Oesterreichische Nationalbank

Eurosystem

Systemically important accounts, network topology and contagion in ARTIS

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PAYMENT AND SETTLEMENT SIMULATION SEMINAR

Helsinki, 28. – 29. August 2007

Agenda

Motivation and Objectives

Network indicators – ARTIS vs. Fedwire

Eigenvalue analysis of ARTIS network indicators

Timeseries analysis of ARTIS network indicators

Systemically important accounts and contagion in ARTIS

The relation of contagion and network structure in ARTIS

Key Findings and Conclusion

Motivation and Objectives

- Last year's result: Network structure relates to the stability of systems.
  - „Congestion and cascades in payment systems“ (Fed NY & Sandia)
  - „The impact of payment topology on operational failures“ (Soramäki)
- We concluded our presentation with the following questions for further research
  - Analyse variance of stress test results across days, banks and scenarios
  - Focus on determinants of differences
- As a consequence we address four research questions with this presentation:
  - How does the network structure of ARTIS relate to stability?
  - Which network indicators are appropriate to capture network structure in the analysis of system stability?
  - Do network indicators help to explain contagion effects?
  - How does this additional information help to identify the relevant network in ARTIS, i.e. which are the systemically important accounts?

ARTIS – Austrian Realtime Interbank Settlement System

- ARTIS is the Austrian component of TARGET.
- The OeNB is in charge of payment system oversight, hence also ARTIS.
- ARTIS is a straight forward gross settlement system with two special features:
  - The stop sending rule as applies to all TARGET systems
  - Debit authorisation, for regular / daily clearing (i.e. credit card settlements)
- For our current research we use ARTIS transaction data from July 2005 to June 2006 (249 business days, excluding active days which are bank holidays in Austria).

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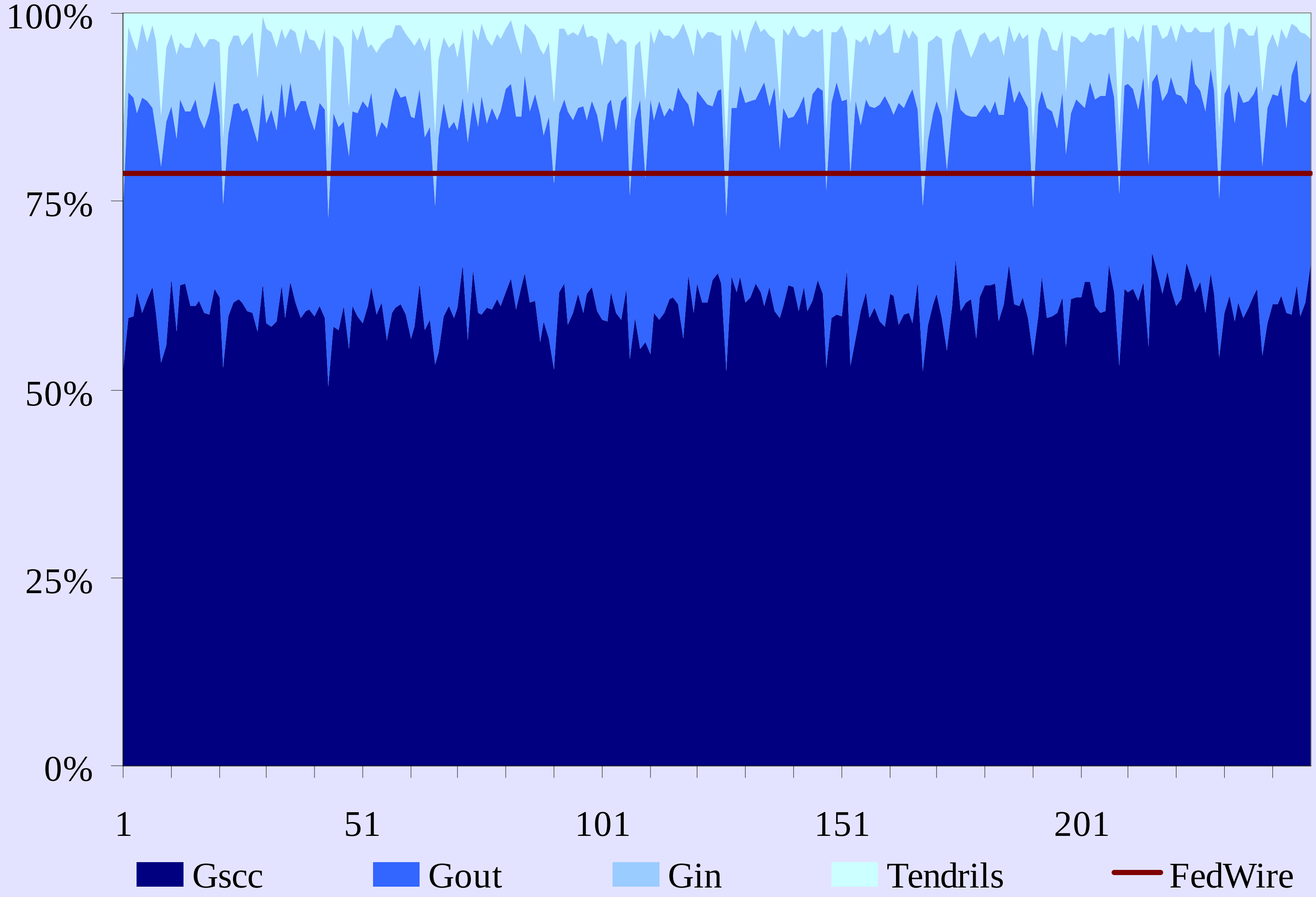
ARTIS vs FedWire – Gwcc and Gscc



ARTIS vs FedWire – Network Ratios

	FedWire	ARTIS				
	Mean	**Mean**	**Median**	**Min**	**Max**	**Stdv**
Payments						
Volume	436,000.0	13,577.8	13,519	8,790	23,919	1,644
Value (EUR mn)	1.3E+09	43,421	42,069	20,672	85,245	9,646
Average (EUR mn)	3.1	3.2	3.0	1.8	6.4	0.699
Connectivity						
Connectivity	0.300	0.086	0.086	0.070	0.100	0.006
Distance Measures						
Avg. Pathlength	2.6	2.3	2.3	2.2	2.5	0.049
Diameter	6.6	4.3	4	4	5	0.440
Others						
Clustering	0.530	0.580	0.582	0.510	0.628	0.020
Average degree	15.2	15.7	15.7	14.4	17.2	0.559
In-betweenness centrality	-	0.008	0.008	0.007	0.009	0.000
Dissimilarity index	-	0.460	0.460	0.387	0.563	0.030

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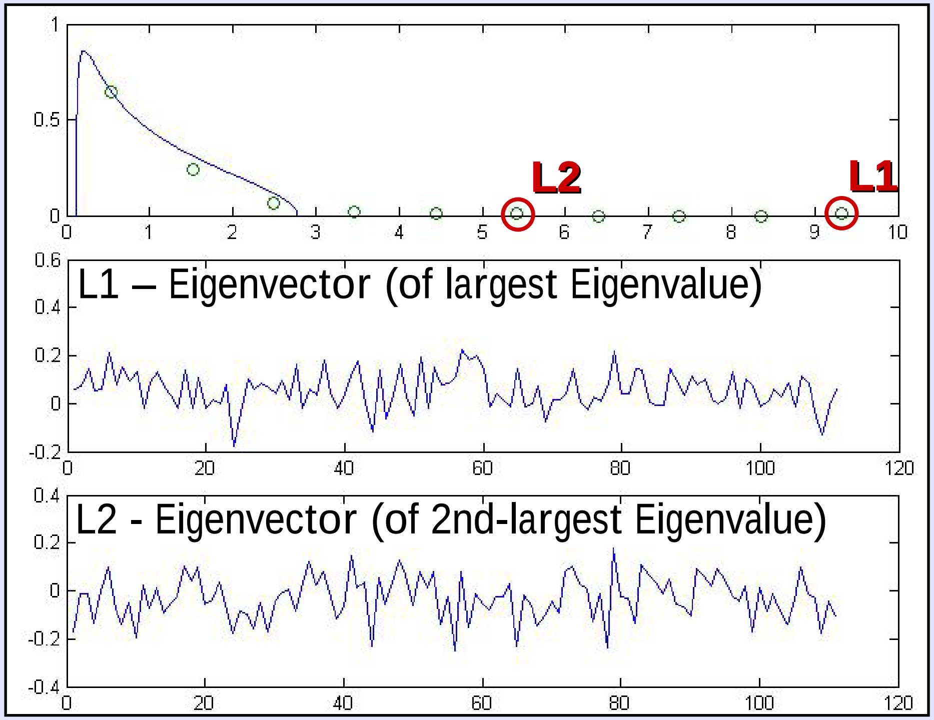
Eigenvalue analysis of network indicators

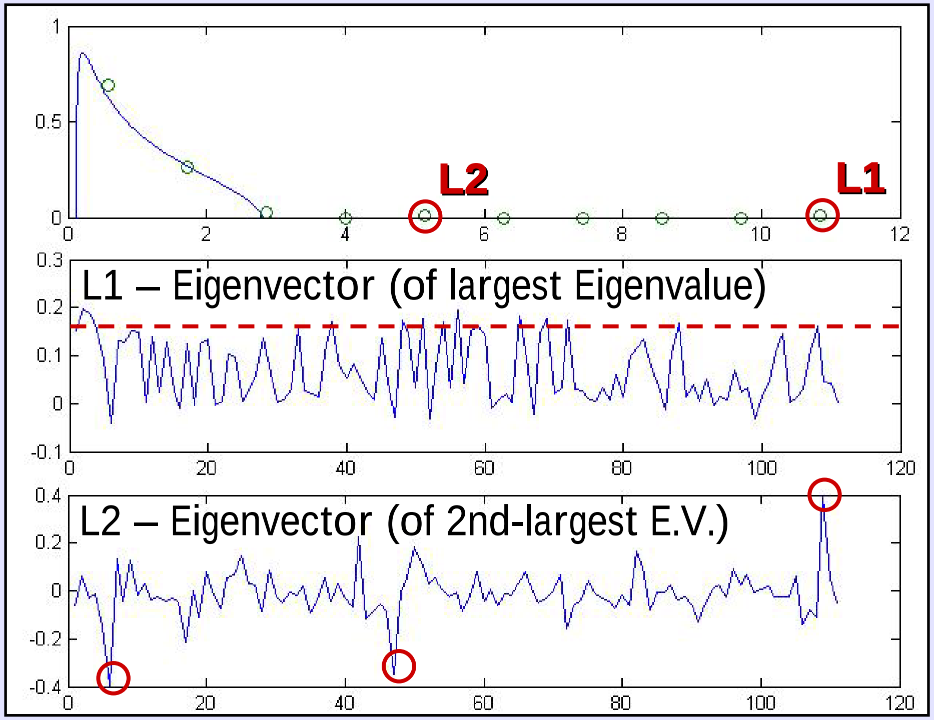
- What do correlations of node level indicators tell us about the network?
- Method: Random matrix theory (RMT)
  - More specifically: Eigenvalues of correlation matrices
  - To uncover commonalities among banks / ARTIS accounts (as applied in portfolio selection theory)
- What do we hope to achieve applying RMT?
  - First, to explore the structure and the behaviour of the payment system participants, as stated in our research questions.
  - Second, to identify structurally and / or behaviourally homogenous groups in our data set, that contain information open to economic interpretation.

An application of random matrix theory

Eigenvalue distribution
(volume of daily payments)



Eigenvalue distribution
(average path length)



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Time series analysis of network indicators

- What do the time series tell us about the network over time?
- Method: Structural time series analysis
  - To estimate unobservable components
- Why do we use a structural time series model?
  - First, the data depends on the behaviour of the payment system participants which is unobservable.
  - Second, we try to identify data points that cannot be explained by the components. We do so in order to ask the question whether these “outliers” contain valuable information that can be interpreted economically.
  - Third, the method allows for exogenous variables which help us to understand how recurring events influence network indicators.

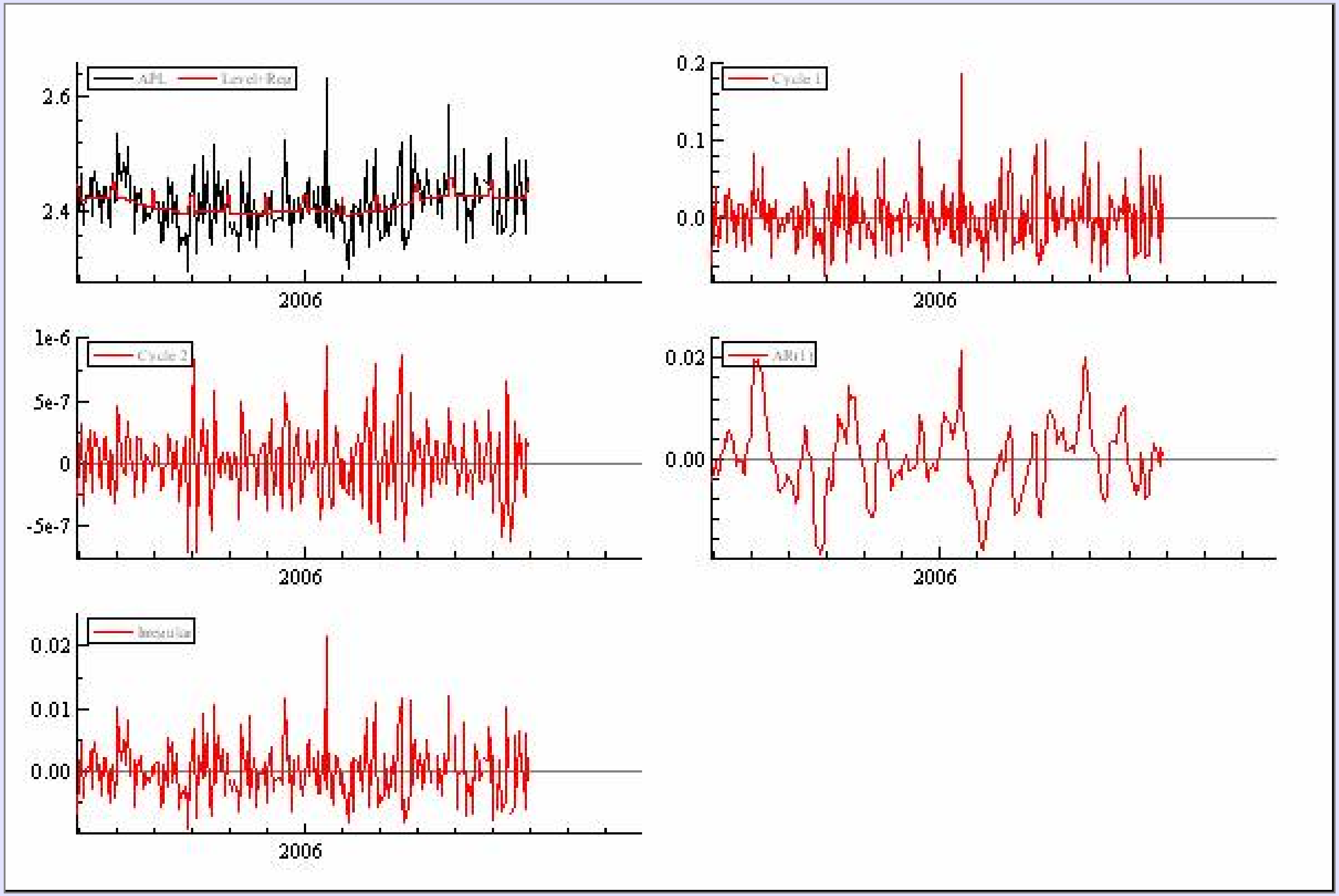
The model for time series analysis of network indicators

$$y_t = \mu_t + \psi_{1t} + \psi_{2t} + \nu_t + \sum_{i=1}^{4} \alpha_i x_i + \sum_{j=1} \phi_j \omega_{jt} + \varepsilon_t \qquad \varepsilon \sim N\left(0, \sigma_\varepsilon^2\right)$$

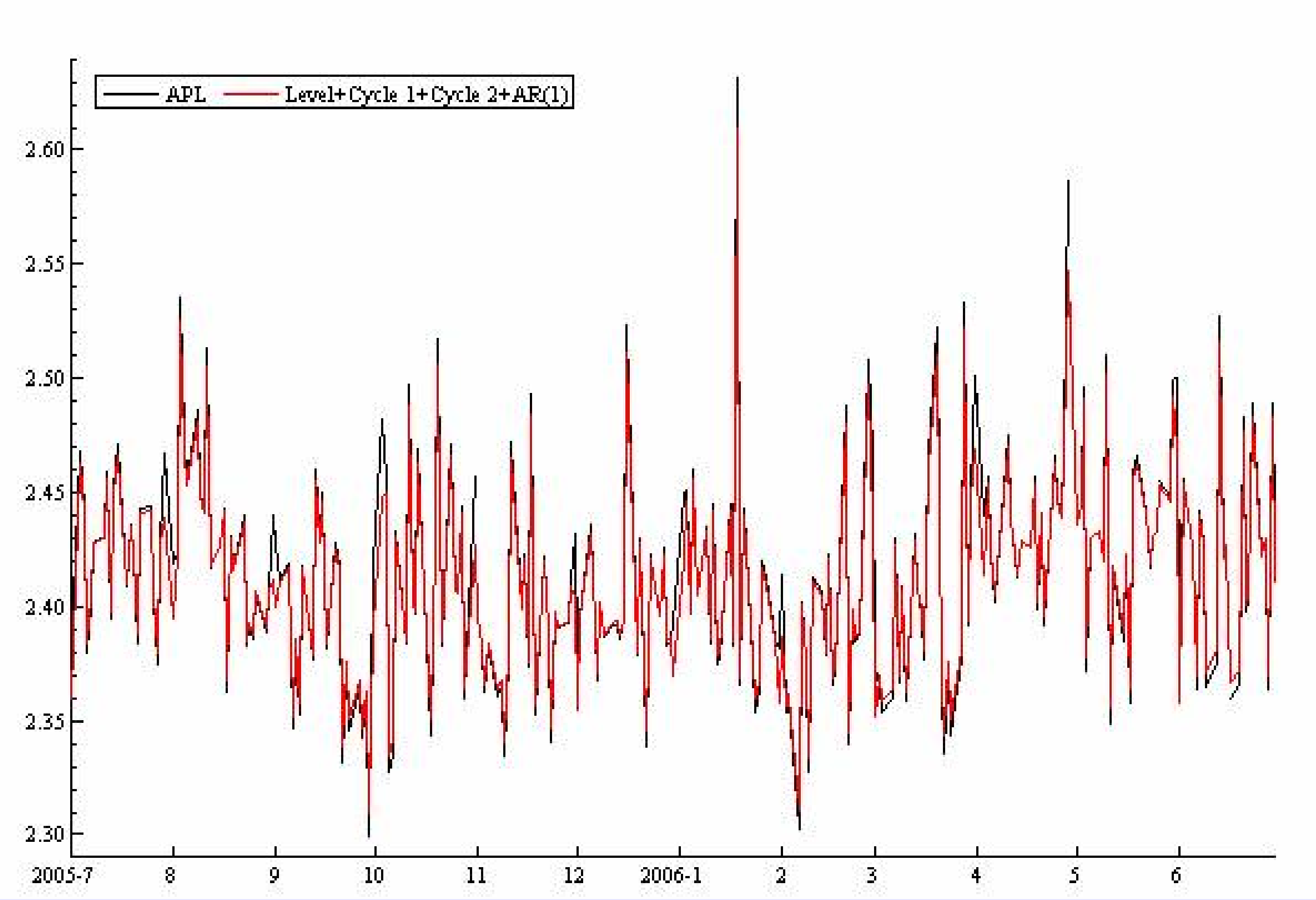
- Trend component
  - Level $\quad \mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \qquad \eta \sim N\left(0, \sigma_\eta^2\right)$
  - Slope $\quad \beta_t = \beta_{t-1} + \zeta_t \qquad \zeta \sim N\left(0, \sigma_\zeta^2\right)$
- Cyclical component
  - Cycle 1 $\quad \begin{bmatrix} \psi_{1t} \\ \psi_{1t}^* \end{bmatrix} = \rho_{\psi 1} \begin{bmatrix} \cos\lambda_{c1} & \sin\lambda_{c1} \\ -\sin\lambda_{c1} & \cos\lambda_{c1} \end{bmatrix} \begin{bmatrix} \psi_{1t-1} \\ \psi_{1t-1}^* \end{bmatrix} + \begin{bmatrix} \kappa_{1t} \\ \kappa_{1t}^* \end{bmatrix}$

    $0 < \rho_{\psi 1,2} \le 1,\ 0 \le \lambda_{c1,2} \le \pi \quad \kappa_{1t}, \kappa_{1t}^* \sim NID(0, \sigma_\kappa^2)$
  - Cycle 2 $\quad \begin{bmatrix} \psi_{2t} \\ \psi_{2t}^* \end{bmatrix} = \rho_{\psi 2} \begin{bmatrix} \cos\lambda_{c2} & \sin\lambda_{c2} \\ -\sin\lambda_{c2} & \cos\lambda_{c2} \end{bmatrix} \begin{bmatrix} \psi_{2t-1} \\ \psi_{2t-1}^* \end{bmatrix} + \begin{bmatrix} \kappa_{2t} \\ \kappa_{2t}^* \end{bmatrix}$
- Autoregressive component $\quad \nu_t = \rho_\nu \nu_{t-1} + \xi_t \qquad 0 < \rho_{\nu 1} < 1 \qquad \xi \sim NID\left(0, \sigma_\xi^2\right)\left(0, \sigma_\xi^2\right)$
- Four exogenous variables $\quad \sum_{i=1}^{4} \alpha_i x_i$
- One intervention dummy variable $\quad \sum_{j=1} \phi_j \omega_{jt}$

Average Path Length (network): estimates of components



Average Path Length (network): estimates of components



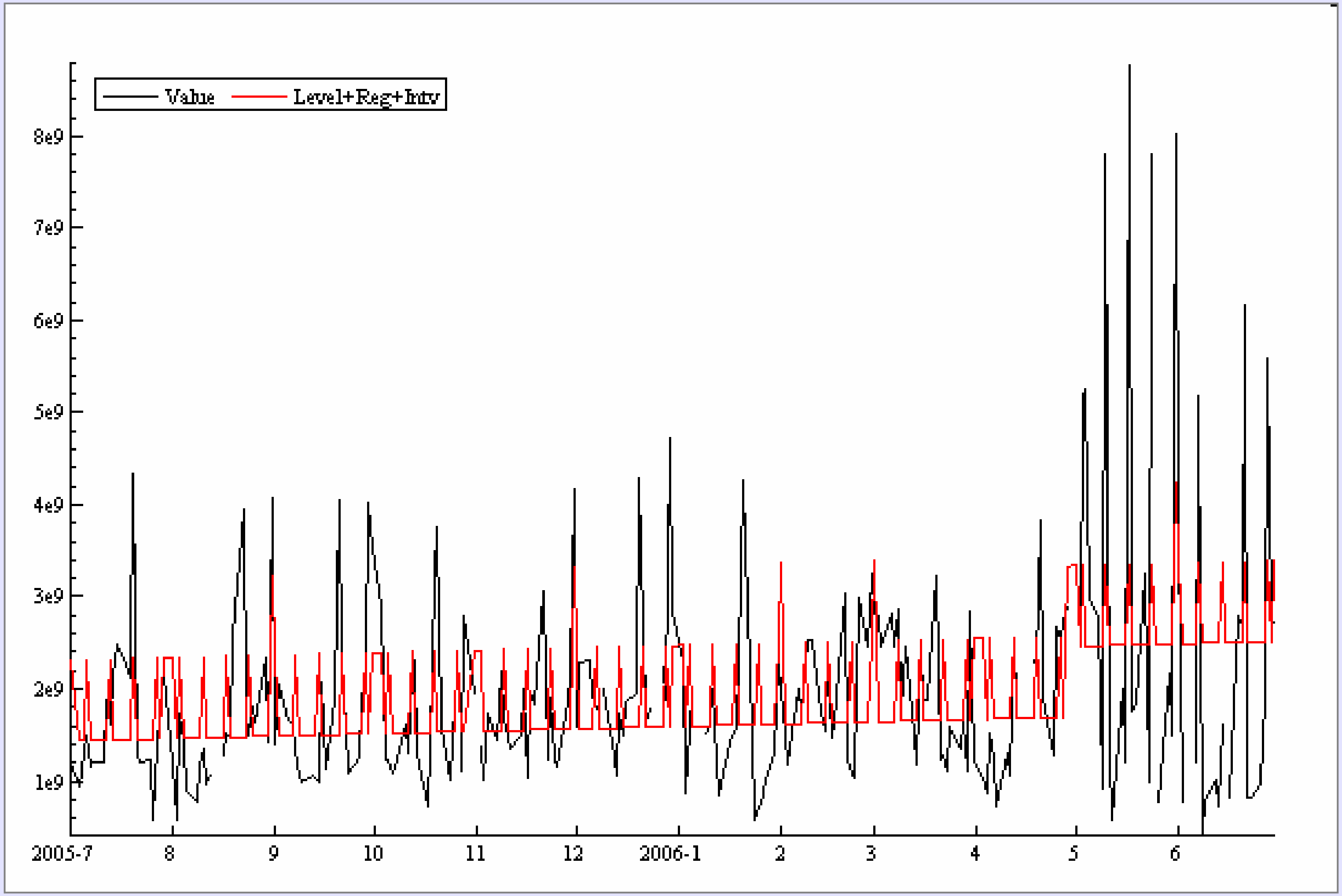
Structural time series models: results for the entire network

Network	*Value*	*Volume*	*Conn.*	*Path L.*	*Degree*	*Inbet. Cent.*	*Diss. Ind.*	*Clust. Ind.*
Components (q-ratio %)								
Level	*0*	*2*	*0*	*0*	*2*	*1*	*0*	*0*
Slope	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Cycle 1	***83***	*0*	***50***	***100***	*8*	*0*	***100***	*5*
Cycle 2	***100***	*0*	*0*	*0*	*0*	*0*	*0*	*0*
AR (1)	***68***	***22***	***100***	*15*	***100***	***24***	***82***	***100***
Irregular	*6*	***100***	*10*	*12*	***93***	***100***	***35***	*5*
Explanatory Variables								
OMO-Day	***** (+)***							**** (-)***
Ch. of Month	***** (+)***		**** (-)***	***** (+)***	***** (+)***	***** (-)***		
VAT Days							*** (+)***	
End of MRR								
Level Break 216								
Diagnostics								
Observations	*249*	*249*	*249*	*249*	*249*	*249*	*249*	*249*
N	*37.3*	*87.7*	*1.6*	*28.8*	*4.9*	*3.9*	*118*	*4.7*
DW	*2.0*	*2.1*	*2.0*	*2.0*	*2.0*	*2.0*	*2.0*	*2.0*
H	*1.2*	*1.4*	*1.1*	*1.3*	*1.0*	*1.1*	*0.7*	*0.9*
R_d^2	***67***	***43***	***45***	***45***	***38***	***42***	***49***	***45***

Structural time series models: results for an individual bank

Bank X	*Value*	*Volume*	*Conn.*	*Path L.*	*Degree*	*Inbet. Cent.*	*Diss. Ind.*	*Clust. Ind.*
Components (q-ratio %)								
Level	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Slope	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Cycle 1	***100***	***57***	*0*	*2*	*0*	*0*	***95***	*0*
Cycle 2	*2*	*0*	*0*	*2*	*0*	*1*	*0*	*0*
AR (1)	***62***	***100***	***100***	***100***	***100***	***36***	***100***	***47***
Irregular	*1*	*1*	***20***	*0*	***63***	***100***	***76***	***100***
Explanatory Variables								
OMO-Day	****** (+)***	****** (+)***				***** (+)***		
Ch. of Month	****** (+)***				****** (+)***	**** (-)***		
VAT Days							**** (+)***	
End of MRR								
Level Break	****** (+)***		***** (-)***	****** (+)***	***** (-)***	****** (-)***		***** (+)***
Diagnostics								
Observations	*249*	*249*	*249*	*249*	*249*	*249*	*249*	*249*
N	*29.6*	*272.9*	*0.4*	*0.94*	*1.4*	*13.5*	*114.7*	*2.3*
DW	*2.0*	*2.0*	*2.0*	*2.0*	*2.0*	*2.0*	*2.0*	*2.0*
H	*2.5*	*1.2*	*0.8*	*0.9*	*1.1*	*1.0*	*0.7*	*0.9*
R_d^2	***58***	***51***	***40***	***45***	***33***	***42***	***48***	***41***

Value time series for a specific bank: trend, exog. var. + interv.



Conclusion from the time series analysis

- The explanatory value of the models is rather high.
- The indicators do feature important commonalities.
- But they also feature important differences.
- At the network level the shock that hit one large bank is not picked up at all.
- The selection of the appropriate indicator the of network structure for the purpose of stability analysis is not trivial
  1. Bank level indicator or network level indicator?
  2. Which indicator?
  3. Problem of data mining!

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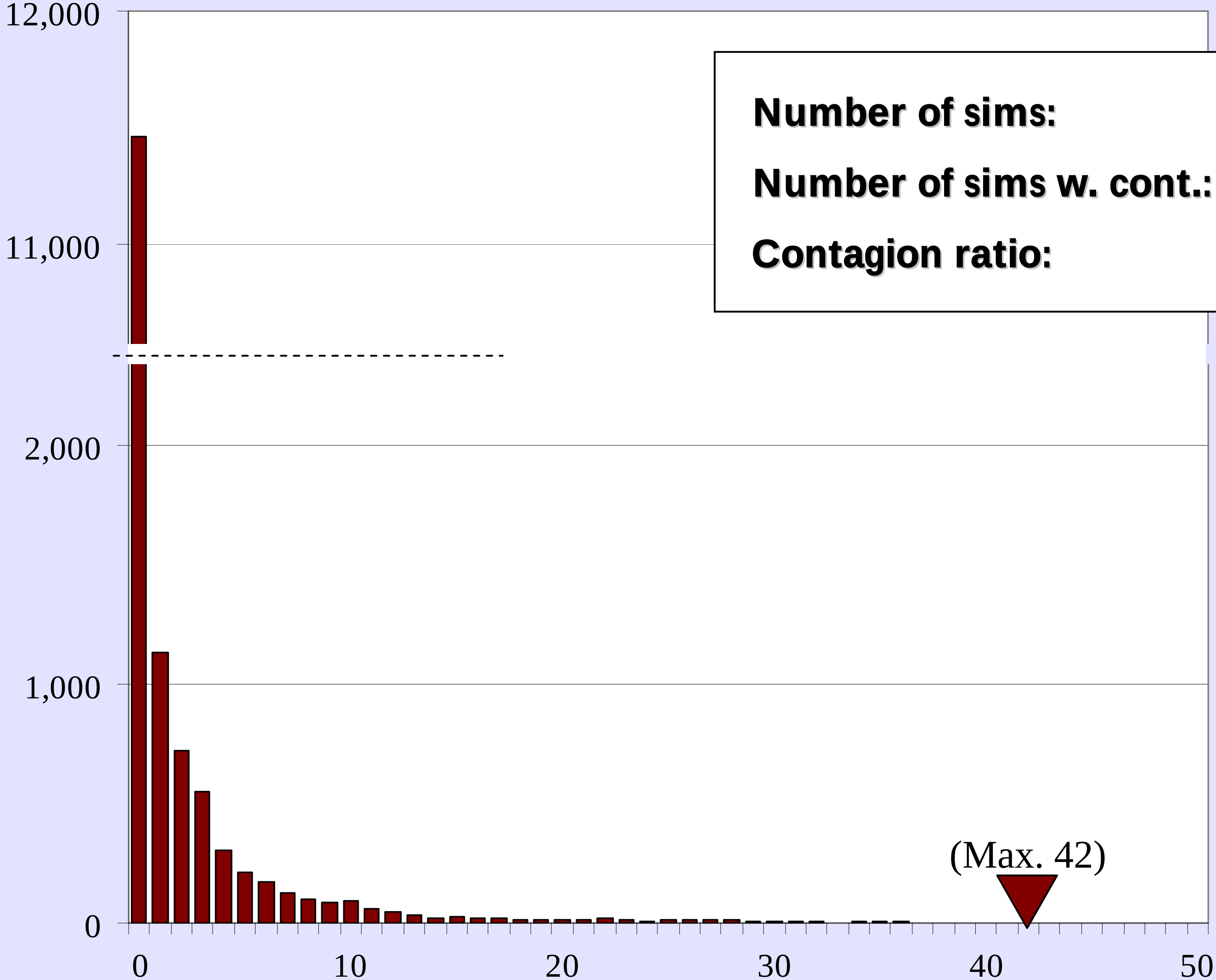
Key Findings and Conclusion

Stress testing ARTIS

- We follow the common practice to simulate one day failures of individual accounts / banks to determine the contagion effects within a payment system.
- To determine systemically relevant banks endogenously (as measured by the contagion they cause), we stress every individual active participant on each day for Q3 2005.
- Based on this identification we stress each of the relevant banks for each day across an entire year.
- We could have continued to use the BoF PSS2 simulator (as we have done in the past), but chose to re-implement the stress testing tool in Matlab.
  - The straight forward nature of ARTIS as realtime gross settlement system.
  - The institutional particularities of ARTIS not foreseen in the BoF PSS2.
  - Our research questions that aim to relate network structure and contagion.

Individual contagious defaults (Q3 2005)

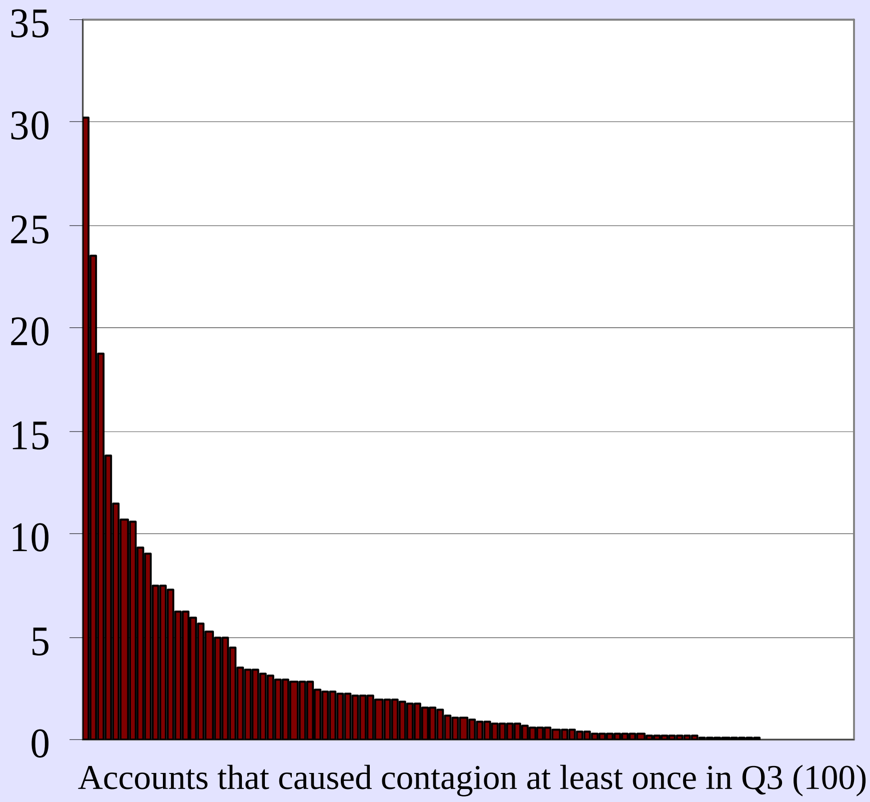


Number of sims:	**15,379**
Number of sims w. cont.:	**3,919**
Contagion ratio:	**25.5 %**

Average contagious defaults (Q3 2005)

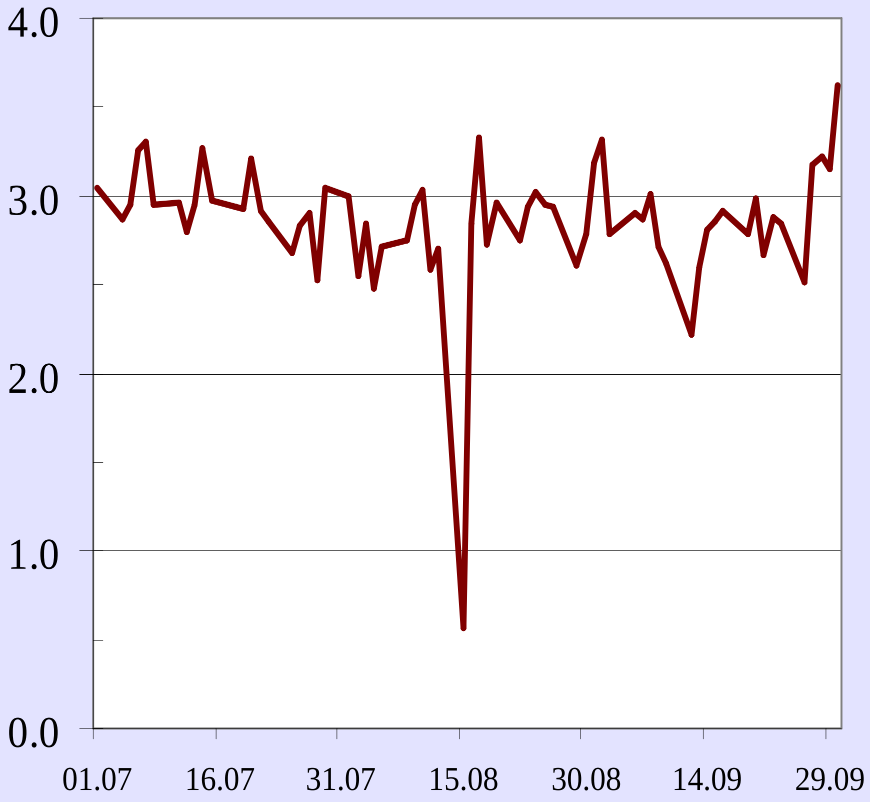
Average contagious defaults per account

(on a daily basis)



Average contagious defaults per day

(devided by the number of sims)



Conclusion from stress testing ARTIS

- The exhaustive simulation of stress to individual institutions / banks confirmed previous research that aimed at identifying systemically important banks based on concentration measures (i.e. Herfindahl-Index).
- The most active accounts (in terms of volume and value) are also the accounts that cause most contagion.
- Although with significant variance, contagion effects remain relatively stable across our sample period (i.e. the four systemically most important accounts, are the systemically most important accounts on almost every day).
- The last point may be explained by several “structural breaks” in terms of the size of banks participating in ARTIS.
- This confirms assumptions as well as results from previous ARTIS research.

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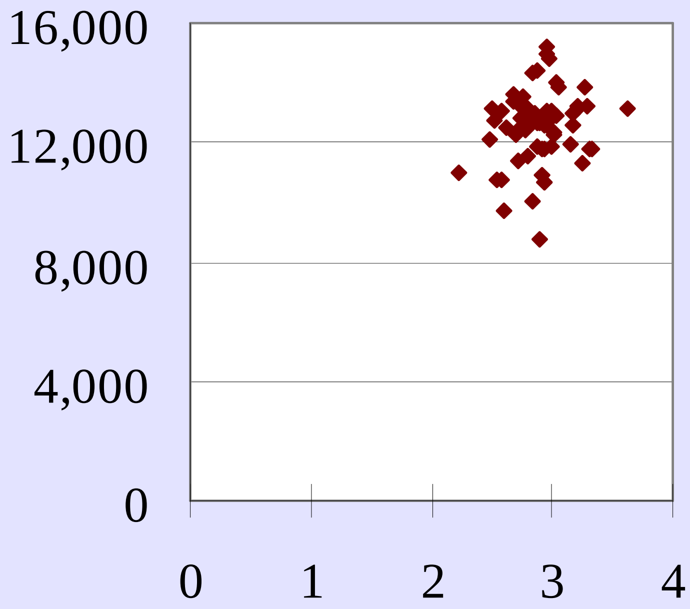
- **The relation of contagion and network structure in ARTIS**
- Key Findings and Conclusion

Contagion and network statistics (network level)

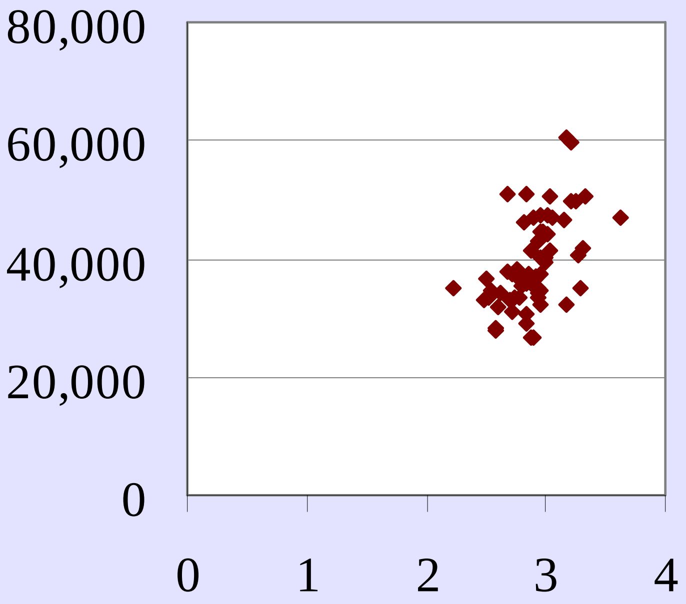
Volume vs. simulated defaults

(on the basis of avg. defaults per day)



Value (EUR bn) vs. simulated defaults

(on the basis of avg. defaults per day)



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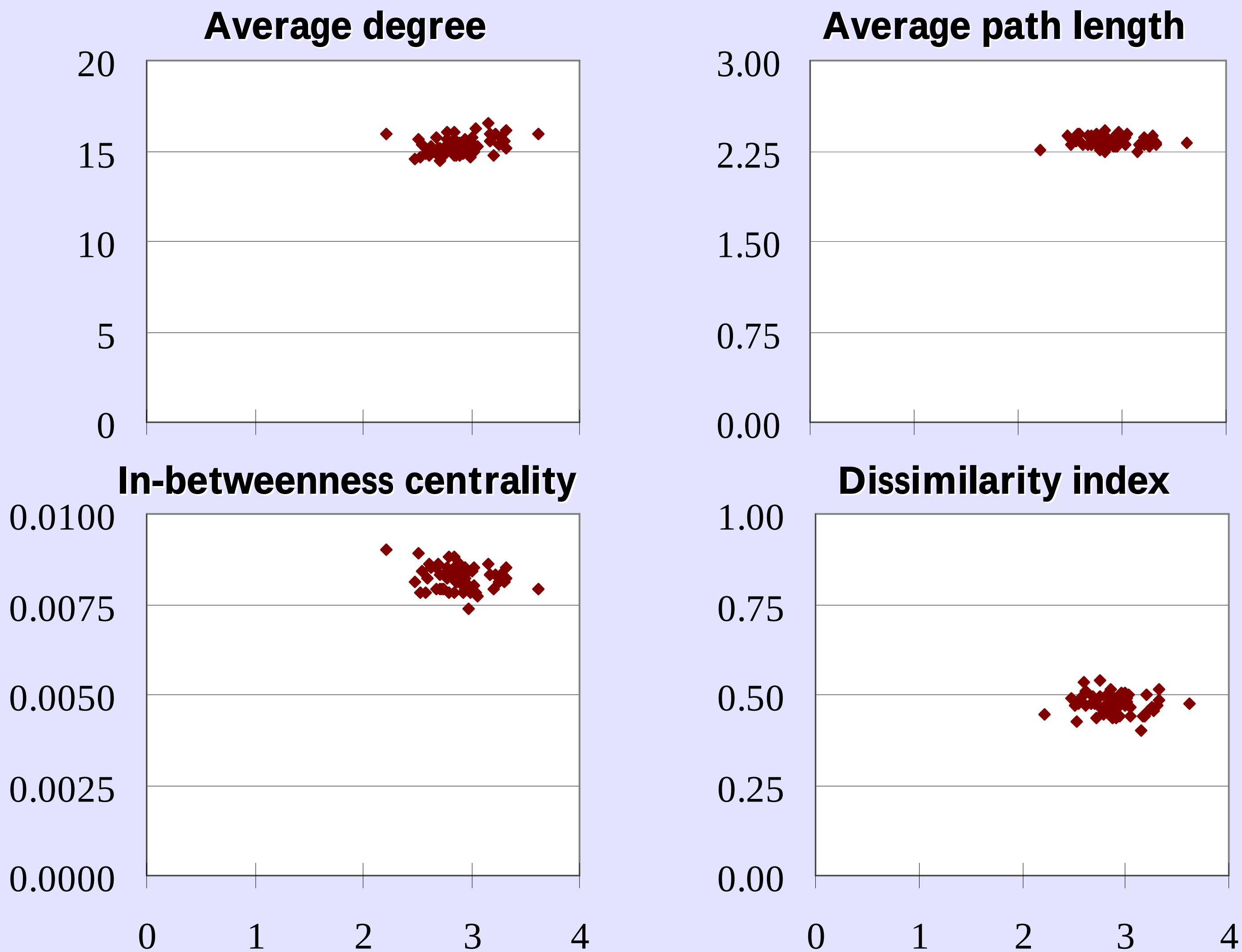
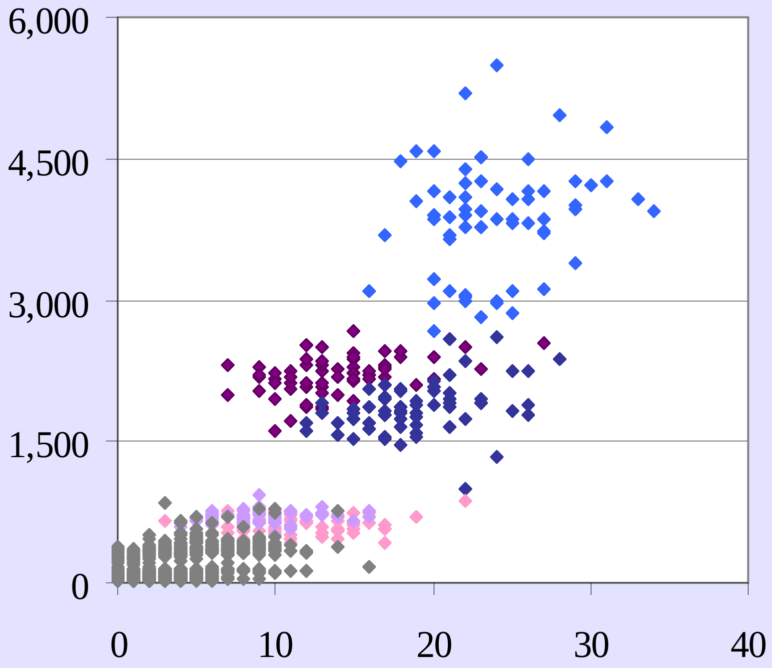


Contagion and network statistics (node level)

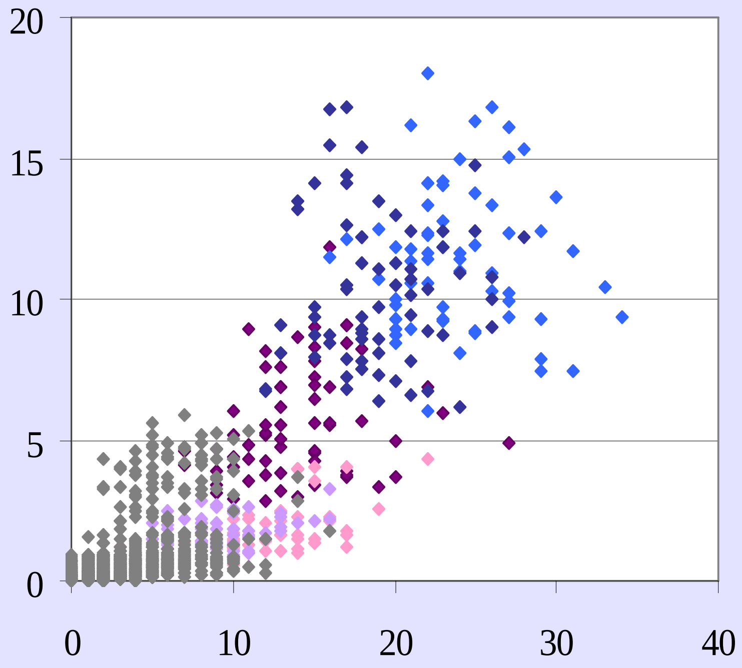
Volume vs. simulated defaults

(top 20 banks, defaults day by day)

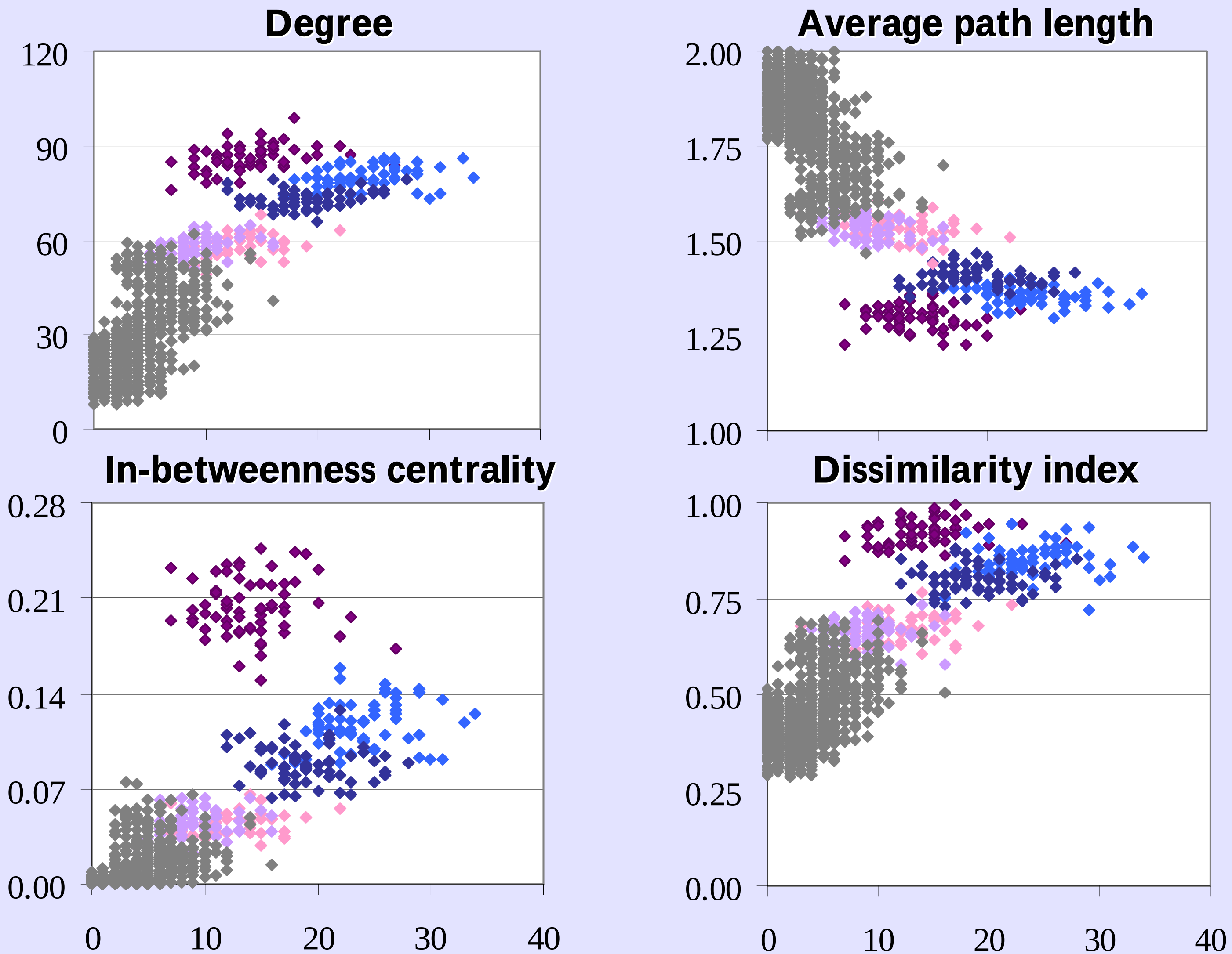


Value (EUR bn) vs. simulated defaults

(top 20 banks, defaults day by day)



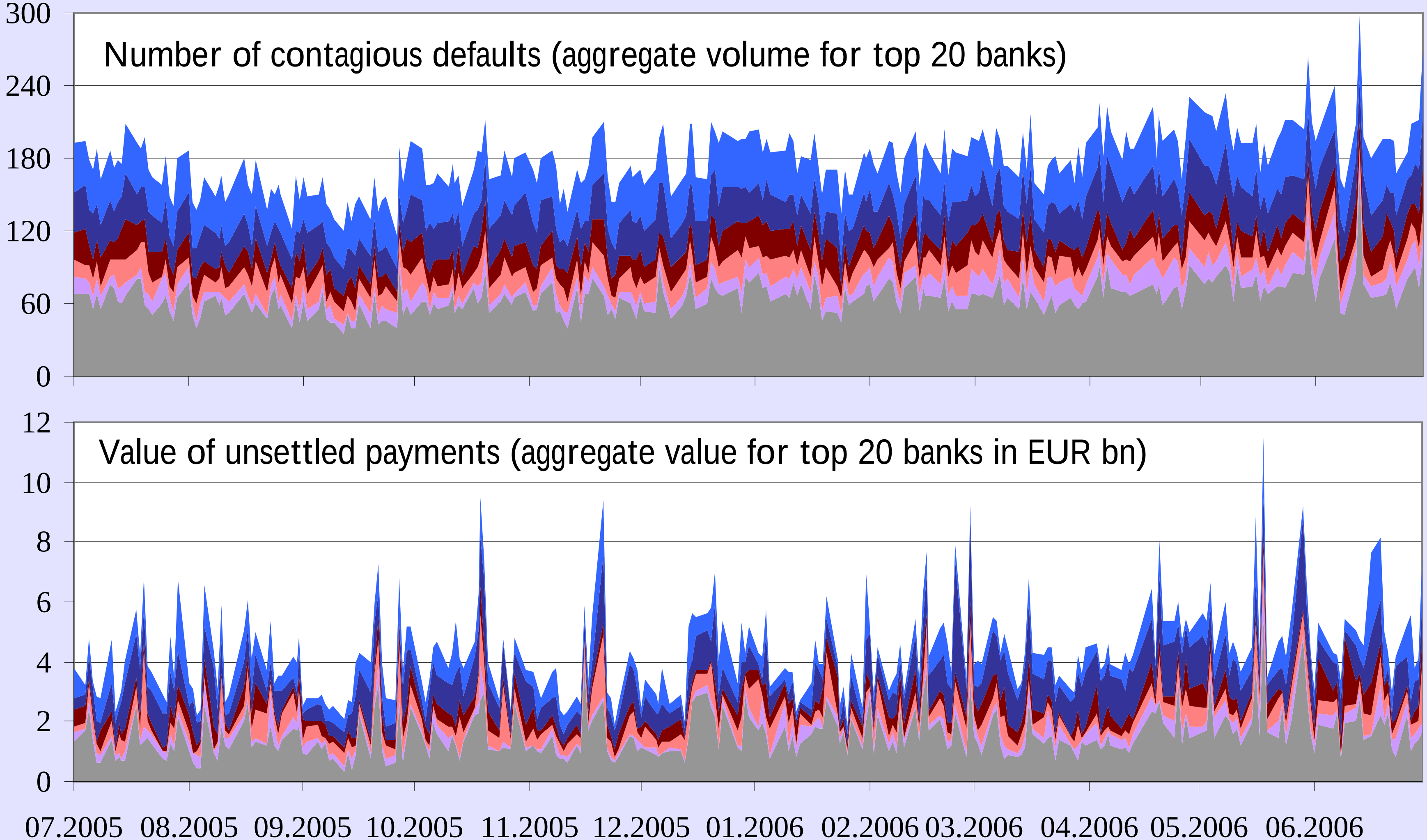
Contagion and network statistics (node level)



Conclusions from relating contagion effects and the network structure of ARTIS

- ARTIS network statistics on the network level appear to have little explanatory power in terms explaining contagion for the sample period.
- ARTIS network statistics on the node level on the other hand seem to have some explanatory power in terms explaining contagion for the sample period, although much of it seems to relate to value and volume the individual node.
- Moreover, the actual structure of the Austrian banking system and their consequences on bank's ARTIS accounts (and consequently their network statistic) seems to obstruct, rather than add additional information.

Optional | More stress tests (from 07.2005 to 06.2006)



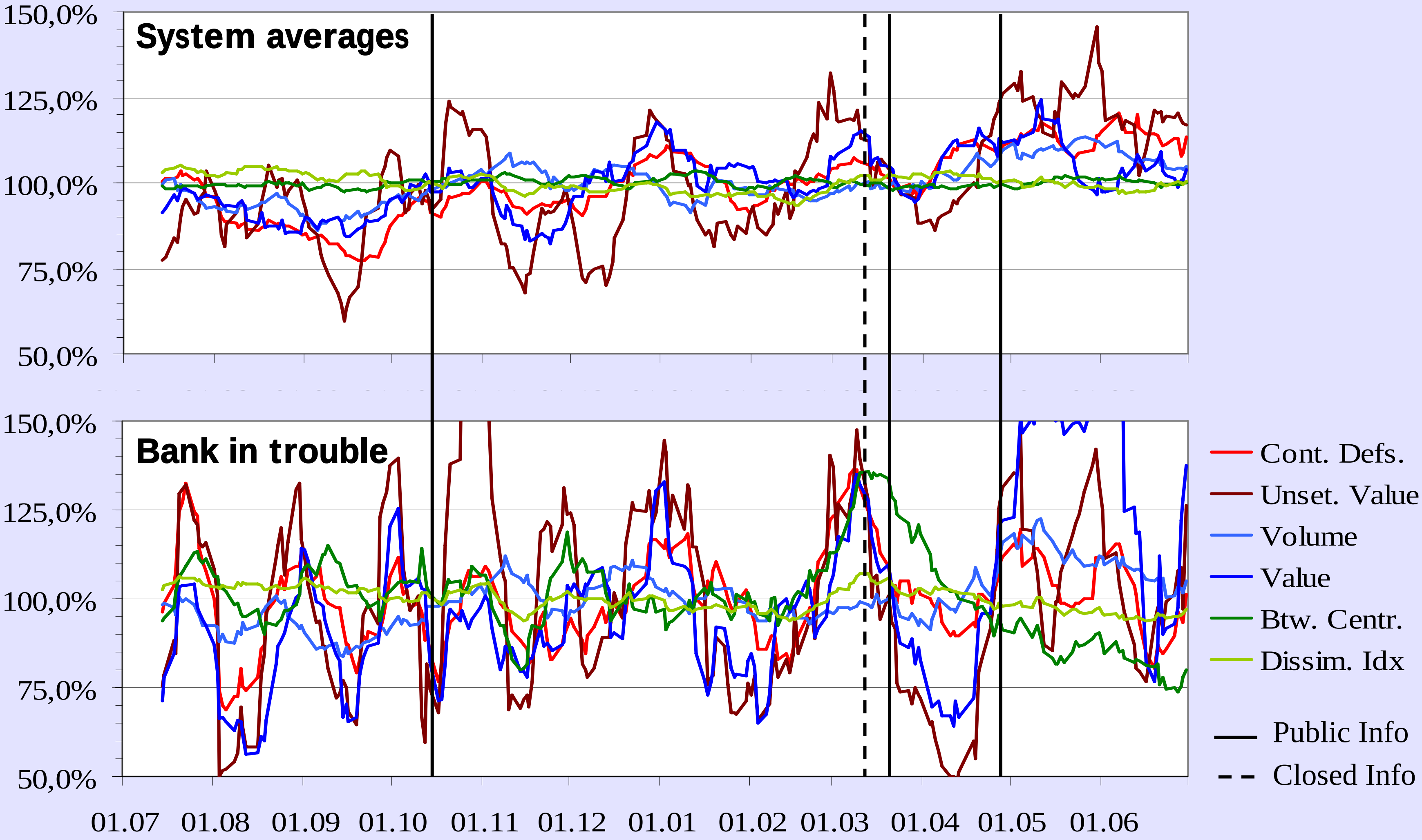
Optional | Correlations of contagion measures and network stats

	Val	Vol	Conn	AvgP	Clust	Degr	BtwC	DisS	Defs	LiqDr	LiqSi	QVol	QVal	DO	Both
Val	-	0.87	0.74	-0.71	-0.61	0.75	0.69	0.75	0.86	0.99	1.00	0.38	0.65	0.52	0.66
Vol		-	0.81	-0.77	-0.66	0.81	0.81	0.82	0.85	0.87	0.87	0.31	0.55	0.43	0.52
Conn			-	-0.97	-0.89	1.00	0.88	0.97	0.82	0.77	0.74	0.39	0.61	0.47	0.59
AvgP				-	0.87	-0.97	-0.85	-0.92	-0.80	-0.74	-0.71	-0.38	-0.59	-0.46	-0.58
Clust					-	-0.89	-0.72	-0.89	-0.69	-0.62	-0.60	-0.35	-0.53	-0.39	-0.51
Degr						-	0.88	0.98	0.82	0.77	0.74	0.39	0.62	0.48	0.60
BtwC							-	0.90	0.70	0.73	0.69	0.29	0.49	0.43	0.49
DisS								-	0.80	0.78	0.74	0.37	0.60	0.48	0.59
Defs									-	0.87	0.86	0.45	0.72	0.49	0.68
LiqDr										-	0.99	0.38	0.65	0.53	0.67
LiqSi											-	0.36	0.63	0.51	0.65
QVol												-	0.45	0.29	0.45
QVal													-	0.48	0.91
DO														-	0.67
Both															-

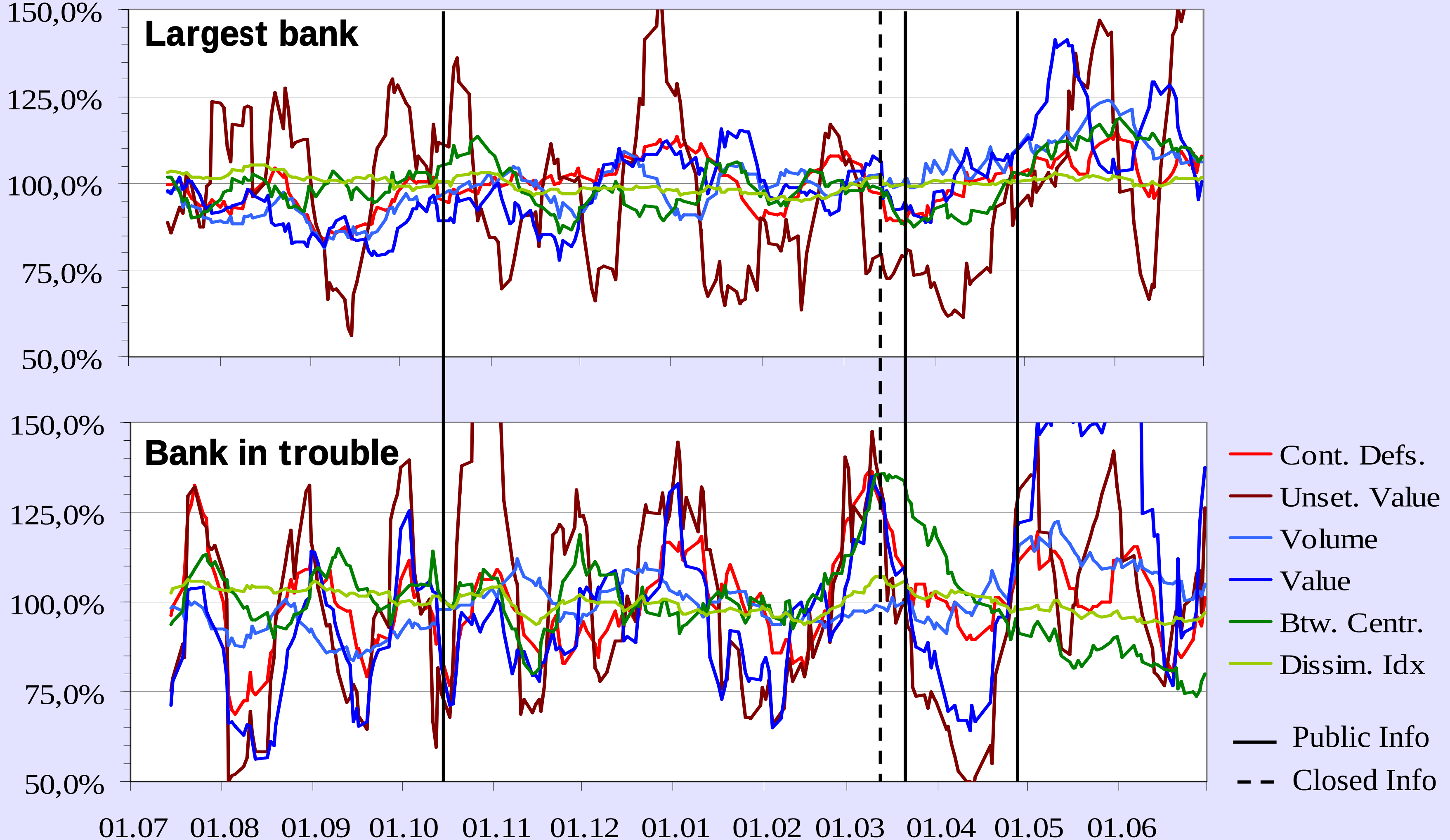
QVal: Value of unsettled payments

Defs: Number of contagious defaults

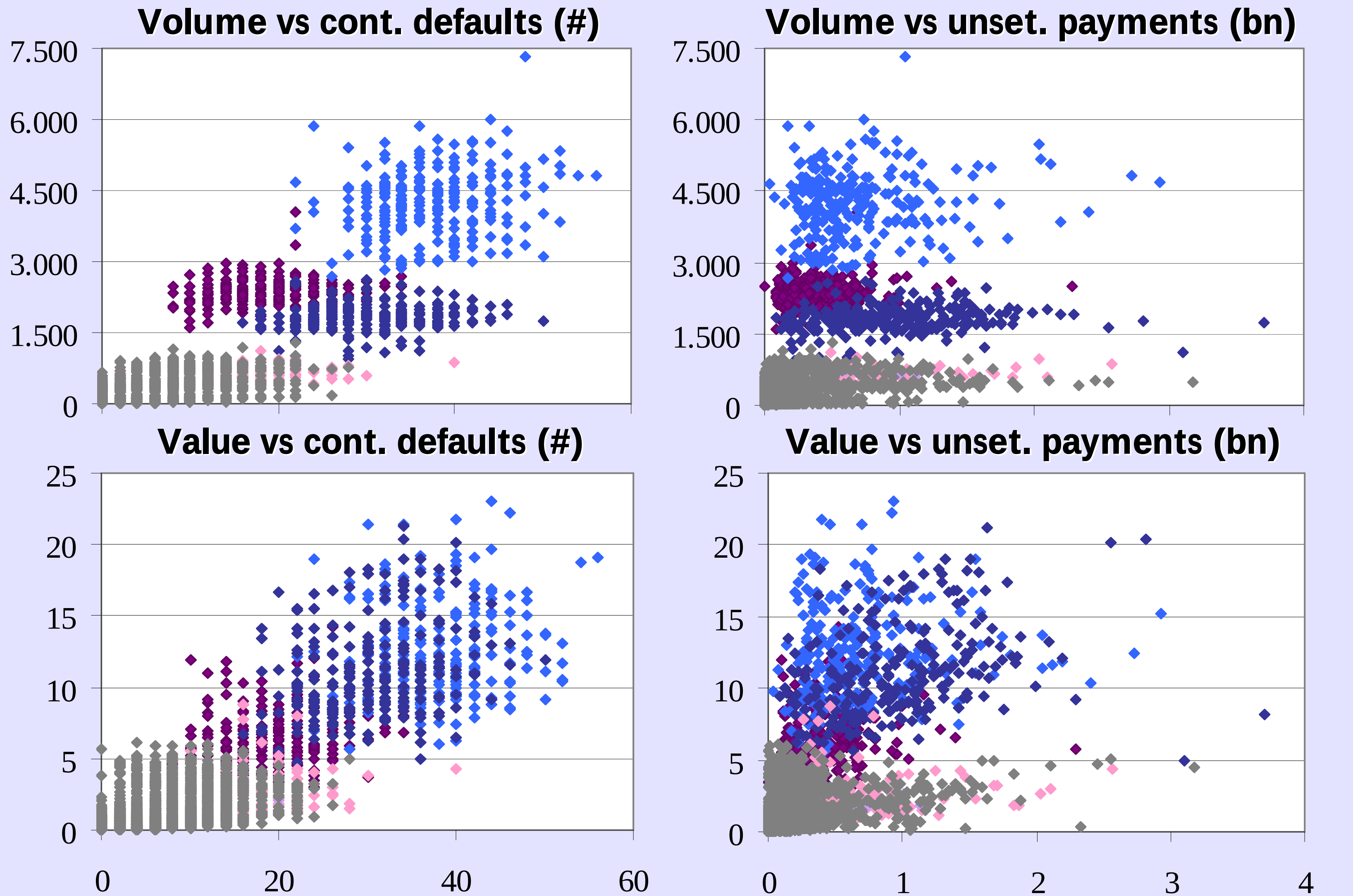
Optional | 10 day moving averages of stress test stats (node level)



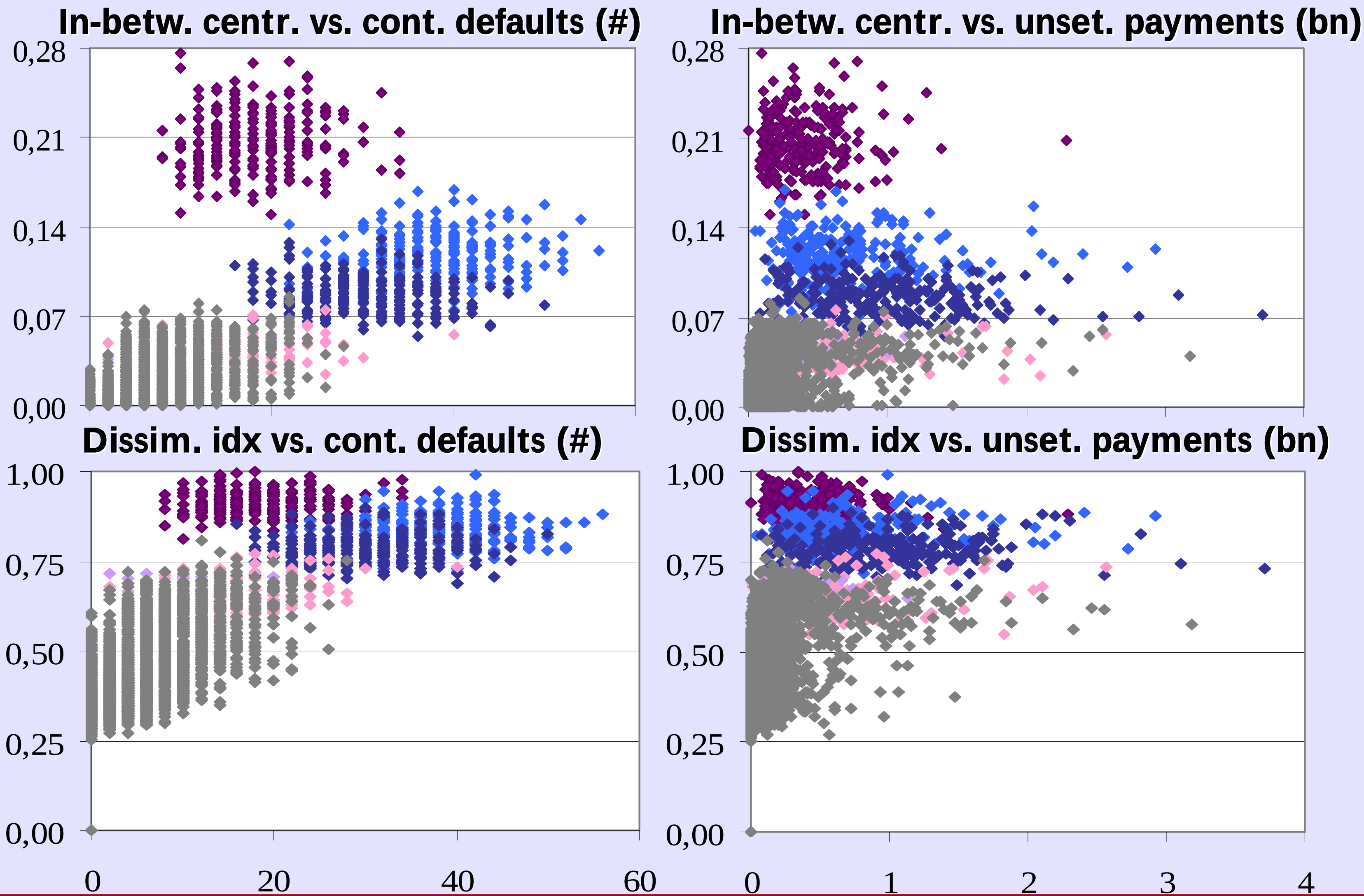
Optional | 10 day moving averages of stress test stats (node level)



Optional | Contagion and network statistics (node level)



Optional | Contagion and network statistics (node level)



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Key findings and conclusions

- Network indicators at the network level are of limited use for stability analysis
  - An observed shock at an individual institution was not captured
  - In simulations they failed to explain the contagion impact
- Network indicators at the node level are of some use for stability analysis
  - An observed shock at an individual institution was captured by some indicators
  - In simulations some indicators contributed to explain the contagion impact
  - But they contain little additional information compared to value and volume
  - Furthermore the selection of the appropriate indicators is not trivial
- To complete our ARTIS related research
  - We plan to conduct a panel data analysis, that explains the variance of the contagion impact across banks and days taking network indicators into account.
  - We thereby hope to clarify the open questions that remain after our presentation.

OESTERREICHISCHE NATIONALBANK

Eurosystem

Thanks a lot for your attention!

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