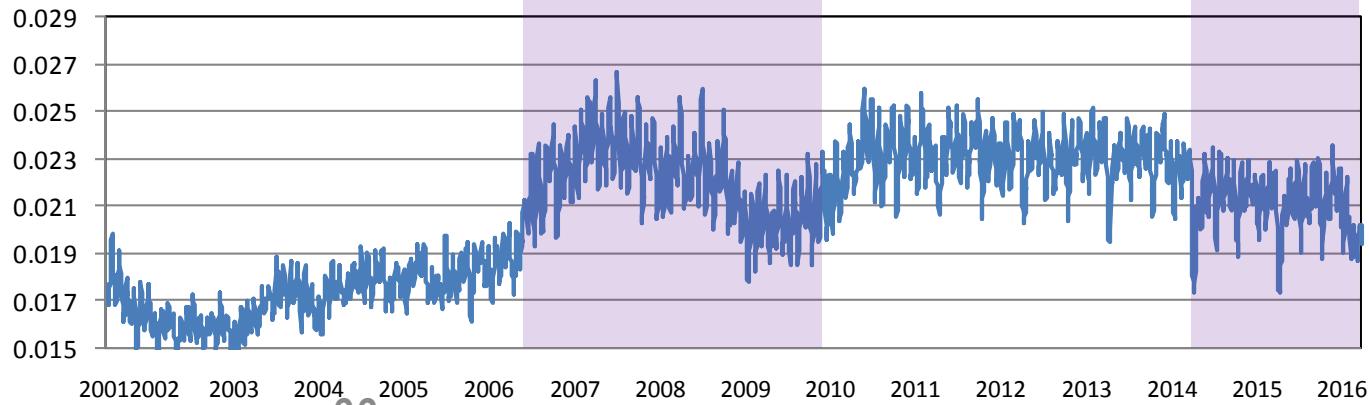
Full dyads
(reciprocated)



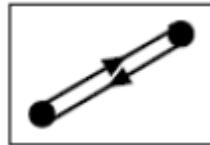
Single dyads
(non-reciprocated)



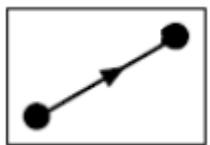
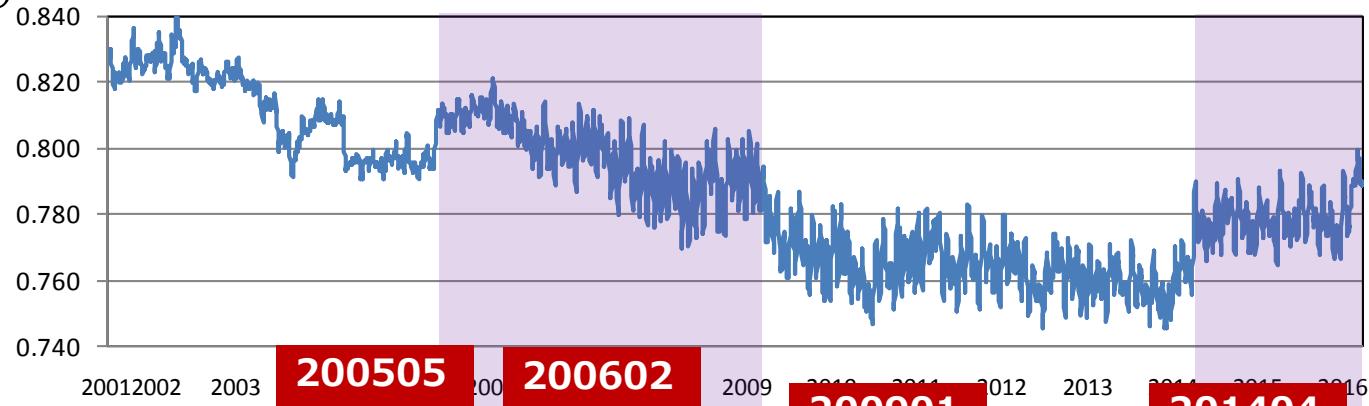
Empty dyads
(disconnected)



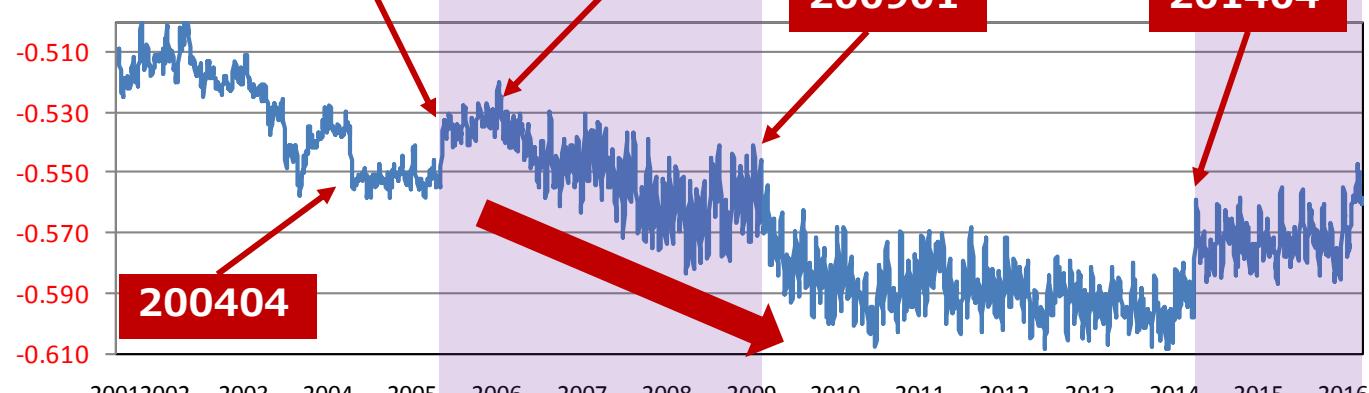
DCM ($\vec{C} = \{k_i^{in}, k_i^{out}\}$)



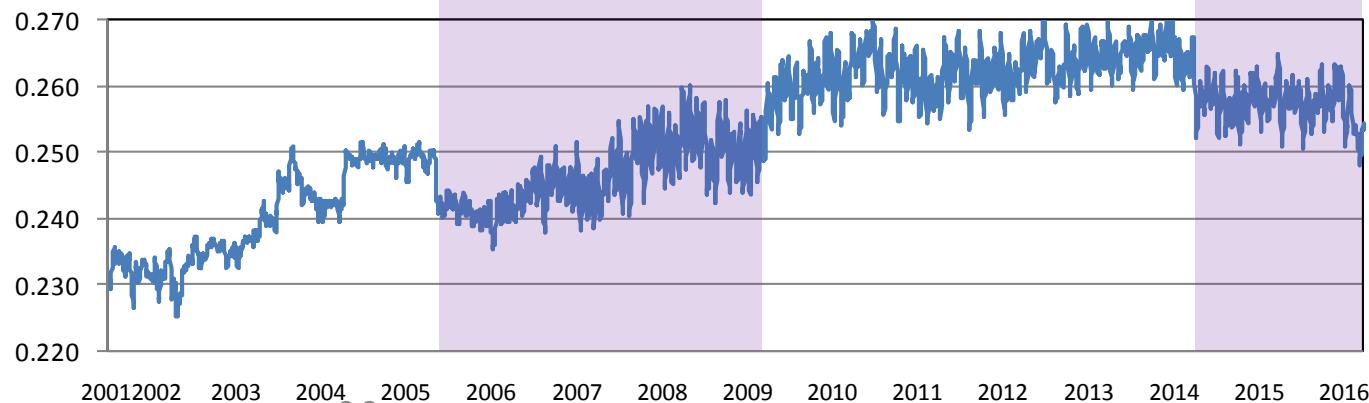
Full dyads
(reciprocated)



Single dyads
(non-reciprocated)

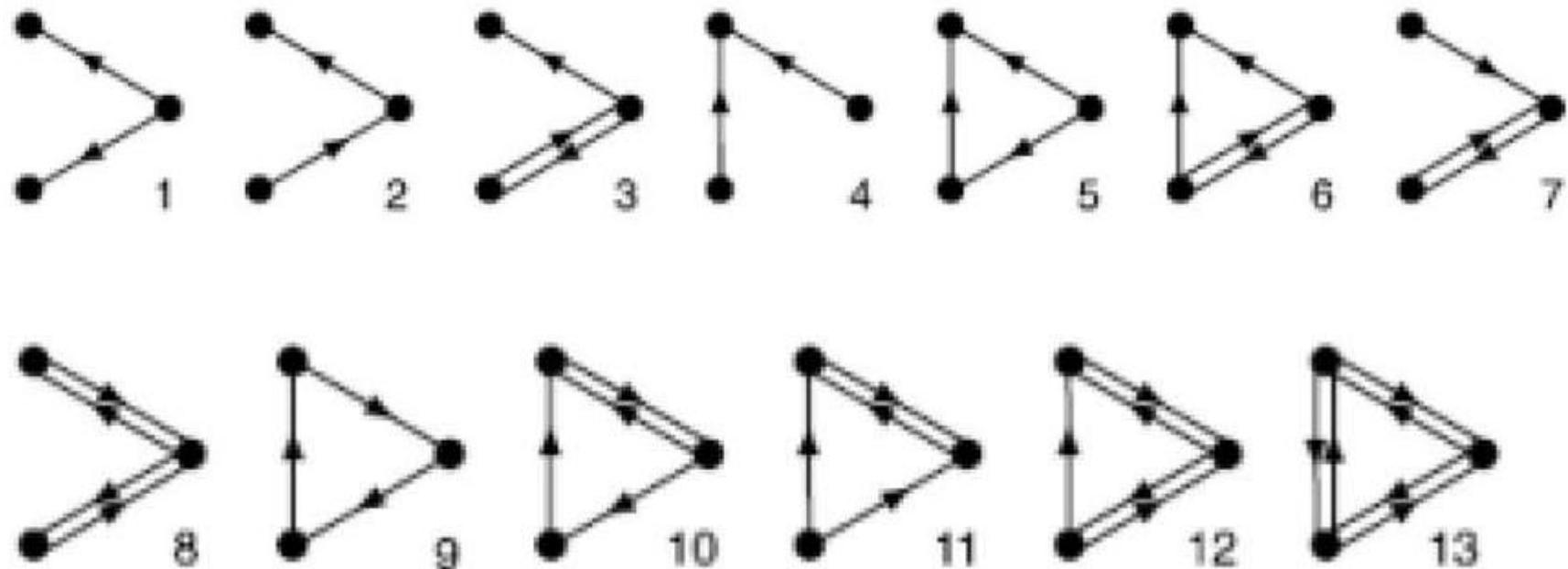


Empty dyads
(disconnected)

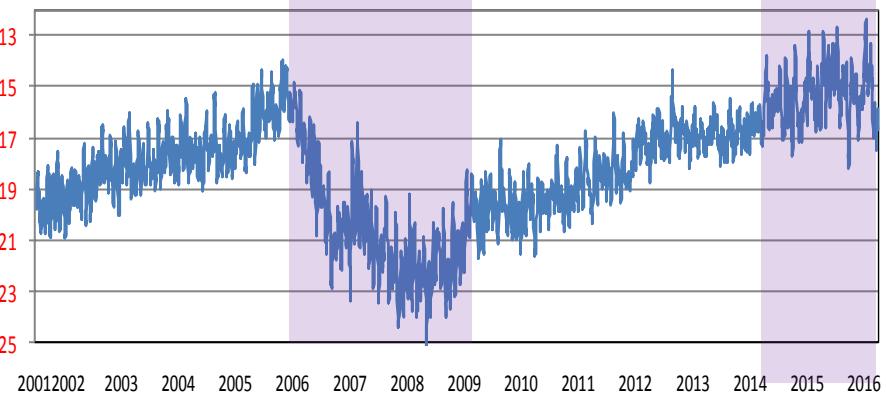
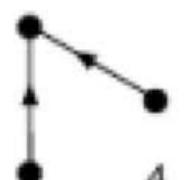
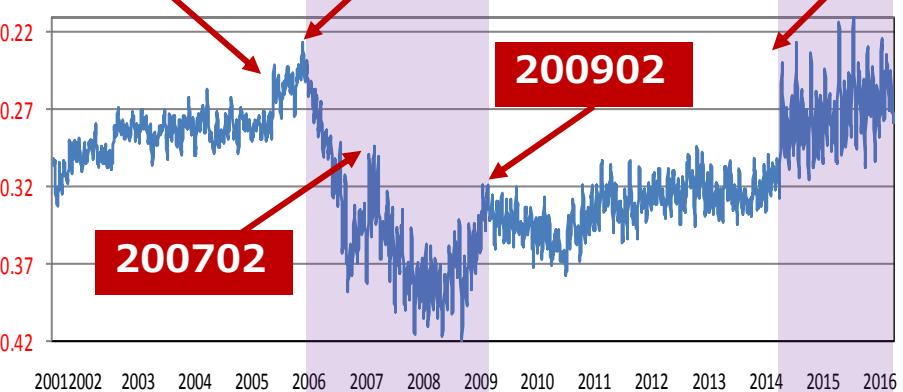
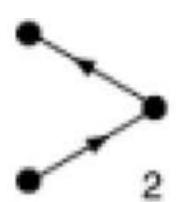
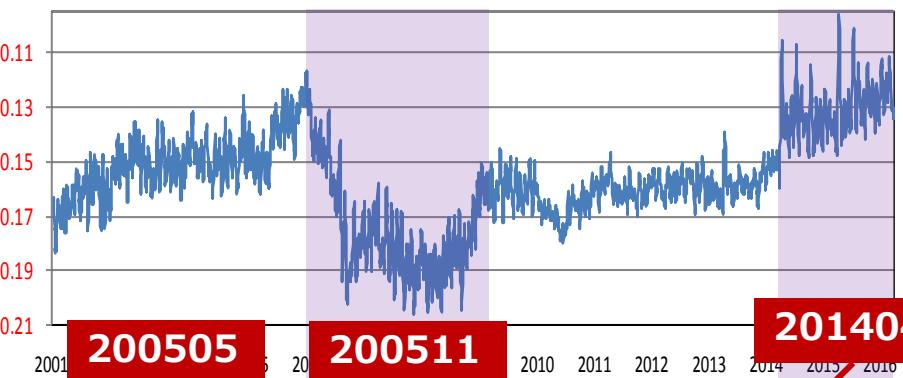


4. Results

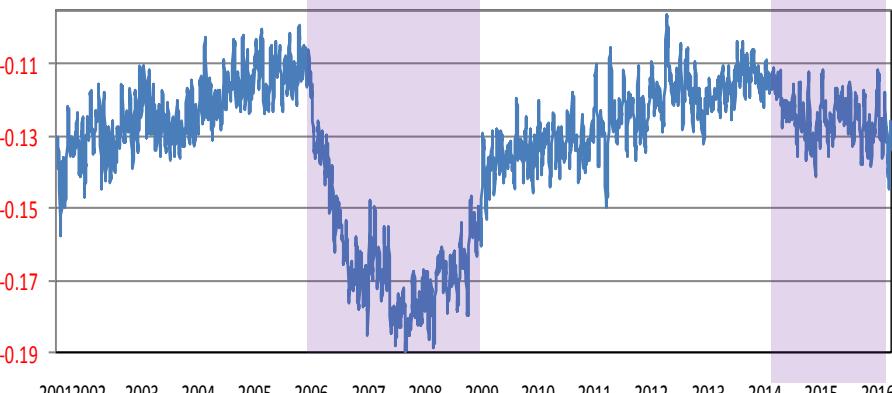
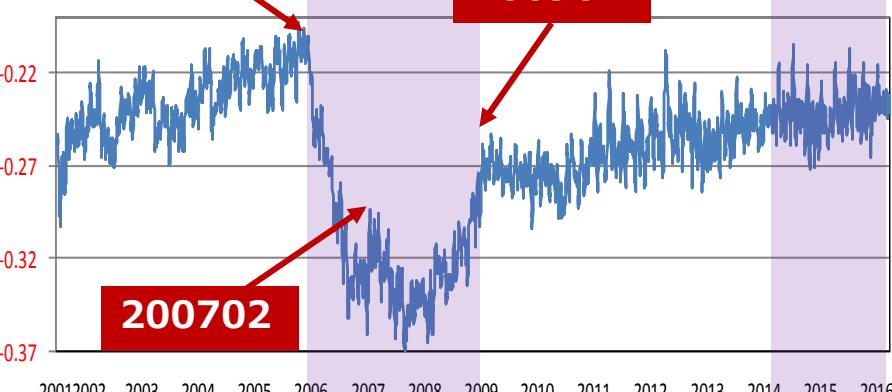
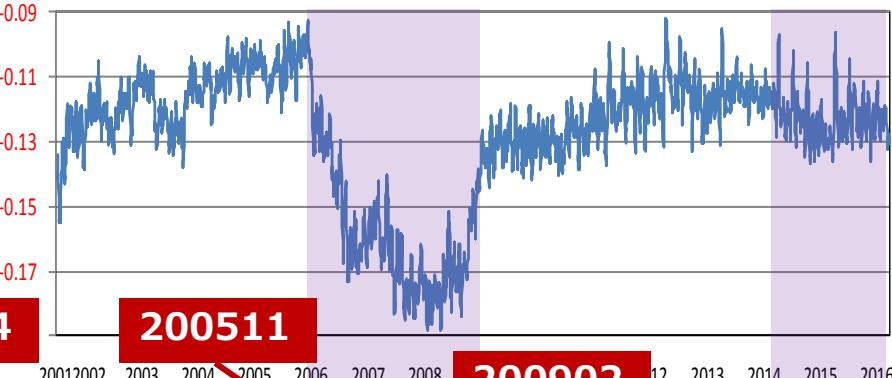
- 13 types of triadic motifs.



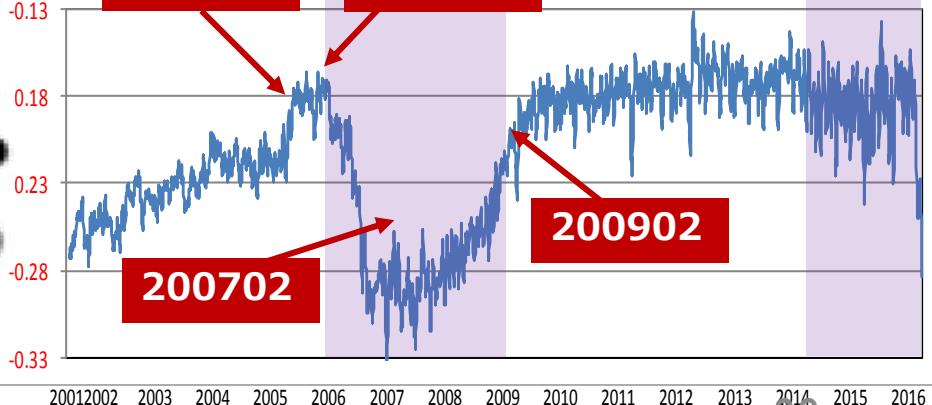
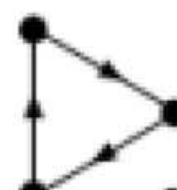
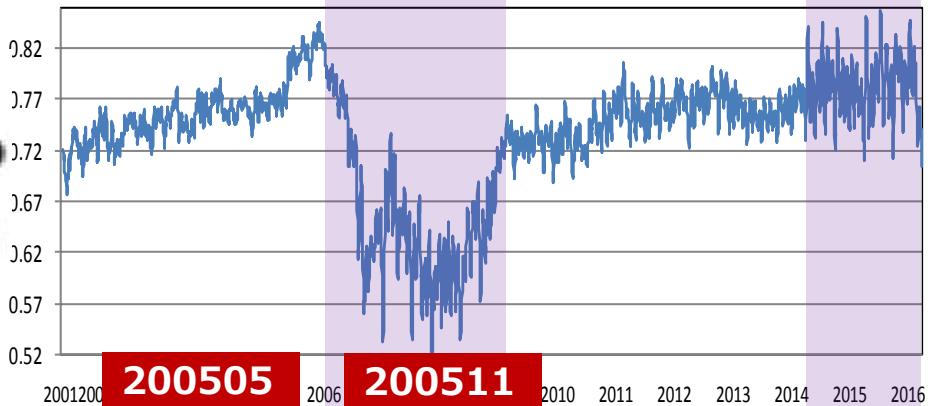
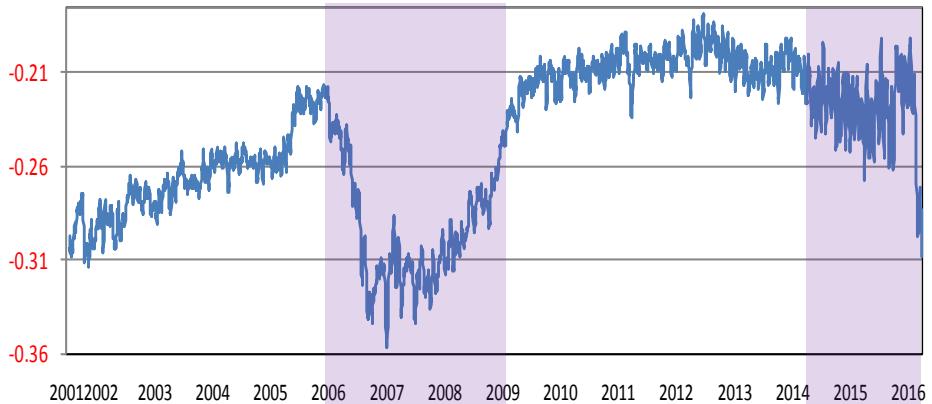
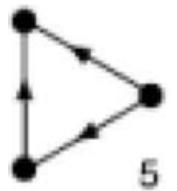
DCM ($\vec{C} = \{k_i^{in}, k_i^{out}\}$)



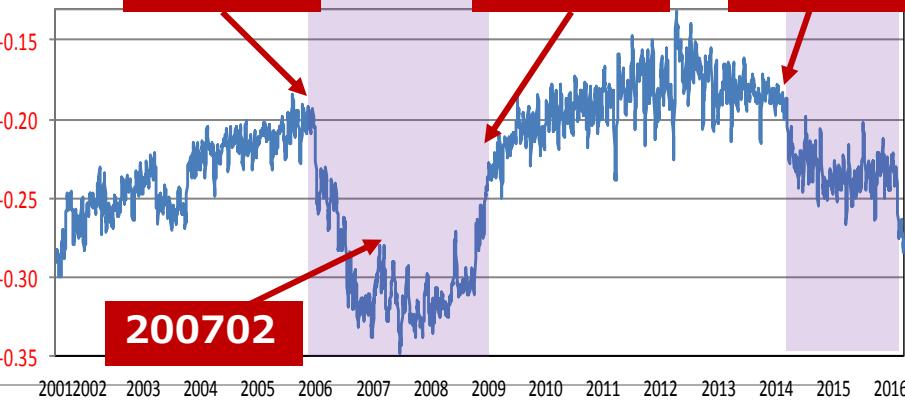
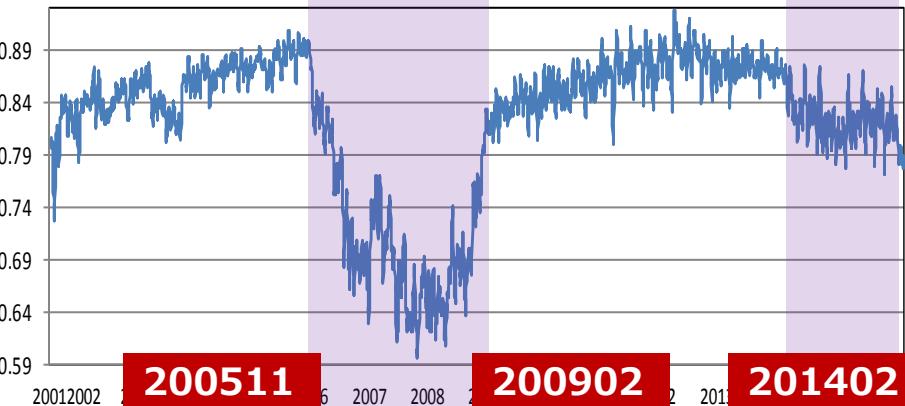
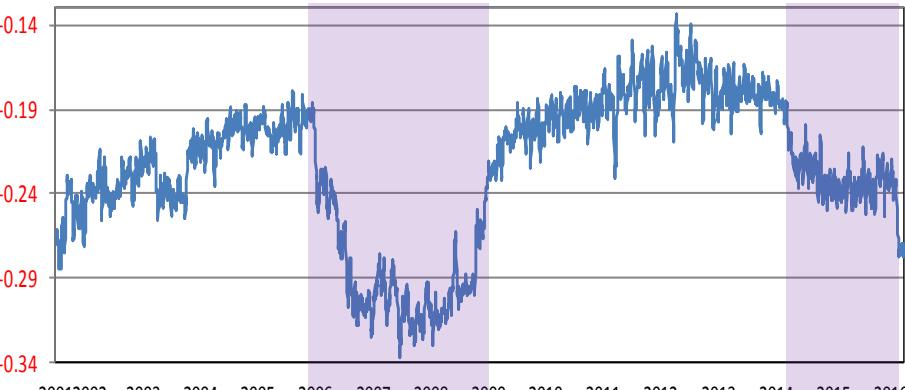
RCM ($\vec{C} = \{k_i^{in}, k_i^{out}, k_i^{both}\}$)



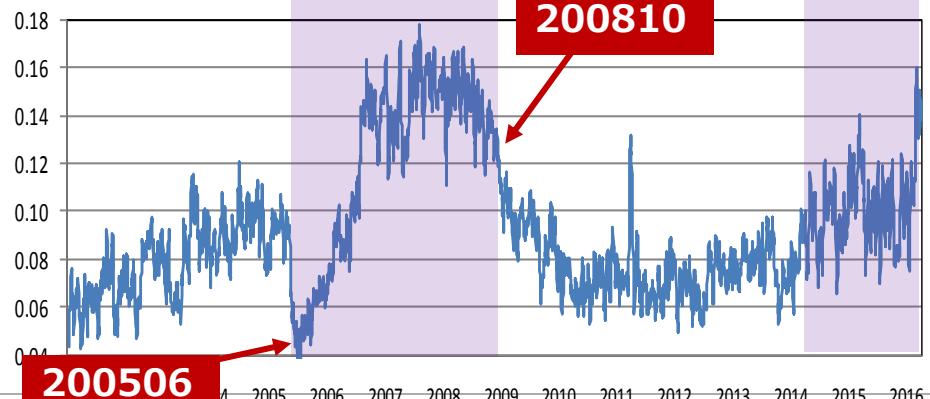
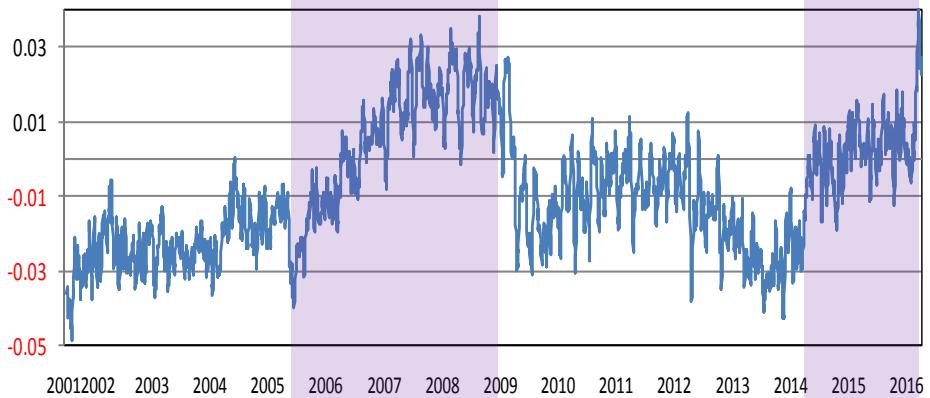
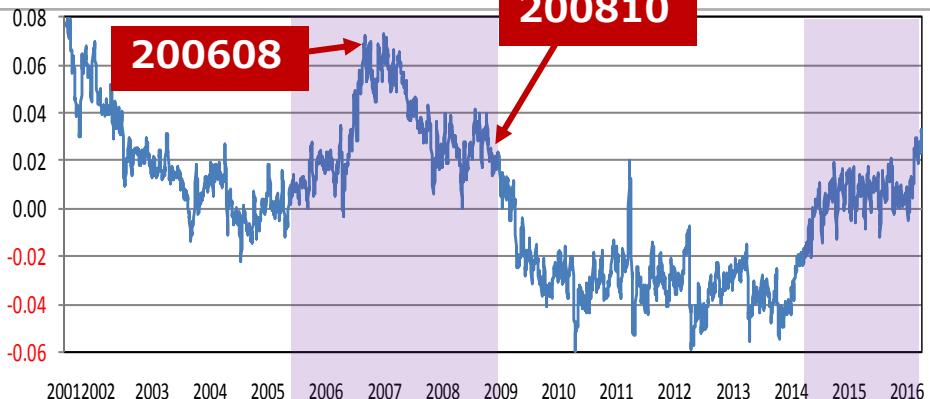
DCM ($\vec{C} = \{k_i^{in}, k_i^{out}\}$)



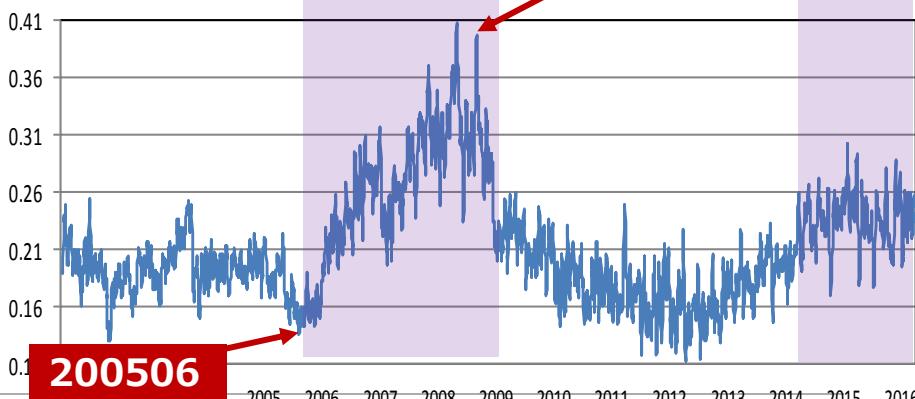
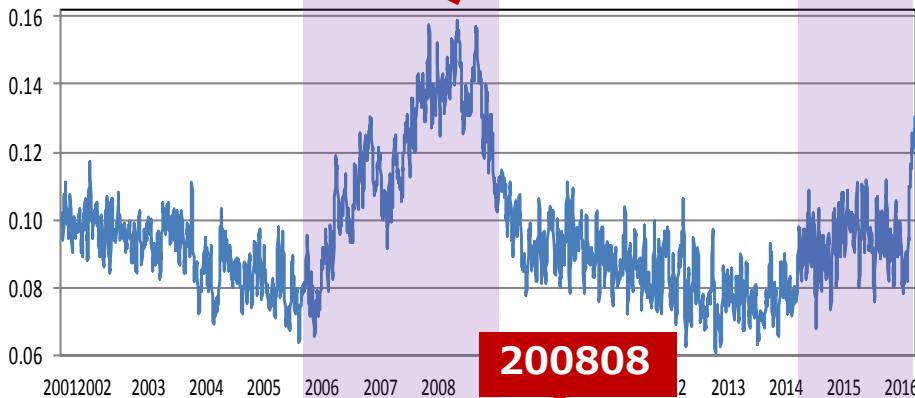
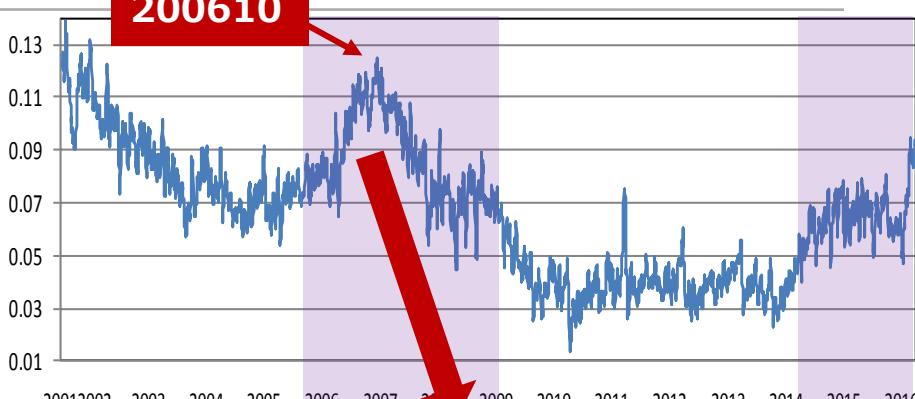
RCM ($\vec{C} = \{k_i^{in}, k_i^{out}, k_i^{both}\}$)



DCM ($\vec{C} = \{k_i^{in}, k_i^{out}\}$)



RCM ($\vec{C} = \{k_i^{in}, k_i^{out}, k_i^{both}\}$)



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5. Preliminary Conclusions

- Can we get any topological precursors from the transaction data?
 - ✓ Even a **simple “binary” representation** highlights the changes of the interbank network.
 - ✓ Observed values are more informative after filtering out topological properties. (# of nodes/links etc.) → **“null model”**
 - ✓ We should consider **strong heterogeneity** of nodes. (Power-law distribution of vertex degrees etc.)

5. Preliminary Conclusions

- How can these topological changes affect the stability of the markets?
(Work in Progress)

- ✓ **Two hypotheses** about the results;
 - Indicate the impending crisis. (= collapse of “Mini-bubble economy” and the global financial crisis)
 - Only show the influence of the BOJ monetary policy.
- ✓ Each motif might have a role and a sequential order.
 - If so, topological changes are correctly captured not by one-single motif, but by all of them. (= “motif profiles”)
→ **“mechanism of action”** behind motif profiles

6. Next Steps

- Clarifying the economic functions of dyadic/triadic motifs.
 (= relationship between market stability and motifs)
- Improving current methodology
 - ✓ Change time-span (daily representation → weekly/monthly representation)
 - ✓ Decompose each period quantitatively (regime-switching model)
 - ✓ ...
- Incorporating other properties of the network.
 - ✓ Weights of the links
 - ✓ Core-Periphery structure
- Applying to other data.
 - ✓ JGB

Thank you!

Appendix. Directed Random Graph (DRG)

$$H(G, \vec{\theta}) = \alpha L = \sum_{i,j} \alpha a_{ij}$$

$$\langle a_{ij} \rangle = p = \frac{e^{-\alpha}}{1 + e^{-\alpha}} = \frac{x}{1+x}$$

→ $L(G) = \sum_{i,j} \frac{x}{1+x}$

$$\sigma[N_m] = \sqrt{\sum_{t \neq s} \left(p_{ts} (1 - p_{ts}) \left(\frac{\partial N_m}{\partial a_{ts}} \right)_{A=\langle A \rangle}^2 \right)}$$

【dyadic-motifs】

$$\langle N_{\leftrightarrow} \rangle = \sum_{i \neq j} p^2 = N(N-1)p^2$$

$$\sigma[N_{\leftrightarrow}] = \sqrt{N(N-1)p(1-p)} (2p)$$

$$\langle N_{\rightarrow} \rangle = \sum_{i \neq j} p(1-p) = N(N-1)p(1-p)$$

$$\sigma[N_{\rightarrow}] = \sqrt{N(N-1)p(1-p)} (1-2p)$$

$$\langle N_{\ast} \rangle = \sum_{i \neq j} (1-p)^2 = N(N-1)(1-p)^2$$

$$\sigma[N_{\ast}] = \sqrt{N(N-1)p(1-p)} (2-2p)$$

Appendix. Directed Configuration Model (DCM)

$$H(G, \vec{\theta}) = \sum_{i,j} (\alpha_i + \beta_j) a_{ij}$$

$$\langle a_{ij} \rangle = p_{ij} = \frac{e^{-\alpha_i - \beta_j}}{1 + e^{-\alpha_i - \beta_j}} = \frac{x_i y_j}{1 + x_i y_j}$$

$$\sigma[N_m] = \sqrt{\sum_{t \neq s} \left(p_{ts} (1 - p_{ts}) \left(\frac{\partial N_m}{\partial a_{ts}} \right)_{A=\langle A \rangle}^2 \right)}$$


$$\left\{ \begin{array}{l} k_i^{in}(A^*) = \sum_{j \neq i} \frac{x_j y_i}{1 + x_j y_i} \quad \forall i \\ k_i^{out}(A^*) = \sum_{j \neq i} \frac{x_i y_j}{1 + x_i y_j} \quad \forall i \end{array} \right.$$

Appendix. Directed Configuration Model (DCM)

[dyadic-motifs]

$$\left\langle N_{\overset{\leftrightarrow}{L}} \right\rangle = \sum_{i \neq j} p_{ij} p_{ji}$$

$$\sigma[N_{\overset{\leftrightarrow}{L}}] = \sqrt{\sum_{t \neq s} [p_{ts}(1-p_{ts})(2p_{st})^2]}$$

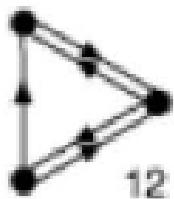
$$\left\langle N_{\vec{L}} \right\rangle = \sum_{i \neq j} p_{ij} (1 - p_{ji})$$

$$\sigma[N_{\vec{L}}] = \sqrt{\sum_{t \neq s} [p_{ts}(1-p_{ts})(1-2p_{st})^2]}$$

$$\left\langle N_{\overset{*}{L}} \right\rangle = \sum_{i \neq j} (1 - p_{ij})(1 - p_{ji})$$

$$\sigma[N_{\overset{*}{L}}] = \sqrt{\sum_{t \neq s} [p_{ts}(1-p_{ts})(2-2p_{st})^2]}$$

[triadic-motifs]



$$N_{12} = \sum_{i \neq j \neq k} a_{ij} a_{ji} a_{jk} a_{kj} a_{ik} (1 - a_{ki})$$

$$\sigma[N_{12}] = \sqrt{\sum_{t \neq s} \left(p_{ts}(1-p_{ts}) \left(\frac{\partial N_{12}}{\partial a_{ts}} \right)_{A=\langle A \rangle} \right)^2}$$

where $\left(\frac{\partial N_{12}}{\partial a_{ts}} \right)_{A=\langle A \rangle} = \sum_{k(\neq t,s)} \left[p_{st} p_{sk} p_{ks} p_{tk} + p_{st} p_{tk} p_{kt} p_{sk} + p_{kt} p_{tk} p_{st} p_{ks} + p_{ks} p_{sk} p_{st} p_{kt} + p_{tk} p_{kt} p_{ks} p_{sk} - 6 p_{st} p_{sk} p_{ks} p_{kt} p_{tk} \right]$

Appendix. Reciprocal Configuration Model (RCM)

$$H(G, \vec{\theta}) = \sum_i \left(\alpha_i k_i^{\rightarrow} + \beta_i k_i^{\leftarrow} + \gamma_i k_i^{\leftrightarrow} \right)$$

where $a_{ij}^{\rightarrow} = a_{ij}(1 - a_{ji})$, $a_{ij}^{\leftarrow} = a_{ji}(1 - a_{ij})$, $a_{ij}^{\leftrightarrow} = a_{ij}a_{ji}$, $a_{ij}^{\neq} = (1 - a_{ij})(1 - a_{ji})$

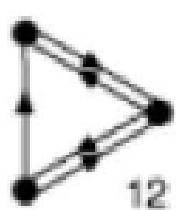
$$\langle a_{ij}^{\rightarrow} \rangle = p_{ij}^{\rightarrow} = \frac{x_i y_j}{1 + x_i y_j + x_j y_i + z_i z_j} \quad \langle a_{ij}^{\leftrightarrow} \rangle = p_{ij}^{\leftrightarrow} = \frac{z_i z_j}{1 + x_i y_j + x_j y_i + z_i z_j}$$

$$\langle a_{ij}^{\leftarrow} \rangle = p_{ij}^{\leftarrow} = \frac{x_j y_i}{1 + x_i y_j + x_j y_i + z_i z_j} \quad \langle a_{ij}^{\neq} \rangle = p_{ij}^{\neq} = \frac{1}{1 + x_i y_j + x_j y_i + z_i z_j}$$

 $\left[\begin{array}{l} k_i^{\rightarrow}(A^*) = \sum_{j \neq i} \frac{x_i y_j}{1 + x_i y_j + x_j y_i + z_i z_j} \quad \forall i \\ k_i^{\leftarrow}(A^*) = \sum_{j \neq i} \frac{x_j y_i}{1 + x_i y_j + x_j y_i + z_i z_j} \quad \forall i \\ k_i^{\leftrightarrow}(A^*) = \sum_{j \neq i} \frac{z_i z_j}{1 + x_i y_j + x_j y_i + z_i z_j} \quad \forall i \end{array} \right]$

Appendix. Reciprocal Configuration Model (RCM)

[triadic-motifs]



$$\langle N_{12} \rangle = \sum_{i \neq j \neq k} p_{ij}^{\leftrightarrow} p_{jk}^{\leftrightarrow} p_{ik}^{\rightarrow}$$

$$\sigma[N_{12}] = \sqrt{\sum_{t \neq s} \left[(\sigma[a_{ts}])^2 \left(\frac{\partial N_{12}}{\partial a_{ts}} \right)_{A=\langle A \rangle}^2 + \sigma[a_{ts}, a_{st}] \left(\frac{\partial N_{12}}{\partial a_{ts}} \right)_{A=\langle A \rangle} \left(\frac{\partial N_{12}}{\partial a_{st}} \right)_{A=\langle A \rangle} \right]}$$

$$\text{where } (\sigma[a_{ts}])^2 = (p_{ts}^{\leftrightarrow} + p_{ts}^{\rightarrow})(1 - (p_{ts}^{\leftrightarrow} + p_{ts}^{\rightarrow}))$$

$$\sigma[a_{ts}, a_{st}] = p_{ts}^{\leftrightarrow} - (p_{ts}^{\leftrightarrow} + p_{ts}^{\rightarrow})(p_{st}^{\leftrightarrow} + p_{st}^{\rightarrow})$$

$$\left(\frac{\partial N_{12}}{\partial a_{ts}} \right)_{A=\langle A \rangle} = \sum_{k(\neq t,s)} \left[p_{st} \left(p_{sk}^{\leftrightarrow} (p_{tk}^{\rightarrow} + p_{kt}^{\rightarrow}) + p_{tk}^{\leftrightarrow} (p_{sk}^{\rightarrow} + p_{ks}^{\rightarrow}) \right) + p_{sk}^{\leftrightarrow} p_{tk}^{\leftrightarrow} \right]$$