Analyzing Non-linear Network Effects in the European Interbank Market

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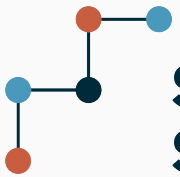

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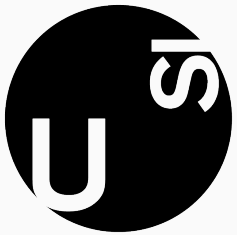

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Introduction

The **interbank market** facilitates the **redistribution of liquidity** within a financial system

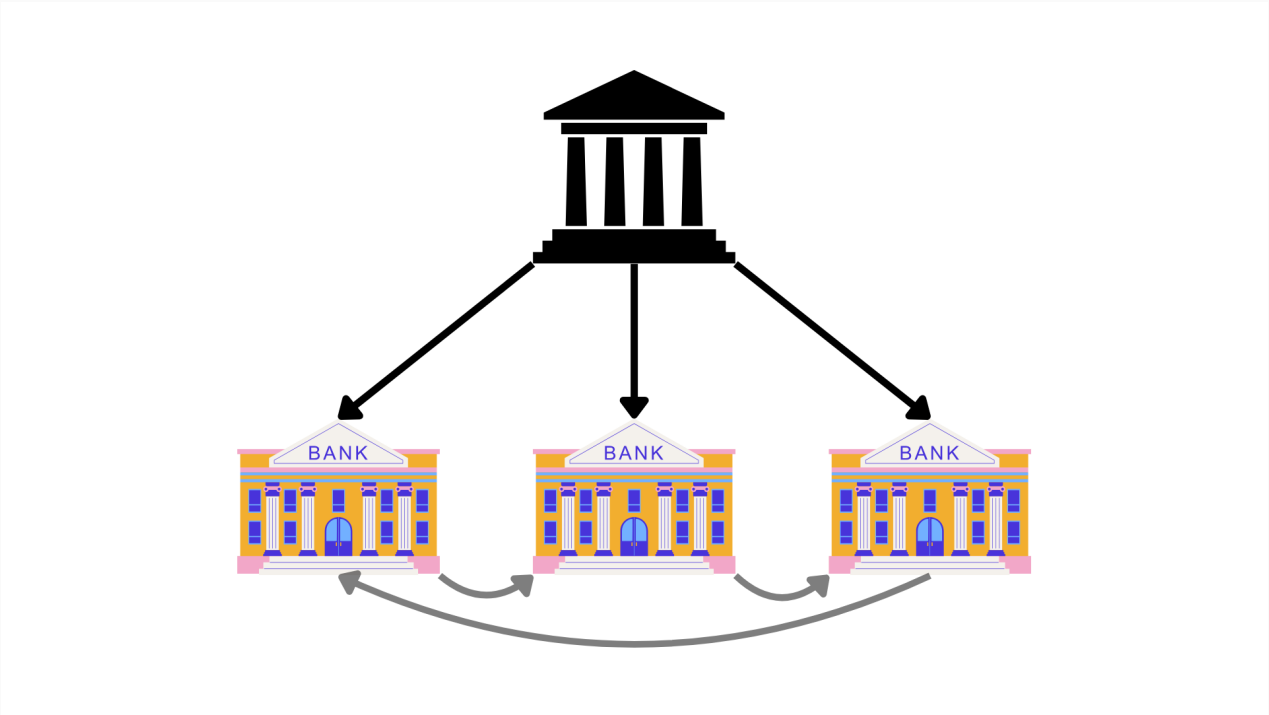
- The **high number of interactions** has prevented until now a detailed network analysis

- Recent **developments in network modeling** allow to analyse more data

Aim: reveal **changes** of patterns in the network's behavior **before** and **after 2008**

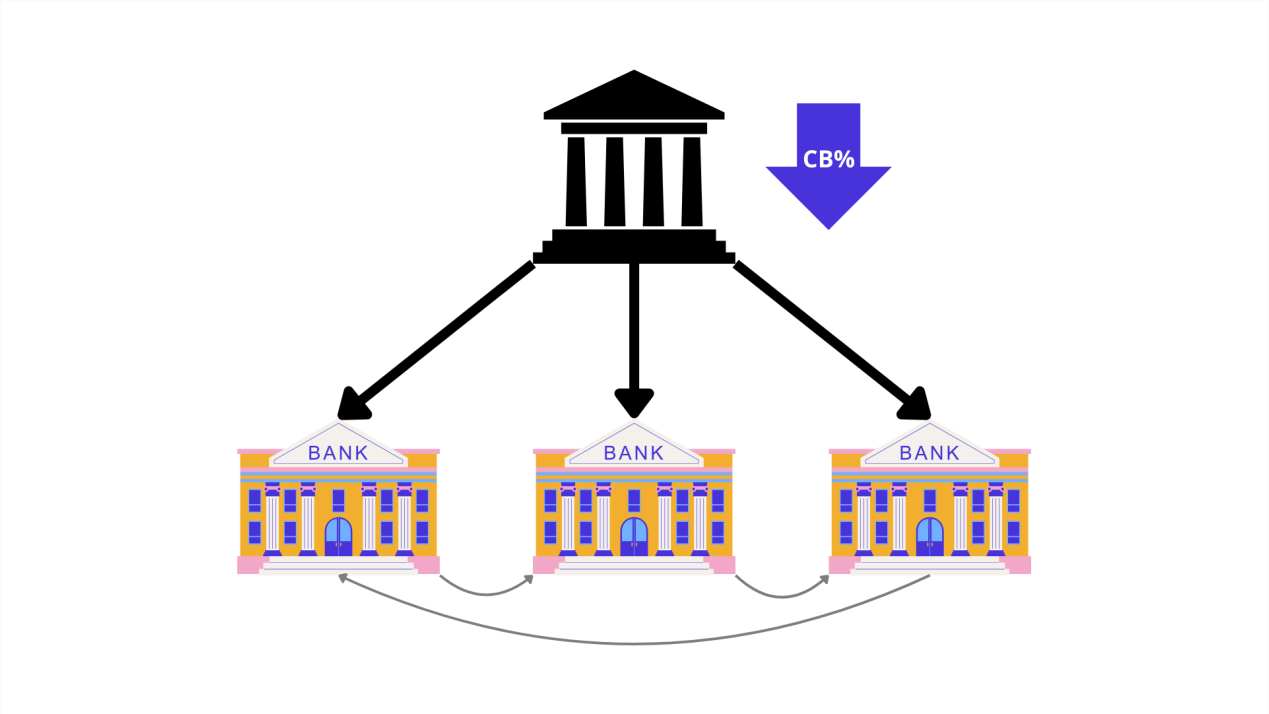
The European banking market

- Primary European Central Bank (ECB) tool: rate at which banks can borrow money from the ECB
- Inerbank market: banks lend money to each other at lower rates than ECB



The European banking market

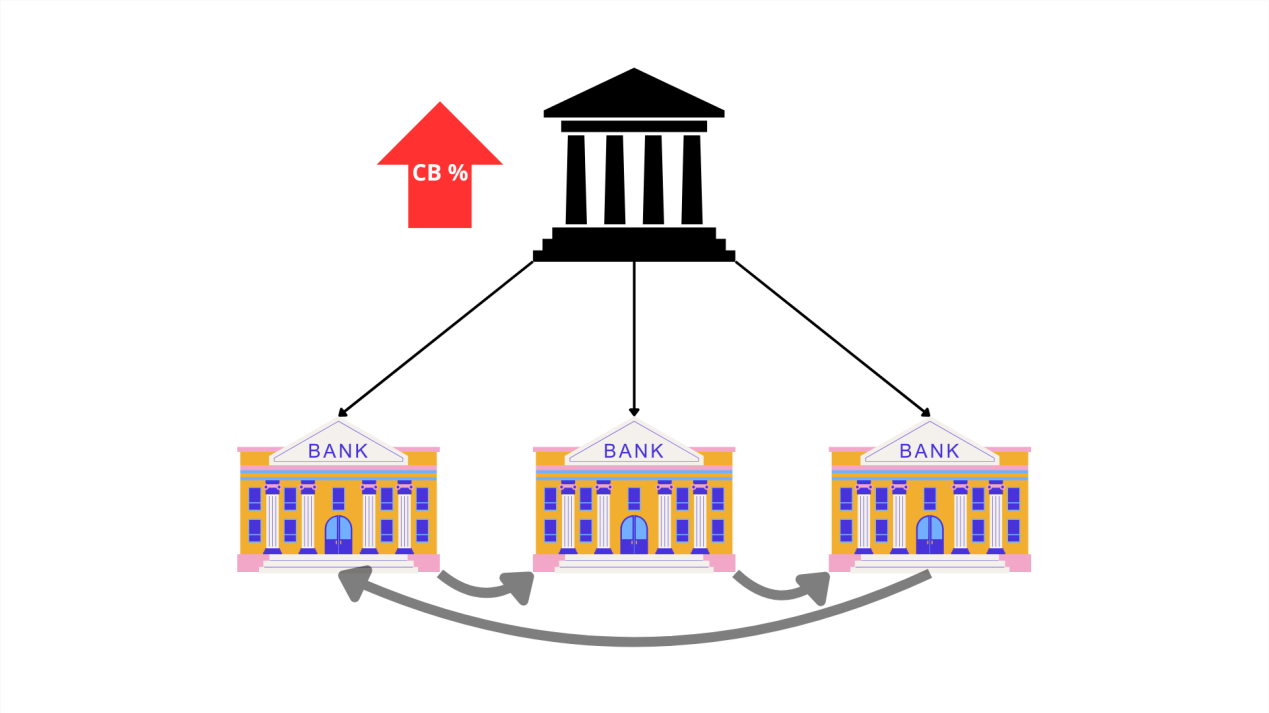
Lower Rates: ECB encourages spending and investment by making borrowing cheaper.



This can boost the economy but also risks increasing inflation if demand outstrips supply.

The European banking market

Higher Rates: can help cool down an overheated economy by making borrowing more expensive.



This slows down spending and investment and reduces inflation.

Empirical setting

- **European interbank market**: trading of cash-equivalent assets of different maturities
- **e-MID trading platform**: time-ordered collection of high-frequency transactions

Market	Duration	Date	Time	Rate	Amount	StartDate	EndDate	Quoter	Aggressor	Verb
TRAS_EUR	ON	02.01.06	09:06:21	2.38	3.6	02.01.06	03.01.06	IT0259	IT0221	Buy
TRAS_EUR	ON	02.01.06	09:09:38	2.38	45	02.01.06	03.01.06	IT0224	IT0210	Buy
TRAS_EUR	ON	02.01.06	09:09:53	2.38	30	02.01.06	03.01.06	IT0171	IT0197	Buy
TRAS_EUR	ON	02.01.06	09:10:14	2.38	25	02.01.06	03.01.06	IT0259	IT0197	Buy
TRAS_EUR	ON	02.01.06	09:10:35	2.38	50	02.01.06	03.01.06	IT0265	IT0197	Buy
TRAS_EUR	ON	02.01.06	09:12:08	2.37	30	02.01.06	03.01.06	IT0171	IT0210	Buy
TRAS_EUR	ON	02.01.06	09:14:07	2.38	5	02.01.06	03.01.06	IT0245	IT0236	Buy
TRAS_EUR	ONL	02.01.06	09:14:12	2.33	250	02.01.06	03.01.06	IT0204	IT0276	Buy

Data: 1'468'463 transactions from 355 institutions in 16 countries

Phase 1: January 4, 1999 - September 15, 2008

Phase 2: September 18, 2008 - December 31, 2015

REMs to model interbank transactions

We propose to model the interbank transaction via the **Deep Relational Event Additive Model (DREAM)**[1]

- **Relational event models (REMs)**[2] are a powerful and flexible tool to model network dynamics
- Provides insights into the **patterns** of interbank **exchanges**.
- Helps to **infer** actor's market **behaviors**

[1] Filippi-Mazzola, E., & Wit, E. C. (2023). Modeling non-linear Effects with Neural Networks in Relational Event Models. *arXiv preprint arXiv:2312.12357*.

[2] Perry, P. O., & Wolfe, P. J. (2013). Point process modelling for directed interaction networks. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, 75(5), 821-849.

Relational Event Modelling

Let $e_i = (s_i, r_i, t_i)$, for $i = 1, \ldots, n$, be a **sequence of relational events** (transactions)

$$N_{sr}(t) = \#\{\text{transactions from } s \text{ to } r \text{ up to time } t\},$$

with $N_{sr}(0) = 0$. $N_{sr}(t)$ is then **local submartingale**.

By Doob-Meyer decomposition:

$$N_{sr}(t) = \Lambda_{sr}(t) + M_{sr}(t)$$

- $\Lambda_{sr}(t)$: predictable increasing process
- $M_{sr}(t)$: residual martingale process

Relational Event Modelling

REMs describe the structure of $N_{sr}(t)$ via a piece-wise inhomogeneous Poisson process:

$$\Lambda_{sr}(t) = \int_0^t \lambda_{sr}(\tau) d\tau$$

such that the **Intensity function** $\lambda_{sr}(t)$ is described as

$$\lambda_{sr}(t \mid \mathcal{H}_t) = \lambda_0(t) e^{\sum_{k=1}^{q} f_k(x_{sr})},$$

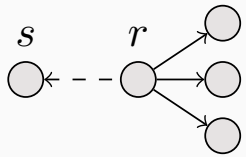
where $f_k(x_{sr})$ is a non-linear function that maps features.

Network features

Monodiadic covariates: capture heterogeneity of financial institutions in the system

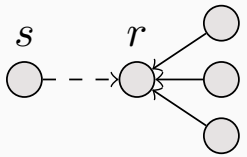
- **Out-degree**: number of outgoing transactions
- **In-degree**: number of incoming transactions

Out-degree



$$x_{od} = \sum_{s \neq r} N_{rs}(t^-)$$

In-degree



$$x_{id} = \sum_{s \neq r} N_{sr}(t^-)$$

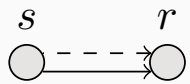
Network features

Dyadic covariates: capture mutual trust in system

Repetition: propensity to engage in similar transactions repeatedly over time

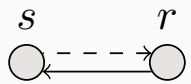
Reciprocity: inclination of banks that acted as providers of liquidity to assume the role of receivers at a later time

Repetition



$x_{rep} = N_{sr}(t^-)$

Reciprocity



$x_{rec} = N_{rs}(t^-)$

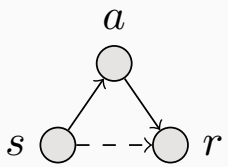
Network features

Triadic covariates: capture subclusters of financial institutions

Transitive closure: assesses how future interactions between two entities a mutual third party

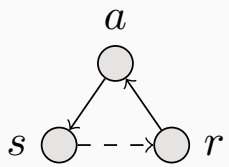
Cyclic closure: reveal complex interdependencies and of reciprocal nature

Transitive closure



$$x_{tc} = \sum_{a \neq s,r} N_{sa}(t^-) N_{ra}(t^-)$$

Cyclic closure



$$x_{cc} = \sum_{a \neq s,r} N_{as}(t^-) N_{ra}(t^-)$$

Network features

Features count everything from the beginning

- Network does **not forget** anything
- Occurrences closer to the current time may be more relevant
- **Significance** of an event **diminishes over time**

Definitions defined can make use of a weighted process

$$N^*_{sr}(t) = \sum_{t_i < t, s_i = s, r_i = r} (t - t_i)^{-\alpha}$$

$\alpha = 0$: past events contribute equally

$\alpha > 0$: recent events have a greater impact

Following Lomi and Bianchi, 2021[3], $\alpha = 0.5$

[3] Lomi, A., & Bianchi, F. (2021). *A time to give and a time to receive: Role switching and generalized exchange in a financial market.* Social Networks, 77, 118-128

Inference - Degenerate logistic likelihood

Likelihood of the process can be expressed as a **degenerate logistic regression**[4]:

$$L(f) = \prod_{i=1}^{n} \left[\frac{\exp\left\{ f(x_{s_i r_i}) - f(x_{s_i^* r_i^*}) \right\}}{1 + \exp\left\{ f(x_{s_i r_i}) - f(x_{s_i^* r_i^*}) \right\}} \right]$$

$f(x_{s_i r_i}) = \sum_{k=1}^{q} f_k(x_{s_i r_i k})$

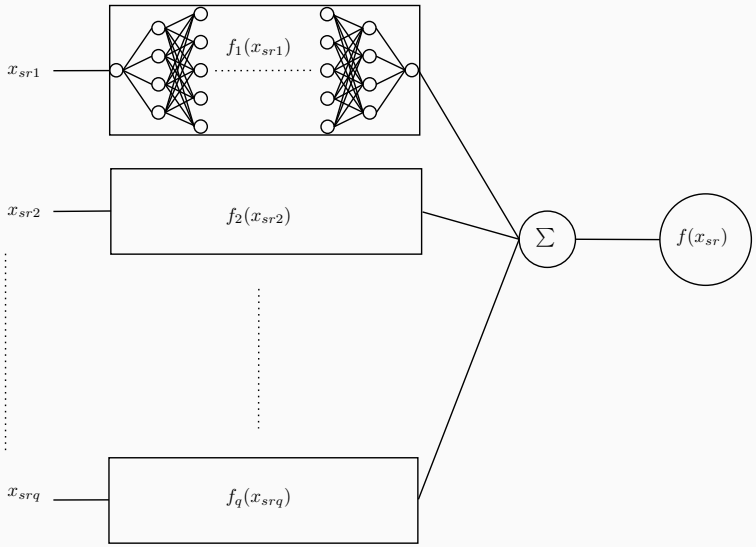
$x_{s_i^* r_i^*}$ is a randomly sampled non-event from the risk-set $\mathcal{R}(t_i)$

$\mathcal{R}(t_i)$: set of all possible events that could have occurred at t_i

[4] Filippi-Mazzola, E. & Wit, E. C., (2024). A stochastic gradient relational event additive model for modelling US patent citations from 1976 to 2022. *Journal of the Royal Statistical Society Series C: Applied Statistics*, 00, 1-17

Inference - Deep Relational Event Additive Model

DREAM: estimate f_k via independent Neural Networks (NNs)

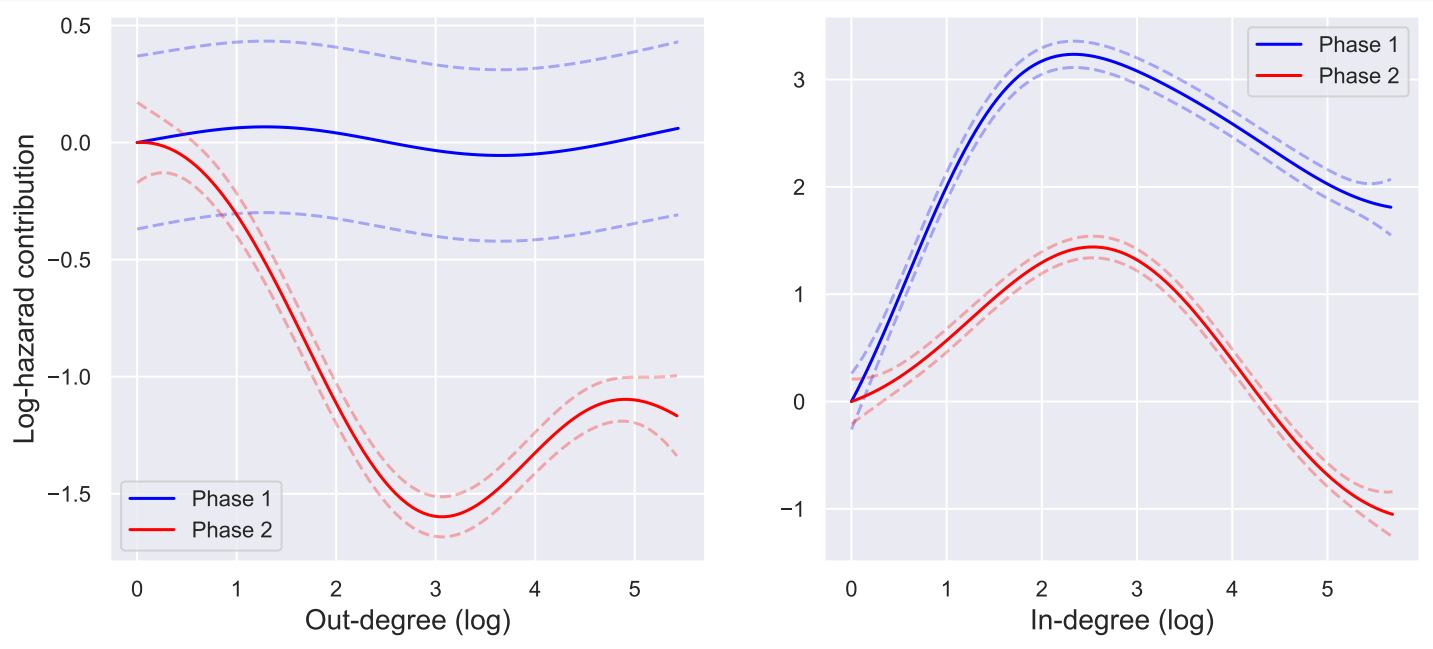


$$L(f) = \prod_{i=1}^{n} \left[\frac{\exp\left\{ f(x_{s_i r_i}) - f(x_{s_i^* r_i^*}) \right\}}{1+\exp\left\{ f(x_{s_i r_i}) - f(x_{s_i^* r_i^*}) \right\}} \right]$$

Where $f(x_{s_i r_i}) = \sum_{k=1}^{q} f_k(x_{s_i r_i k})$

- NNs are trained simultaneously
- Optimizer: ADAM
- Uncertainty bands are computed with a combination of Gaussian Processes and Bootstrap

Results - Monodiadic covariates



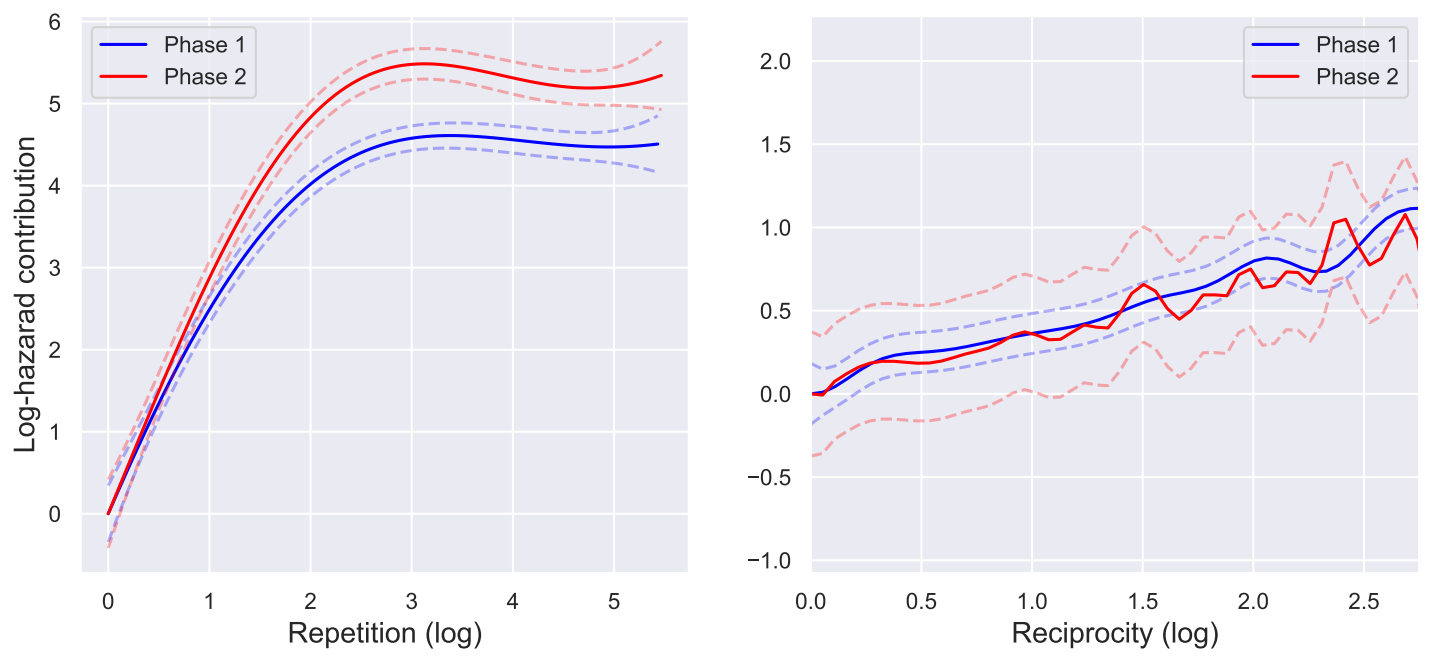
Out-degree:

- Phase 1: almost no effect in the first phase
- Phase 2: the more a bank borrows, the less likely it borrows again

In-degree:

- Difference in the tendency to seek additional loans
- The probability of receiving a loan is three times higher in phase 1

Results - Dyadic covariates

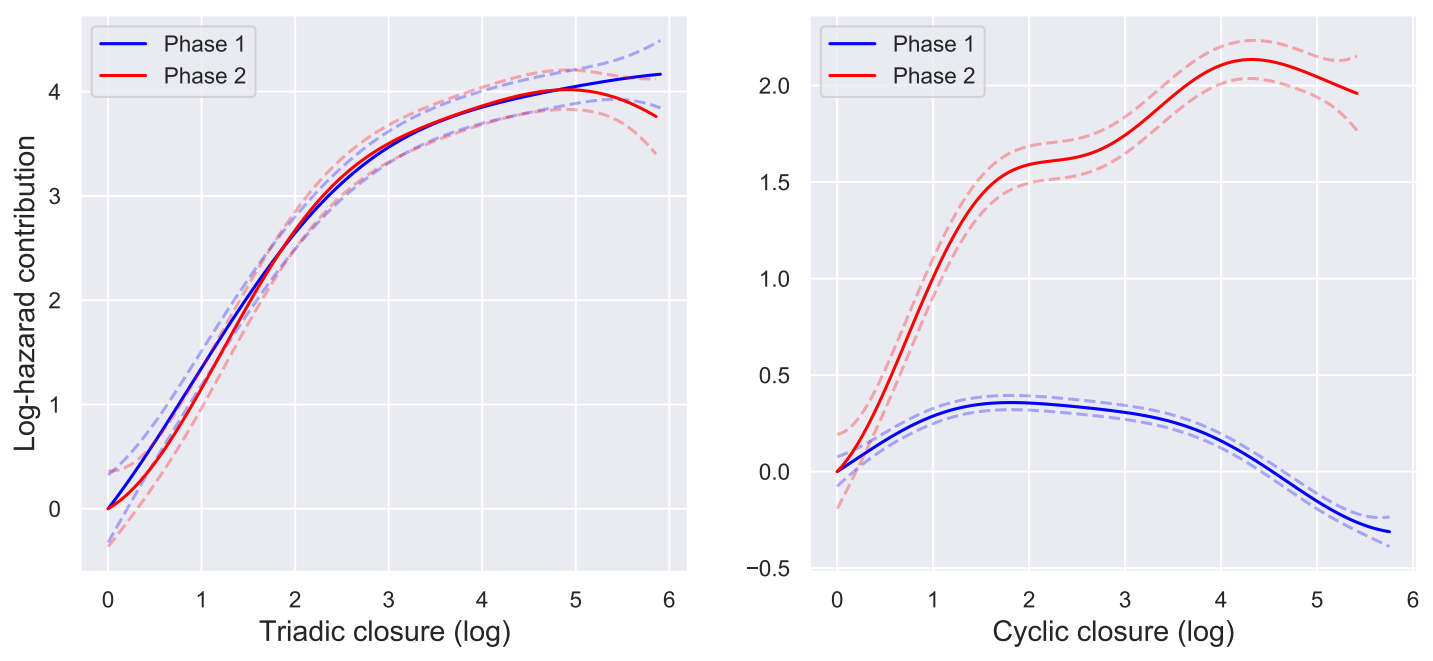


Repetition:

- tendency to re-engage in transactions with previous partners
- stronger propensity in phase 2

Reciprocity: crisis did not alter the reciprocal nature of transactions

Results - Triadic covariates



Triadic closure: identical increasing trend for both phases

Cyclic closure:

- Phase 1: no emphasis on cyclic patterns
- Phase 2: trust and relationships are more crucial

Summary

We used **DREAM** model transactions in the European interbank market

To **investigate** transaction drivers we estimated **three sets of network effects**

Differences in some effects **before and after** the **2008** economic crisis

Post-crisis banks demonstrated a **decreased propensity to borrow**

Future analysis:

- consider **multiple segmentations** depending on different financial events
- include **exogenous characteristics** from the institutions