Spatial dependence and data-driven networks of international banks

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Outline

Motivation

Motivation

- When correlations are used to estimate networks, what do we have?
  - Could be measuring common shocks
    - These are important as well, and often the focus of much work, especially with respect to stress analysis.
    - Such research emphasizes change of structure, change of network measures, as possible indicators.
    - Problems occur when common shocks make the adjacency matrices very ill behaved.
  - Our paper takes a different approach: Where can we ask the data for cross-sectional connections?
  - **Focus:** Splitting the connections into time-series and cross-sectional effects.

Motivation

- Organization of the paper
  - To what extent can we remove strong common factors so we can “isolate” purely spatial dependence
    - Testing CD: Pesaran (2013)
    - Measuring CD: Bailey, Kapetanios and Pesaran (2012)
  - Once these effects are removed, simple regularization techniques are applied.
    - Multiple testing: Bailey, Pesaran and Smith (2014)
  - Does this network make sense?
    - What do network structure and centrality measures look like?
    - How do these networks compare to networks using actual bilateral exposure data?
    - How does the network structure evolve in time?
  - Where they make less sense, why, and how can we correct for this.
    - Example we present is of regional variation

Motivation

- Preaching to the choir: the ability to describe networks through non-bilateral data is very useful.
- Network analysis applied to financial markets (banks) in the context of financial stability analysis
  - Interbank lending, payment systems
  - CDS markets
  - Balance sheet exposures
  - Trading
  - Correlation networks **(No separation between common factors and CSD)**

Related literature

- Graph theory methods
  - Undirected
  - Well defined but rigid network structures (hierarchy, single links)
  - Minimum Spanning Trees (MST) / Planar Maximally Filtered Graphs (PMFG)
- Multivariate time series methods
  - Directed, VAR-type $\rightarrow$ causality, spillovers
  - Regularization required
  - Methodological focus, less emphasis on network structure
  - Superficial analysis of common factors

- Spatial dependence: spill-over effects that are not pervasive in nature (CWD)
  - Nodes relationship = purely spatial dependence + effect of common factors
  - Pervasive dependence ‘contaminates the data’ and produces misleading estimates
  - Strong common factors need to be removed to highlight spatial dependence
  - Spatial proximity: similarity of business lines, common balance-sheet or market exposures, common accounting practices or technological linkages
  - Bailey et al. (2013) $\rightarrow$ US house prices

Empirical Application

Sample

- Daily log-returns between Jan-1999 and Jan-2014, 3933 observations
- 418 banks (396 after filtering), 3 large regions, 46 countries
  - EMEA–26 countries, 133 banks: AT, BE, CH, CY, CZ, DE, DK, ES, FI, FR, GB, GR, HU, IE, IT, NL, NO, PL, PT, RU, SE, TR, IL, ZA, EG, QA
  - Asia: 12 countries, 172 banks: AU, CN, HK, IN, JP, KR, LK, MY, PH, SG, TH, TW
  - Americas: 8 countries, 113 banks: AR, BR, CL, CO, PE, MX, CA, US
- Sample includes delisted, bankrupt, M&A and newly listed banks $\rightarrow$ unbalanced panel

Procedure to obtain a W matrix

1. Removal of strong factors from returns series (Asymptotic Principal Components)
2. CD testing on residuals for remaining excess common cross dependence
3. Correlation matrix based on CWD residuals
4. Holm–Bonferroni method to establish significant correlations
5. Undirected network / data driven spatial weight matrix **W**

Removal of strong factors

Using unobserved common → (APC)

$$y_{it} = \alpha_i + \beta_i' \hat{f}_t + u_{it}$$

$$\hat{u}_{it} = y_{it} - \hat{\alpha}_i - \hat{\beta}_i' \hat{f}_t$$

Connor and Korajczyk (1988) and Korajczyk and Sadka (2008), unbalanced panel

Testing cross-section dependence

Pesaran, 2013

$$CD_P = \sqrt{\frac{2}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T_{ij}} \hat{\rho}_{ij} \right)$$

where $CD_P \overset{H_0}{\sim} N(0,1)$ and $\hat{\rho}_{ij} = \frac{\sum_{t \in T_i \cap T_j} (\hat{u}_{it} - \bar{\hat{u}}_i)(\hat{u}_{jt} - \bar{\hat{u}}_j)}{\left[\sum_{t \in T_i \cap T_j} (\hat{u}_{it} - \bar{\hat{u}}_i)^2 \right]^{1/2} \left[\sum_{t \in T_i \cap T_j} (\hat{u}_{jt} - \bar{\hat{u}}_j)^2 \right]^{1/2}}$

Measuring cross-section dependence

Bailey, Kapetanios and Pesaran (2013) α test:

Rate at which the cross-section average (CSD proxy) tends to zero:

$$O\left(N^{2\alpha-1}\right), \text{ for } \frac{1}{2} < \alpha < 1$$

Modified for unbalanced panel

Simple Regularization

Holm-Bonferroni multiple comparison test using correlation matrix and corresponding p-values

Control the family-wise error rate (FWER) at level $\alpha = 0.05$ (ρ_{Min}=0.079)

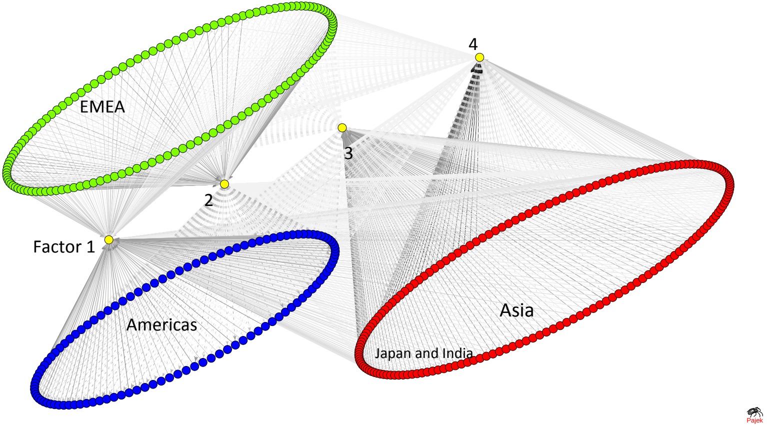
Conservative test $\rightarrow$ sparsity of **W**

Procedure:

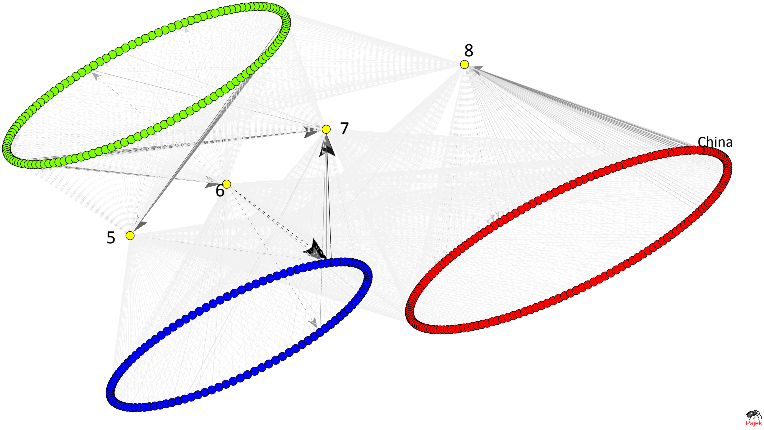
- Sort the $m = \frac{N(N-1)}{2}$ p-values $P_1, \ldots P_m$ and associated hypotheses $H_1 \ldots H_m$ in order of smallest to largest
- Recursively, FWER is achieved when $P_i \leq \frac{\alpha}{m}$

Results

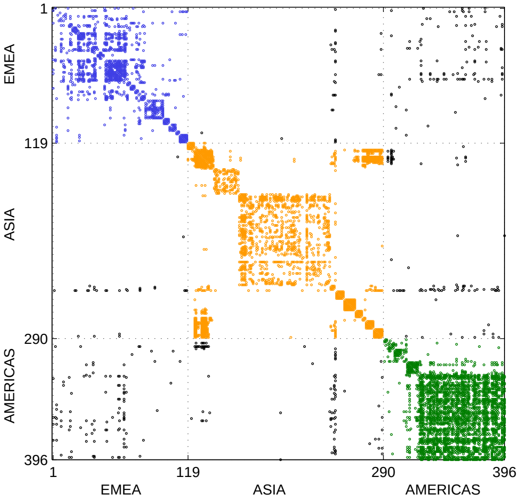
Factors 1-4 (of 11 factors)



Principal Components Factors 5-8 (of 11 factors)



Sparsity plot – Principal components (11 factors)



W network (396 banks)

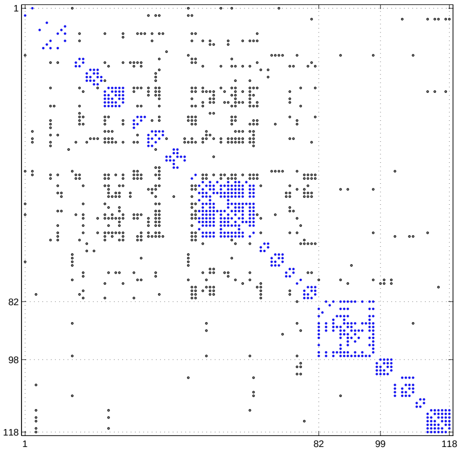
- No evidence of strong CSD: $CD_P = -0.24(0.81)$, $\alpha \rightarrow$CWD
- Rich and hierarchical structures:
  - Sparsity
  - Geographical homophily
    - 6.7% cross-regional, 2/3 with US banks, hubs in transmission
    - Within regions, 23% are cross-country, mostly EMEA
  - Non-connected nodes, cliques
- Sparse network, low density: 0.041
- Small world properties:
  - Low diameter (9)
  - Low average path length (3.43)
  - High clustering clustering coefficient (0.5403)
  - Scale Free, Power law distribution (α=2.63, $\in [2, 3]$))
  - **Implication**: shock to a node propagates quickly to any other node in the network

W network (396 banks)

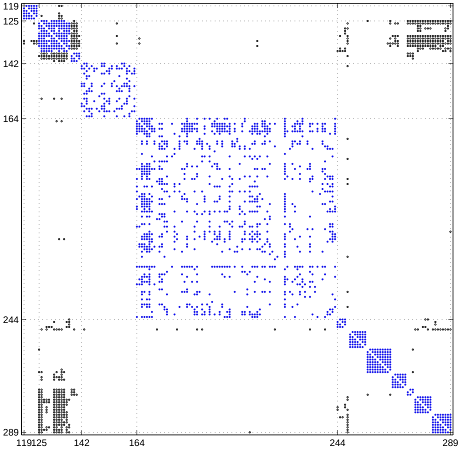
- Degree distribution
  - Skewed degree distribution
  - Positive assortativity (**!**), hierarchical structure and large network
  - Rich-club phenomenon (highly connected and mutually linked nodes)
- Centrality measures (betweenness, Bonacich-Katz and eigenvector centrality)
  - US, Japanese and Chinese banks as SIFI
  - EMEA banks have only high degree
  - Anomalous measures: (geographical) multicommunity structure
- Tiering analysis (SIFI identification, Craig and Von Peter, 2014)
  - 40 core banks = 2 EMEA + 8 Asia + 30 Americas (US)
  - Relevant role in cross-regional spillovers
  - American banks are the core nodes

Sparsity plot – Subnetwork (EMEA)

Highly interconnected across borders

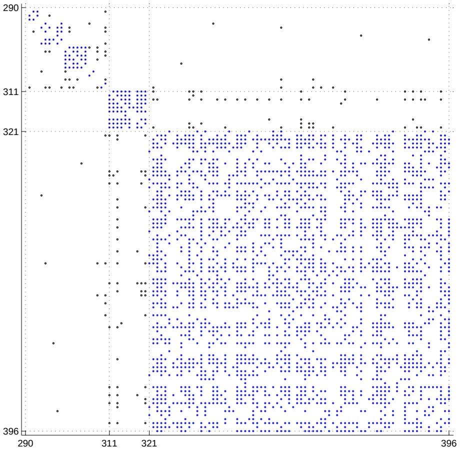


Sparsity plot – Subnetwork (Asia)

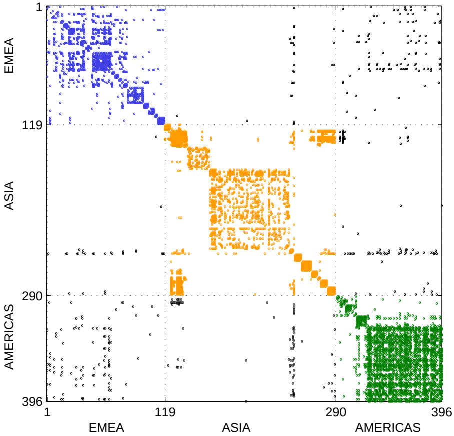


Sparsity plot – Subnetwork (Americas)

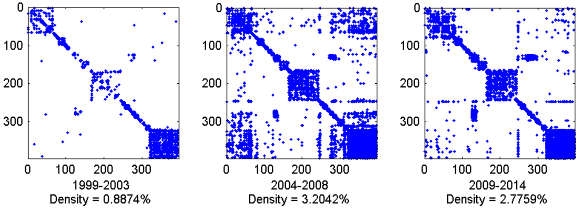
US banks role



Sparsity plot – Subnetwork (Cross-regional)



Sparsity plot – Subnetwork (Cross-regional)



W network and sub-network structures

	W	W_{EMEA}	W_{Asia}	$W_{Americas}$	$W_{Cross-regional}$
Size	396	118	171	107	145
Density	0.0407	0.083	0.075	0.231	0.1247
Diameter*	9	7	7	7	6
Average path length*	3.43	2.89	3.16	2.21	2.38
Average degree	16.1	9.7	12.7	24.5	18.0
Maximum degree	64	32	44	57	52
Average neighbor degree	21.9	12.7	17.7	29.9	24.2
Assortativity	0.377	0.373	0.024	0.242	0.284
Betweenness	0.00580	0.01410	0.01140	0.01130	0.00964
Bonacich-Katz	-0.0582	-0.3834	-0.1874	-0.2042	-0.1891
Eigenvector centrality	-0.0230	-0.0569	0.0418	-0.0758	0.0558
Clustering	0.5403	0.5473	0.5986	0.5671	0.4601
Core banks	40	18	21	37	30

- Higher density stronger small-world properties
- Geographic homophily, hierarchical structure
- Global cores are also regional core banks

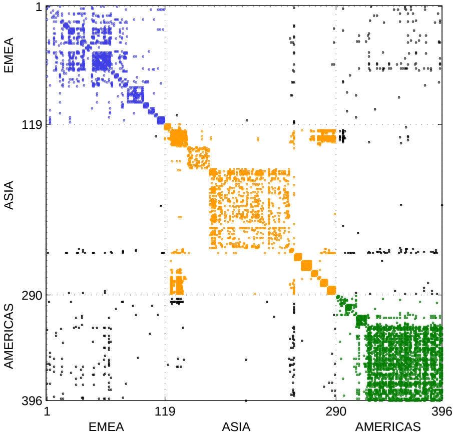
Regional Cores are also International Cores?

- I worry that the community structure of our sample means that we are confusing common regional effects with strong cross sectional dependence.
  - Note the paradox that needs to be solved:
    - The regional effects create connections that are really common shocks.
    - But internationally these correlations with common shocks could be the result of a core bank's connection with banks of that country.
    - So we want the international connection, but not the other.
- One approach: modify the factors
  - We have tried some of this with varying degrees of success. For example, we could use Breitungs regional factors.
- The other is modify the measure
  - A new definition of the core

New Core

- Note the blocky structure of our adjacency matrices

Sparsity plot – Subnetwork



New Core

Network model of tiering

- A network exhibiting tiering should have this block-model form:

$$M = \begin{pmatrix} CC & CP \\ PC & PP \end{pmatrix} = \begin{pmatrix} \mathbf{1} & \mathbf{RR} \\ \mathbf{CR} & \mathbf{0} \end{pmatrix} = \left(\begin{array}{ccc|ccccc} 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ \hline 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

- Special kind of core-periphery model: emphasis on relation *between* core and periphery
- Tight on core, lax on periphery, makes sense for interbank market.

New Core

International model of tiering

- A network exhibiting tiering should have this block-model form:

$$M = \begin{pmatrix} CC & CP \\ PC & PP \end{pmatrix} = \begin{pmatrix} \mathbf{1} & \mathbf{RR} \\ \mathbf{CR} & \mathbf{0} \end{pmatrix} = \left(\begin{array}{ccc|ccccc} 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ \hline 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{array}\right)$$

- If the ones in the periphery are due to regional factors, then these connections should not be penalized in the PP portion.

Results of the new core

- Smaller core (23): 7 EMEA + 10 Asia + **6 Americas**
- Chinese and US banks still dominate
- More presence of European banks (UK, IT)
- Network topology matters for identification of global banks (SIFIs)

Concluding Remarks

- Method to compute undirected networks based on interconnected bank stock returns taking into account common factors CSD
  - Market-based adjacency matrix for a spatio-temporal analysis of shocks across banks
  - Input for spillover analysis at large and international scale
  - Alternative approach to private exposure-based adjacency matrices
- Network characteristics
  - Rich and hierarchical structures
  - Small world properties in global network and regional subnetworks
  - Regional patterns $\rightarrow$ spatial pattern although agnostic APC was applied
  - Identification of central banks / groups of banks
  - Identification of (modified) core-periphery structure

Thank you for your attention

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