Efficiency, Risk and the Gains from Trade in Interbank Markets

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July 30, 2023

AMES 2023 - Singapore

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Motivation

- **Interbank Market Integration:**
  Degree to which banks are interconnected by bilateral lending and borrowing
  Practically: Share of final loans financed through "own funds" (other than interbank liabilities)

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Ex-ante **ambiguous effects** of interbank market integration

- Aggregate Volatility: Contagion risk vs Risk diversification
- Aggregate Welfare: Liquidity provision vs Volatility

This Paper

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   - How do gains depend on concentration and network structure?

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    - What if we don't allow banks to trade with each other (autarky)?
    - How do gains depend on concentration and network structure?
2. Study distinct **Monetary Policy** tools for financial stability
    - **SS-Lender-of-Last-Resort** (SS-LoRL):
      Supply short-term liquidity to banks with idiosyncratic adverse shocks, discount window
    - **Cyclical-LoRL**: Expand/contract liquidity at business cycle frequency
    - Quantification of systematically important banks

This Paper

1. **Quantitative model of the interbank market** embedded in **DSGE model**
   - Inspired by trade literature (with twist):
     ⇒ interbank market with gross positions due to short-term liquidity mismatches
     ⇒ tractable solution despite high degree of heterogeneity
     ⇒ maps directly to data
   - New-Keynesian model with interbank credit spread in the natural interest rate
     ⇒ shocks to interbank market funding costs have aggregate effects
   - Analytical formulas for static and dynamic gains from trade, LoLR policy

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2. Application: **Detailed microdata on German banking market**
   - Test model predictions: US financial crisis transmitted through interbank market
   - Estimate key elasticities and recover "wedges" by fitting the model to microdata
   - Quantify gains from trade for Germany
   - Quantify policy implications (i.e., Lender-of-last-resort)

Findings

1. Level of market integration **sufficient statistic** for SS gains
   + market structure key to dynamic gains (bank concentration, network)

Literature review

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   - 70% due to static efficiency gains, 30% due to reduction in volatility
   - Size and direction dependent on market structure, elasticities

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4. Persistent reduction in interbank market activity after the Great Recession lowers gains from trade by 0.56%
5. LoLR intervention increases SS welfare by 2%
   + minor effects of countercylical policy

Literature review

Model

Trade model of interbank market + DSGE model

Key Timing Assumption

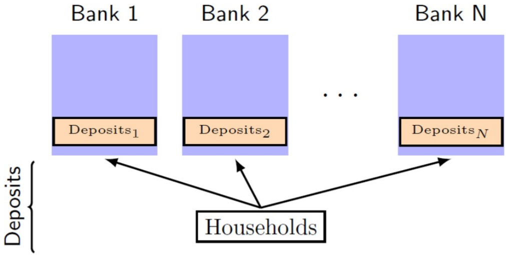
- Discrete time periods (quarters), index t
  ⇒ Rational expectations, financial contracts are settled, shocks
  ⇒ **DSGE model active**

- Time continuum within a quarter, index τ
  ⇒ Perfect foresight, financial contracts are made, liquidity mismatch shocks
  ⇒ **Interbank trade model active**

- Example: $C_{t,\tau}$ consumption in quarter t at instance τ

Model - Households

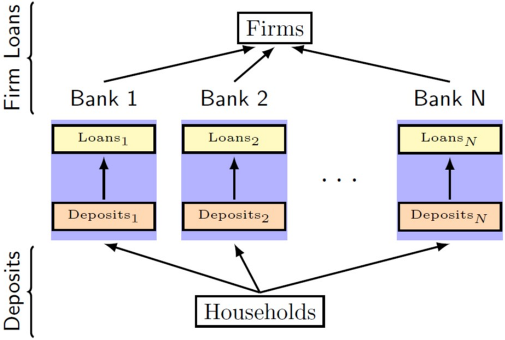
- Standard representative household with dynamic consumption-savings problem
- **Special**: Utility from holding **deposits** in N banks, $\left(1 - T_t^n \cdot z_{t,\tau}^n\right) \frac{D_{t,\tau}^n}{P_t}$
    - $(1 - T_t^n)$: average preference at t
    - Preference shock $z_{t,\tau}^n \overset{\text{i.i.d.}}{\sim} Weibull$, mean one, shape parameter κ
- **Reshuffling of deposits** across banks within continuum: **Liquidity Shocks**



Details

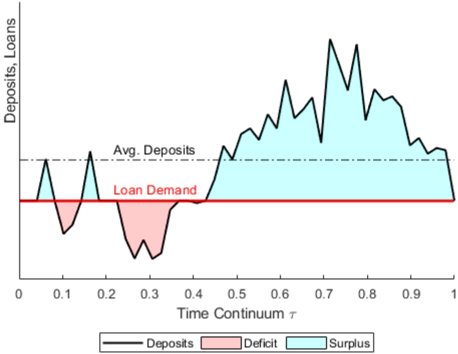
Model - Firms

- Standard New-Keynesian Firms with Calvo-Pricing
- CES over N types of capital, financed with loans from N banks, full depreciation
- Demand shocks a_t^n (taste shifters in CES), demand elasticity σ
- **Assumption**: Loan rate $R_{t,\tau}^{F,n}$ is constant over continuum (credit line)



Details

Model - Banks



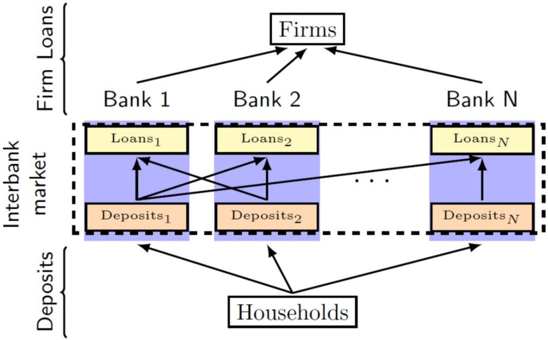
- **Liquidity Mismatch**: Banks face deficit/surplus of available funds
- Cannot pass adjustment to firms (fixed loan rate $R^{F,n}_{t,\tau}$)
- Motivation to trade on interbank market

Model - Banks

- Funding $M_{t,\tau}^{in}$ from own deposit division ($i = n$) or borrow from other banks
- Transaction costs d_t^{in}: Costs of assessing collateral value, enforcement, etc.
- Interbank interest rate if bank n borrows from i

$$R_{t,\tau}^{I,in} = R_t^B \cdot d_t^{in} \cdot T_t^i \cdot z_{t,\tau}^i$$

- Borrow from **least cost lender** at each moment τ



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Model - Equilibrium Interbank Market

- Share in bank n's loans financed by interbank loans from bank i

$$\lambda_t^{in} = \left(\frac{d_t^{in} \cdot T_t^i}{\Phi_t^n} \right)^{-\kappa}$$

  - d_t^{in}: Transaction costs between i and n
  - T_t^i: Depositor preferences for bank i
  - Φ_t^n: Credit spread of bank n in t

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- Credit spread for bank n (over bond rate)

$$\Phi_t^n = \left[\sum_{i=1}^{N} \left(d_t^{in} \cdot T_t^i \right)^{-\kappa} \right]^{-1/\kappa}$$

- κ turns out to be the supply elasticity of funds in the interbank market

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- Firm loan rates

$$R_t^{F,n} = \left(\frac{\sigma}{\sigma - 1} \right) \cdot \Phi_t^n \cdot R_t^B$$

Model - Steady State

- Aggregate **own trade share**

$$\lambda^{Own} = \left[\sum_{n=1}^{N} s^n \cdot (\lambda^{nn})^{\frac{\sigma-1}{\kappa}} \right]^{\frac{\kappa}{\sigma-1}}$$

- Steady state **credit spread**

$$\widetilde{R}^I = \underbrace{\left(\lambda^{Own}\right)^{1/\kappa}}_{\text{Interbank Market}} \cdot \underbrace{\left[\sum_{n=1}^{N} a^n \cdot (T^n)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}}_{\text{Deposit Preferences}}$$

- Intuition
  - Efficient interbank markets $\downarrow \lambda^{Own}$ pass smaller transaction costs to interbank rate
  - Stronger preferences for deposits $\downarrow T^n$, lower compensation to depositors $\downarrow R^{D,n}$

Welfare Expressions

Gains from Trade

$$\mathbb{J} \equiv E\left[\frac{U_t - U_t^{AU}}{U_x X}\right]$$

- U_t: Welfare in period t under integration
- U_t^{AU}: Counterfactual welfare under Autarky (banks have to finance loans with own sources)
- $U_x X$: Scaled to share of SS consumption X under integration

- Closed-form solution for SS gains
- Dynamic gains require 2nd order approximation

Welfare Expressions

Steady State Gains from Trade

$$\mathbb{J}^{ss} \equiv \frac{U - U^{AU}}{U_x X} = -\left(\frac{\alpha}{1-\alpha}\right)\frac{1}{\kappa} \cdot \log\left(\lambda^{Own}\right)$$

- Aggregate own share of funding (λ^{Own}) **sufficient statistic** for welfare
- $\lambda^{Own} = \left[\sum_{n=1}^{N} s^n \cdot (\lambda^{nn})^{\frac{\sigma-1}{\kappa}}\right]^{\frac{\kappa}{\sigma-1}}$
- With $\kappa \approx \sigma - 1$: equal to 1-Aggregate interbank share
- **Intuition:** more integration $\Rightarrow$ lower credit spread $\Rightarrow$ lower capital cost
- Equivalent to Arkolakis et al. (2012) for gains from trade in International Trade

- SS Gains from Trade weakly positive! When can integration hurt? Contagion!

Welfare Expressions

Gains from Trade: 2nd-Order Approximation

$$\mathbb{J} = \mathbb{J}^{ss} + \frac{1}{2}\left[\sigma_T^2 \cdot \mathfrak{J}^T + \sigma_a^2 \cdot \mathfrak{J}^a + \sigma_I^2 \cdot \mathfrak{J}^I\right] + \text{h.o.t.} \, ,$$

- σ_T^2, σ_a^2, σ_I^2: Variances of deposits shocks, loan demand shocks, transaction cost shocks
- $\mathfrak{J}^T$, $\mathfrak{J}^a$: Gain/Cost due to deposit preference shocks, loan demand shocks
  $\Rightarrow$ Higher concentration leads to higher volatility
- $\mathfrak{J}^I$: Gain/Cost due to of transaction costs shocks
  $\Rightarrow$ Interbank integration amplifies shocks

Full Formula

Welfare Expressions

Special case: no central bank, no correlation across transaction cost shocks

$$\mathfrak{J}^I \propto \underbrace{\sum_{n=1}^{N} s^n \cdot [1-\lambda^{nn}]}_{\text{Full Diversification } \geq 0} - \underbrace{\left[\Theta_0 + \Theta_1 \cdot H^F\right] \cdot \sum_{n=1}^{N} \omega^n \cdot \left[H^{I,n} - (\lambda^{nn})^2\right]}_{\text{Exposure Risk}},$$

- $H^{I,n} = \sum_{j=1}^{N} \left(\lambda^{jn}\right)^2$: Herfindahl of funding sources of bank n
- $H^F = \sum_{n=1}^{N} (s^n)^2$: Herfindahl of bank concentration in loan market
- s^n, ω^n: weights for loan market size of bank n, contribution to H^F of bank n
- Θ_0, Θ_1: constants dependent on α, κ and σ

- Dynamic gains smaller (or negative) if
  - High level of concentration in loan market, H^F large
  - Low participation or concentrated funding sources, $H^{I,n}$ large
  - $|\sigma - \kappa| >> 0$: loan demand and fund supply have very different elasticities

Quantification - Gains from Trade

Table: Welfare Gains under alternative values of σ and κ

Gains from trade, in %			
	σ		
κ	7	27.1	100
7	5.45	2.10	-15.9
15	3.33	1.83	0.55
26.7	2.18	**1.33**	0.68
100	0.62	0.48	0.32

Steady state gains, in %			
	σ		
κ	7	27.1	100
7	3.74	1.74	3.41
15	2.47	1.25	0.62
26.7	1.72	**0.95**	0.48
100	0.61	0.45	0.26

- Steady state gains from trade **underestimate total gains**
- **Preferred Calibration**: Integration reduces volatility of the banking sector
- **Possible**: Higher volatility due to integration can reduce welfare

More Results

Event-Study: 07/08 US Financial Crisis

- **Contagion:** How do shocks propagate through the interbank market? And to the real economy?

Data

Event-Study: 07/08 US Financial Crisis

- **Contagion:** How do shocks propagate through the interbank market? And to the real economy?
- Funding cost shock through interbank markets:
  1. Some large German banks *directly* exposed to US financial crisis in 2007/08 though their assets in US banks
  2. Cut lending in German interbank market in response
  3. Domestic borrowing banks are *indirectly* exposed through interbank network

Data

Event-Study: 07/08 US Financial Crisis

Construct *indirect* exposure of bank n to US financial crisis

$$Exposure_{t0}^{US,n} = \sum_{i \neq n}^{N} \frac{M_{t0}^{in}}{\sum_{i' \neq n}^{N} M_{t0}^{i'n}} \mathcal{M}_{t0}^{US,i}$$

- M_{t0}^{in}: bank n liabilities with bank i
- $\mathcal{M}_{t0}^{US,i}$: direct exposure of lender i to US bank assets
- Base period $t0$ at 2006Q1 (10 quarters before Lehman collapse)
- Mean: 2.3b, 25th percentile: 950m, 90th percentile: 3.4b

Data

Event-Study: 07/08 US Financial Crisis

Difference-in-Difference:

1. more or less *indirectly* exposed banks
2. before and after US crisis (event date 2007Q3)

$$\log y_t^n = \rho_n + \mu_t + \sum_{\tau=2004Q4}^{2011Q4} \delta_\tau \left(Exposure_{2006Q1}^{US,n} \times \mu_\tau \right) + \beta' X_t^n + u_t^n$$

- Include bank FE, quarter FE, controls for direct exposure and asset composition
- Outcomes y_t^n: loan interest rate, loan amount, interbank borrowing, "own share"
- 240 banks over 29 quarters

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- Include bank FE, quarter FE, controls for direct exposure and asset composition
- Outcomes y_t^n: loan interest rate, loan amount, interbank borrowing, "own share"
- 240 banks over 29 quarters
- **Identification assumption**:
  More or less exposed banks have same changes in y_t^n in the absence of US financial crisis.

Event-Study: 07/08 US Financial Crisis

Interbank borrowing

Interest rate on outstanding final loans

At mean indirect exposure (2.3b):

- 20% drop on interbank borrowing
- 20 b.p. higher interest rates on firms/household loans

Parametric Alternative | Pre-trends

Event-Study: 07/08 US Financial Crisis

Outstanding final loans

Own share of funding

At mean indirect exposure (2.3b):

- 5% drop on firms/household loans
- 3.5% higher reliance on own funds

Parametric Alternative | Pre-trends

Conclusions

- Interbank market integration is characterized by a risk-efficiency trade-off (*efficiency* vs *contagion* vs *diversification*)
- Develop a model of the interbank market that accommodates a high degree of heterogeneity in banks' characteristics and nests into a standard New Keynesian model
- Derive analytical approximations to Gains from Trade (dynamic and static)
- Calibrate the model using proprietary micro-data on the universe of German MFI. Sizable Gains from Trade (around 1.3%)
- Provide evidence of the transmission of the 2007/08 US financial crisis via the German interbank market

BACKUP

Literature

- **Financial accelerator:** Bernanke & Gertler (1986), Kiyotaki & Moore (1997), Bernanke *et al.* (1998) ...
- **Financial networks:** Allen & Gale (2000), Acemoglu *et al.* (2015), **?**, Babus & Hu (2017), Babus & Kondor (2018), Farboodi (2021) ...

  ⇒ Detailed network structure but limited implications for welfare
- **Interbank market + DSGE:** Gertler *et al.* (2016), Piazzesi *et al.* (2019) and De Fiore *et al.* (2018)

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This paper:
Trade model of interbank market with high degree of heterogeneity
+ (fairly standard) DSGE model

⇒ Detailed network structure + link to aggregate welfare and volatility

Back

Stylized Facts

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   Detail

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5. Core-Periphery structure: core banks over 100 connections, periphery < 20
   Detail

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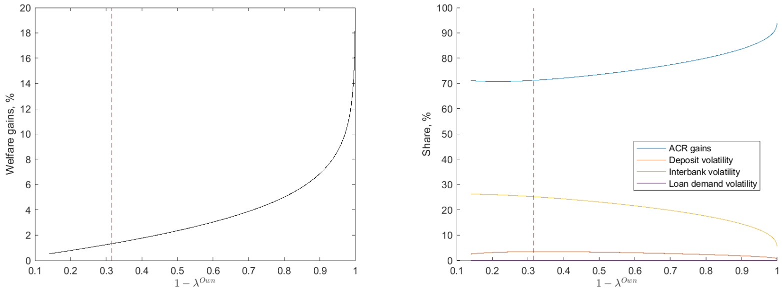
Quantification - Gains from Trade



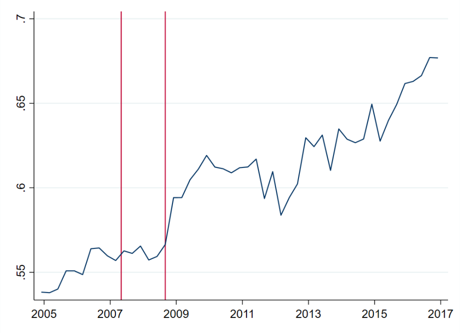
(a) Gains from trade

(b) Decomposition of gains

Here: decrease SS-level of transaction costs continuously to 1 and compare to autarky

Back

Quantification - Great Recession



Aggregate "own" share of funding

- Persistent drop in interbank market size after Great Recession ($\sim$ 10ppt)
- Change steady state level of transaction costs at onset of Great Recession

	Pre-2007Q2	Post-2008Q3	Difference
$\mathbb{J}$, in %	1.73	1.17	-0.56

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Quantification - Monetary Policy

1) SS-LoLR

- Provides liquidity to banks facing short-term liquidity shocks
- Sets cap on funding costs
- Similar to discount window
- Orthogonal to cyclical policy, no effect on business cycle volatility
- New Keynesian structure not necessary, would also be present in RBC

$$E\left[\frac{U_t - U_t^{no-LoLR}}{U_x X}\right] = -\left(\frac{\alpha}{1-\alpha}\right)\cdot\left(1+\frac{1}{\kappa}\right)\cdot\log\left(1-\xi^0\right) \approx 2\%$$

- Pre-crisis central bank intervention $\xi^0 = 3.5\%$

Back

Quantification - Monetary Policy

2) Cyclical-LoLR

- Expand/contracts fund supply in response to business cycle fluctuations
- Financial shocks enter aggregate economy as supply shocks!
- Stabilization requires contracting funds in response to credit spread shock

$\Rightarrow$ Very minor effect on Gains from Trade

Contour Graph

3) Conventional Monetary Policy

- Similar logic as for Cyclical-LoRL
- Optimal coefficient on credit spread close to zero and positive
- Implies raising rates in response to credit spread shock

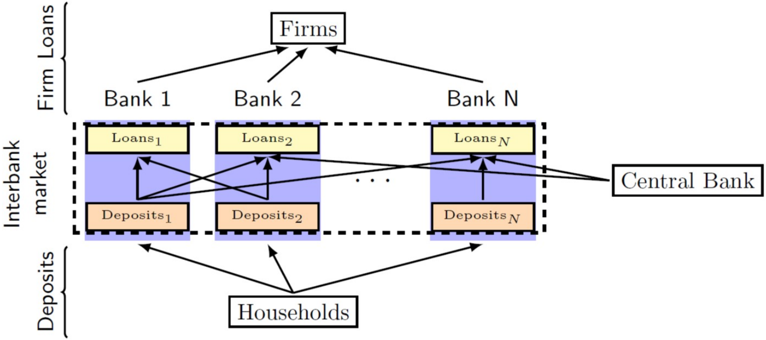
$\Rightarrow$ Very small welfare effect

Back

Model - Central Bank

- Additional lender (index 0) in the network (no depositors, free money creation)
- Lend to banks, at **ad-hoc penalty rate**
- Profits rebated to depositors (rep HH)

$$R^{I,0n}_{t,\tau} = \text{penalty}_{t,\tau} \cdot E_t \left[R^{I,n}_{t,\tau} \right]$$



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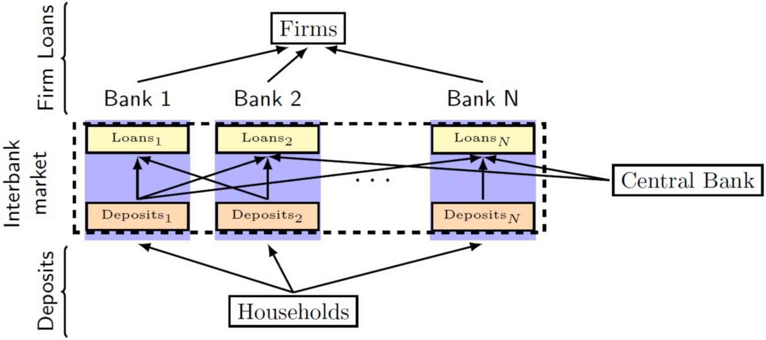

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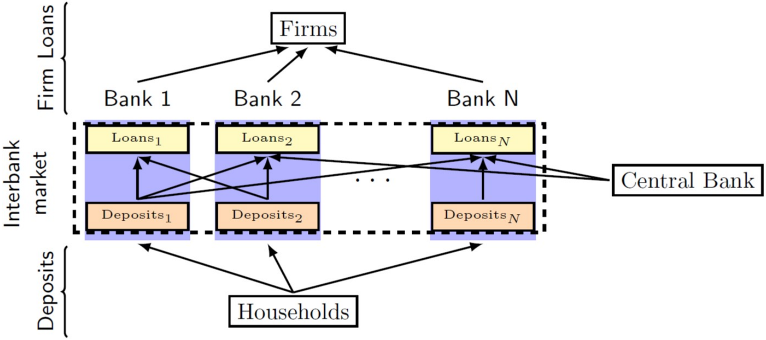
$$R_{t,\tau}^{I,0n} = e^{\varpi_1} \cdot \underbrace{\left(\frac{\Phi_t^n}{\Phi^n}\right)^{-\varpi_2} \cdot z_{t,\tau}^0}_{\text{Cyclical-LoLR}} \cdot E_t\left[R_{t,\tau}^{I,n}\right]$$



Model - Equilibrium Interbank Market

- Share in bank n's loans financed by loans from bank i and with Central Bank

$$\lambda_t^{in} = \left(\frac{d_t^{in} \cdot T_t^i}{\Phi_t^n} \right)^{-\kappa}; \qquad \xi_t^{0n} = \left[1 + e^{\kappa \varpi_1} \cdot \left(\frac{\Phi_t^n}{\Phi^n} \right)^{-\kappa \varpi_2} \right]^{-1}$$

  - d_t^{in}: Transaction costs between i and n
  - T_t^i: Depositor preferences for bank i
  - Φ_t^n: Credit spread of bank n in t w/o central bank
  - Φ^n: Credit spread of bank n in SS w/o central bank

Model - Equilibrium Interbank Market

- Share in bank n's loans financed by loans from bank i and with Central Bank

$$\lambda_t^{in} = \left(\frac{d_t^{in} \cdot T_t^i}{\Phi_t^n} \right)^{-\kappa}; \qquad \xi_t^{0n} = \left[1 + e^{\kappa \varpi_1} \cdot \left(\frac{\Phi_t^n}{\Phi^n} \right)^{-\kappa \varpi_2} \right]^{-1}$$

- Credit spread for bank n (over bond rate) with Lender-of-Last-Resort

$$\widetilde{R}_t^{I,n} = \Phi_t^n \cdot \left(1 - \xi_t^{0n}\right)^{1/\kappa}$$

  - Φ_t^n: Credit spread of bank n w/o central bank

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- Credit spread for bank n (over bond rate) with Lender-of-Last-Resort

$$\widetilde{R}_t^{I,n} = \Phi_t^n \cdot \left(1 - \xi_t^{0n} \right)^{1/\kappa}$$

- Aggregate **loan rate**

$$R_t^F = \left(\frac{\sigma}{\sigma - 1} \right) \cdot \widetilde{R}_t^I \cdot R_t^B; \qquad \widetilde{R}_t^I = \underbrace{\left[\sum_{n=1}^{N} a_t^n \left(\widetilde{R}_t^{I,n} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}}_{\text{Aggregate credit spread}}$$

Lender-of-Last-Resort

$$R_{t,\tau}^{I,0n} = e^{\varpi_1} \cdot \left(\frac{\Phi_t^n}{\Phi^n}\right)^{-\varpi_2} z_{t,\tau}^0 \cdot E_t\left[R_{t,\tau}^{I,n}\right]$$

- $\varpi_1 \Rightarrow$ Steady state level of intervention ξ^0 (SS-LoLR)
- $-\varpi_2 \Rightarrow$ Countercyclical response (Cyclical-LoLR)

Gains from existence of discount window for simple case $\varpi_2 = 0$:

$$E\left[\frac{U_t - U_t^{no-LoLR}}{U_x X}\right] = -\left(\frac{\alpha}{1-\alpha}\right) \cdot \left(1 + \frac{1}{\kappa}\right) \cdot \log\left(1 - \xi^0\right)$$

- SS gains due to cap on funding costs (extreme idiosyncratic liquidity crunch)
- Orthogonal to usual conventional and unconventional monetary policy!
- We also allow for $\varpi_2 > 0$ and Taylor rule targeting of aggregate credit spread

Data

Confidential microdata on the universe of German MFIs ("banks")

- Supervisory data from Deutsche Bundesbank
- MFIs represent 65% German financial sector (other 35% Insurers+Invest. funds)
- Bilateral MFI positions (+1.5M Euros threshold), quarterly, 2002-2017
- MFI balance sheets, monthly, 1999-2017
- Interest rates by +200 largest MFIs ($\sim$ 70% of MFI sector), monthly, 1999-2017
- Foreign exposure +80 largest MFIs, by country and asset/liability type

Stylized Facts
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Stylized Facts
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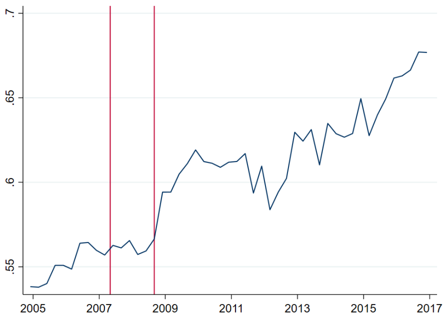
Stylized Fact 1: Aggregate trade openness - own share of funding



Notes: Calculated as $1 - \frac{\text{Interbank Liabilities}}{\text{Assets} - \text{Interbank Assets}}$

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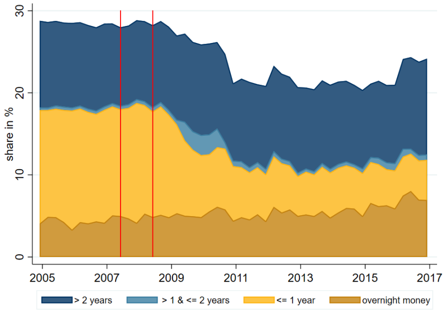
Stylized Fact 1: Interbank liabilities by maturity



Interbank liabilities by maturity, lines correspond to onset of financial crisis period

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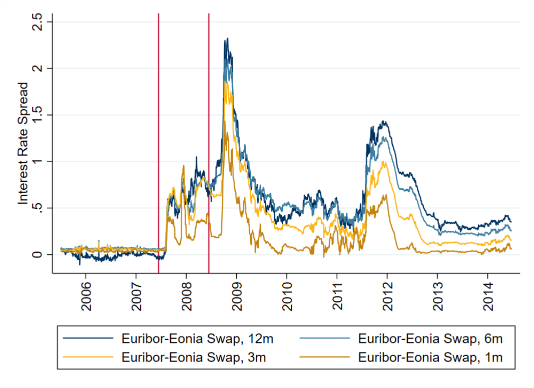
Stylized Fact 2: Transitory and permanent variation in credit spread



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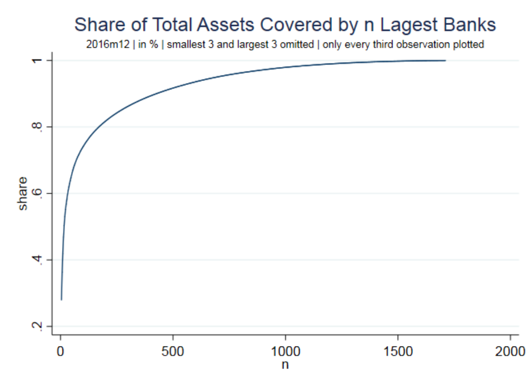
Stylized Fact 3: Bank concentration



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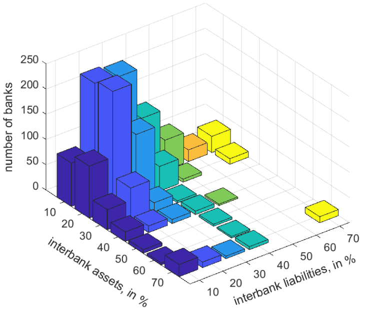
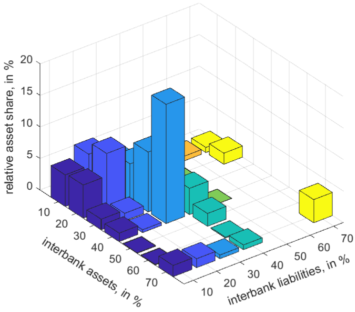
Stylized Fact 4: MFI asset/liability share of balance sheet



(a) Bank count



(b) Share total assets

Share of interbank assets and liabilities on the balance sheet. (a) Bank count and (b) Share of total assets.

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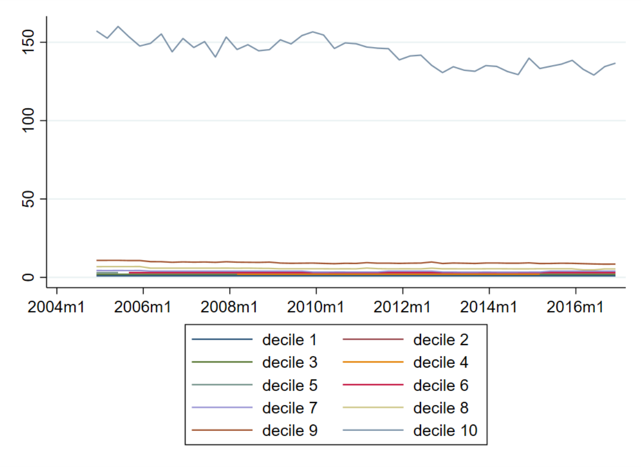
Stylized Fact 5: Average number of interbank connections, by decile



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Event-Study: 07/08 US Financial Crisis

Parametric Alternative:

$$\log y_t^n = \rho_n + \tilde{\mu}_t + \delta Exposure_{2006Q1}^{US,n} \times Post_{2008Q3} + \beta' X_t^n + u_t^n$$

- Drop 2007Q3-2008Q2 due to ambiguous timing of crisis
- Include bank FE, quarter FE, controls for direct exposure and asset composition
- Outcomes y_t^n: loan interest rate, loan amount, interbank borrowing, "own share" in funding
- 240 banks over 25 quarters
- **Identification assumption**:
  More or less exposed banks have same changes in y_t^n in the absence of US financial crisis.

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Event-Study: 07/08 US Financial Crisis - Parametric specification

Table: Difference-in-difference results on indirect exposure to US financial crisis

	(1) Loan Rate	(2) Loans	(3) Own Share	(4) Borrowing
$Exposure_{t0} \times Post_t$	0.0006***	-0.0229***	0.0125***	-0.0789***
	(0.0001)	(0.0032)	(0.0046)	(0.0177)
Observations	3,612	3,612	3,578	3,609
R-squared	0.9299	0.9925	0.8805	0.9556
Controls	yes	yes	yes	yes
Mean of Exposure	2.275	2.275	2.275	2.275

Regression compares outcomes between 2006Q1 to 2007Q2 and after Lehman collapse in 2008Q3 until 2011Q4 for more or less indirectly exposed banks to US financial crisis. Initial asset exposure to lenders in US market taken in 2006Q1. Controls include direct asset exposure to US and loan shares of non-MFI and household loans, each broken down into maturity of less than 1 year, between 1 and 5 years and more than 5 years as well as separate shares for secured and unsecured mortgages. All regressions include bank fixed effects and quarter fixed effects. Standard errors clustered at level of bank group-quarter. Source: Research Data and Service Centre (RDSC) of Deutsche Bundesbank, AUSTA, BISTA, VJKRE, ZISTA, 2004m12 - 2011m12, own calculations. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

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Event-Study: 07/08 US Financial Crisis - Pretrends

Table: Pre-trends for results on indirect exposure to US financial crisis

	(1) Loan Rate	(2) Loans	(3) Own Share	(4) Borrowing
$Exposure_{t0} \times Post_{t0}$	-0.0002*	-0.0035	-0.0101***	0.0030
	(0.0001)	(0.0034)	(0.0037)	(0.0085)
Observations	1,812	1,812	1,801	1,812
R-squared	0.9585	0.9958	0.9496	0.9884
Controls	yes	yes	yes	yes
Mean of Exposure	2.275	2.275	2.275	2.275

Regression compares outcomes between 2004Q4 to 2005Q4 and the pre-period in main regression (2006Q1 until 2007Q2) for more or less indirectly exposed banks to US financial crisis. Initial asset exposure to lenders in US market taken in 2006Q1. Controls include direct asset exposure to US and loan shares of non-MFI and household loans, each broken down into maturity of less than 1 year, between 1 and 5 years and more than 5 years as well as separate shares for secured and unsecured mortgages. All regressions include bank fixed effects and quarter fixed effects. Standard errors clustered at level of bank group-quarter. Source: Research Data and Service Centre (RDSC) of Deutsche Bundesbank, AUSTA, BISTA, VJKRE, ZISTA, 2004m12 - 2007m6, own calculations. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

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Representative Household

$$\max \sum_{j=0}^{\infty} \beta^j E_t \left[\log\left(X_{t+j}\right) - \left(\frac{\eta}{\eta+1}\right) \int_0^1 N_{t+j}^{1+\frac{1}{\eta}} \, d\tau \right]$$

where

$$X_t = \int_0^1 C_{t,\tau} + \sum_{n=1}^{N} \int_0^1 \left(1 - z_{t,\tau}^n \cdot T_t^n\right) \frac{D_{t,\tau}^n}{P_t} \, d\tau$$

- Non-separable money in the utility

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- Shock to $z_{t,\tau}^n \implies$ Reallocation of deposits over bank network
- Bank preferences $z_{t,\tau}^n \overset{\text{i.i.d.}}{\sim} \textit{Weibull}$, mean one, shape parameter κ

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- Bank preferences $z_{t,\tau}^n \overset{\text{i.i.d.}}{\sim} Weibull$, mean one, shape parameter κ
- Interest rate on deposits

$$R_{t,\tau}^{D,n} = z_{t,\tau}^n \cdot T_t^n \cdot R_t^B \qquad \forall\, n, \tau$$

Back

Firms

- Standard New-Keynesian Firms
  - Continuum $[0, 1]$ of firms, index ν
  - Monopolist competition
  - Calvo price stickiness, θ

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$$Y_{t,\tau}(\nu) = \left(\frac{K_t(\nu)}{\alpha}\right)^{\alpha} \left(\frac{A_t N_{t,\tau}(\nu)}{1-\alpha}\right)^{1-\alpha}$$

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- $K_t(\nu)$ CES aggregator of N types of capital

$$K_t(\nu) = \left[\sum_{n=1}^{N} (a_t^n)^{1/\sigma} K_t^n(\nu)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

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- Capital accumulation

$$K_t^n(\nu) = \frac{I_t^n(\nu)}{P_t}$$

Back

Firms

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- Borrow at constant rate over the quarter $R_{t,\tau}^{F,n} = R_t^{F,n}, \quad \forall \tau$

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- Aggregate loan demand

$$L_t^n = a_t^n \left(\frac{R_t^{F,n}}{R_t^F} \right)^{-\sigma} L_t \, ; \qquad R_t^F = \left[\sum_{n=1}^{N} a_t^n \left(R_t^{F,n} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

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Bank Model

Each bank, two divisions (for expositional purposes only)

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- **Deposits division**
  - Obtain deposits Representative Household
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- **Deposits division**
  - Obtain deposits Representative Household
  - Provide funds to loan divisions (own or other's)
- **Loan division**
  - Provide loans to firms
  - Obtain funds from deposit divisions (own or other's)

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Deposits Division

- Production function

$$\sum_{i=1}^{N} d_t^{ni} \cdot M_{t,\tau}^{ni} = D_{t,\tau}^{n}, \quad \forall n$$

$$d_t^{nn} = 1, \quad \forall t$$

- d_t^{ni}: Costs of assessing collateral value, enforcement, etc.

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- d_t^{ni}: Costs of assessing collateral value, enforcement, etc.

- Interbank interest rate

$$R_{t,\tau}^{I,ni} = R_t^B \cdot d_t^{ni} \cdot T_t^n \cdot z_{t,\tau}^n$$

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Loan Division

- Funding constraint: $L_t^n \leq \sum_i M_{t,\tau}^{in}$

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- Interest rate on loans

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- Credit spread

$$\widetilde{R}_t^{I,n} = \frac{E_t \left[R_{t,\tau}^{I,n}\right]}{R_t^B}$$

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Central Bank

- Lender-of-last-resort
  - Additional bank in the network
  - No depositors, free money creation
  - Lend to banks, at a penalty rate

$$R_{t,\tau}^{I,0n} = e^{\varpi_1} \cdot \underbrace{\left(\frac{\Phi_t^n}{\Phi^n}\right)^{-\varpi_2} \cdot z_{t,\tau}^0}_{\text{variable component}} \cdot E_t\left[R_{t,\tau}^{I,n}\right]$$

  - Φ_t^n: credit spread without lender-of-last-resort intervention

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  - Φ_t^n: credit spread without lender-of-last-resort intervention

- Risk-free rate R_t^B follows a Taylor rule

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Model solution

- New-Keynesian Phillips curve

$$\hat{\pi}_t = \Omega\,\hat{\tilde{y}}_t + \beta E_t\left[\hat{\pi}_{t+1}\right]$$

- Dynamic IS equation

$$\hat{\tilde{y}}_t = -\left[1 + \alpha\left(\frac{\eta}{\eta+1}\right)\right] \cdot \left[\hat{r}_t^B - E_t\left[\hat{\pi}_{t+1}\right] - \hat{\imath}_t^n\right] + E_t\left[\hat{\tilde{y}}_{t+1}\right]$$

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- Financial variables

$$\hat{\tilde{r}}_t^I = \rho_I \cdot \hat{\tilde{r}}_{t-1}^I + \vartheta_1 \cdot \left[\varepsilon_t^T + \varepsilon_t^I\right] + \vartheta_2 \cdot \varepsilon_t^a$$

$$\widehat{\log\left(\lambda_t^0\right)} = \rho_I \cdot \widehat{\log\left(\lambda_{t-1}^0\right)} + \vartheta_3 \cdot \left[\varepsilon_t^T + \varepsilon_t^I\right]$$

  - ε_t^T: Aggregate shock to depositor preferences
  - ε_t^I: Aggregate shock to transaction costs
  - ε_t^a: Aggregate shock to loan demand

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Calibration

Parameter	Value	Description	Source
η	1	Frisch labor supply elasticity	Standard
β	0.99	Discount factor	Standard
ϵ	7	Elasticity of substitution intermediate output	Standard
θ	0.55	Calvo price stickiness	Standard
α	0.4	Capital share in production	Aggregate data
σ	27.1	Firm's loan elasticity of demand	Estimation, Sec. 6
κ	26.7	Interbank loan elasticity of demand	Estimation, Sec. 6
$\bar{\Pi}$	0	Target inflation rate	Standard
γ_π	2.5	Taylor rule inflation response	Standard
γ_y	1.5	Taylor rule output gap response	Standard
γ_I	0	Taylor rule interbank rate response	Baseline assumption
ϖ_1	0.12	Fixed penalty rate	Match 3.5% pre-crisis CB trade share
ϖ_2	0.25	Variable penalty rate responsiveness	Educated guess
ρ_I	0.77	Persistence interbank shocks	Estimation, Sec. 6
ζ_T	0.077	Covariance depositor preferences shock	Estimation, Sec. 6
$\zeta_{I,B}$	0.052	Covariance interbank transactions shock, same borrower	Estimation, Sec. 6
$\zeta_{I,L}$	0.52	Covariance interbank transactions shock, same lender	Estimation, Sec. 6
$\zeta_{I,X}$	0.025	Covariance interbank transactions shock, different lender and borrower	Estimation, Sec. 6
$\sigma_a \cdot (1-\zeta_a)$	0.001	Standard deviation firm-loan demand shock and covariance, joint	Estimation, Sec. 6
σ_T	0.028	Standard deviation depositor preferences shock	Estimation, Sec. 6
σ_I	0.04	Standard deviation interbank transactions shock	Estimation, Sec. 6

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Full gains from trade formula

$$\mathbf{J} = \mathbf{J}^{ss} + \frac{1}{2}\left[\sigma_a^2 \cdot \mathfrak{J}^a + \sigma_T^2 \cdot \mathfrak{J}^T + \sigma_I^2 \cdot \mathfrak{J}^I\right] ,$$

where:

$$\mathfrak{J}^a = (1-\zeta_a)\left[\aleph_5 \cdot \left[H^{F,AU} - H^F\right] - 2(\aleph_5 - \aleph_4) \cdot \sum_{i=1}^{N}\left(s^{i,AU} - s^i\right) a^i\right]$$

$$\mathfrak{J}^T = (1-\zeta_T) \cdot \left[\aleph_3 \cdot \left[H^{F,AU} - H^F\right] + \left[(\aleph_0\kappa - \aleph_2) + \aleph_3 \cdot H^F\right] \cdot \left[1 - H^I\right] - \aleph_3 \cdot \sum_{i=1}^{N}\sum_{n\neq i}\sum_{j=1}^{N} s^i s^n \lambda^{ji}\lambda^{jn}\right]$$

$$\mathfrak{J}^I = \aleph_0\kappa \cdot \left(1 - \lambda^{Avg}\right) - \left[(\aleph_0\kappa - \aleph_2) + \aleph_3 \cdot H^F\right] \cdot \beth^I \cdot H^I$$
$$- \zeta_{I,B} \cdot \left[(\aleph_0\kappa - \aleph_2) + \aleph_3 \cdot H^F\right] \cdot \left[H^O - H^I\right]$$
$$- \zeta_{I,L} \cdot \aleph_3 \cdot \sum_{i=1}^{N}\sum_{n\neq i}\sum_{j\neq\{i,n\}} s^i s^n \lambda^{ji}\lambda^{jn}$$
$$- \zeta_{I,X} \cdot \aleph_3 \cdot \sum_{i=1}^{N}\sum_{n\neq i} s^i s^n \left[(1-\lambda^{ii})(1-\lambda^{nn}) - \sum_{j\neq i}\lambda^{ji}\lambda^{jn}\right] .$$

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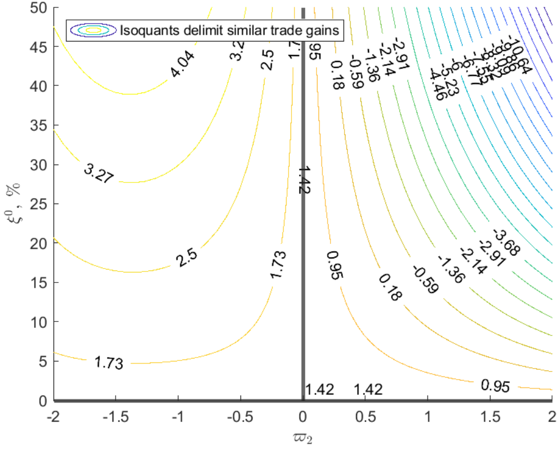
Lender-of-Last-Resort

Gains from trade $\mathbb{J}$, different calibrations ϖ_1 and ϖ_2



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