The Missing Links

A global study on uncovering financial network structure from partial data

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The usual disclaimer applies: these views are my own and do not necessarily represent the views of Deutsche Bundesbank or any of the other institutions involved in the project.

Outline

- Motivation
- Research questions
- Methodolgy
  - algorithms
  - similarity metrics
- Data
  - summary of networks
- Results
- Way forward

Motivation

- Networks are ubiqitious in finance
  - credit exposures
  - funding structures
  - derivative contracts
- Network analysis is a big industry
  - *contemporaneous* – mapping, reporting, visualization
  - *forward-looking* – stress-testing, risk-analytics

Motivation

- Network analysis often requires high-frequency and **granular micro-level data**, which is not always forthcoming
- Data gathering (by central banks and banking supervisors) was – at best – patchy in the run-up to the financial crisis
- The **G-20 Data Gaps Initiative** has strengthen the reporting and collection of financial data by member countries
- Data are generally not available beyond regulatory perimeters
- Most empirical research focus on networks from a single country ignoring international / non-banking sector links

Motivation

- Overcoming data limitations – network reconstruction
- Several algorithms currently exist:
  - maximum entropy
  - minimum density
  - probability map
  - bayesian methodology
- Sarlin et al. (2014) use maximum-entropy to construct a network of links between EU banks and non-bank entities
- Several studies use maximum entropy to reconstruct interbank exposures and subject them to stress-tests (e.g., Upper, 2011)

Research questions

- **What is the best method to reconstruct networks?**
- What is a good fit and how can we back-test results?
- Do different *types* of networks need different methods?

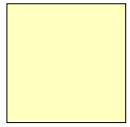
Our contribution

- Horse-race between 7 network reconstruction methods
- Collate and present summary statistics for 25 different financial networks spanning 13 jurisdictions
- Rules-of-thumb to make an informed choice on the appropriate network reconstruction method to use

Methodology

- We run and test the horse-race using data on 24 different domestic financial networks and one international network
- Detailed granular data on the full-set of bilateral exposures
- Postulate we only know the aggregate exposures
- Reconstuct the networks using the aggregate expsosures only
- Compare reconstructions with the actual networks

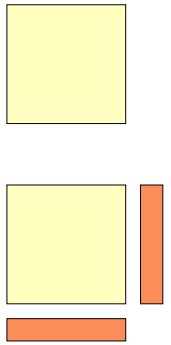
Methodology



Step 1 Original network

Methodology

Step 1 Original network



Compute the totals or marginals

Step 2

Methodology

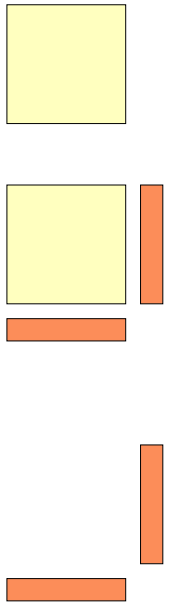
Step 1 Original network

Compute the totals or marginals

Step 2

"Forget" actual network

Step 3



Methodology

Step 1 Original network

Compute the totals or marginals

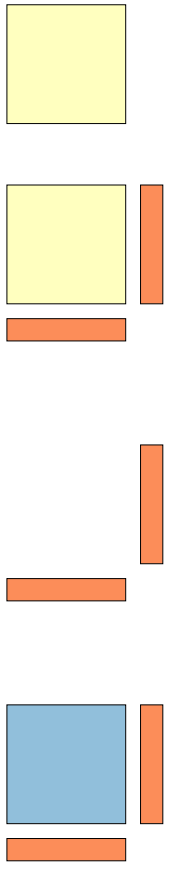
Step 2

"Forget" actual network

Step 3

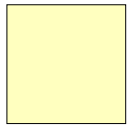
Reconstruct network (7 algorithms)

Step 4



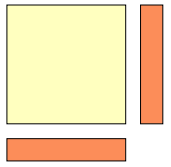
Methodology

Step 1 Original network



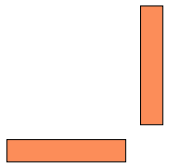
Compute the totals or marginals

Step 2



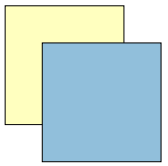
"Forget" actual network

Step 3



Reconstruct network (7 algorithms)

Step 4



Compare reconstruction with actual network

Step 5

Reconstruction methods

Authors	Code	Short Description
Anand et al. (2015)	*Anan*	*Minimum Density* method which minimises the number of links required for distributing a given volume of loans
Baral and Fique (2012)	*Bara*	*Copula* to allocate the marginals
Battiston et al. (2012)	*Batt*	*Fitness model* that determines the likelihood of linkage
Drehmann and Tarashev (2013)	*Dreh*	*Perturbed maximum entropy* method
Halaj and Kok (2013)	*Hala*	*Probability map* for the likelihood of links
Mastrandrea et al. (2014)	*Mast*	*Configuration model* for the distribution of the reconstructed networks; **constraints are only satisfied on average**
Upper (2011)	*Maxe*	*Maximum entropy* method

Similarity measures

Measure	Short Description
Hamming	Sum of the difference between the original and estimated adjacency matrices. This measure captures the number of instances where the original matrix had a link, but the estimated did not (false negative) and where the original matrix did not have a link, but the estimated matrix did (false positive); range: $[0, \infty)$
Jaccard	The inverse of the number of links belonging to both the original and estimated networks divided by the number of links that belong to at least one network; range: $[0, 1]$
Cosine	Angle between the vectorized original network and estimated network; range: $[0, 1]$
Jensen	Jensen-Shannon divergence between networks, where we normalize all entires in the networks to sum up to one; range: $[0, \infty)$.
Accuracy	The percentage of true positive and true negative links

Collection of networks

Type	Number	Countries
Interbank	13	Brazil, BIS, Canada, Denmark, France, Germany, Hungary, Italy, Mexico (x3), Netherlands
Payment	5	Brazil, Mexico (x3), US
Repo	2	Denmark, Mexico
FXS	1	Hungary
CDS	2	UK, US
Equity	1	Mexico
Derivatives	1	Mexico

◂ Further details

Summary of interbank networks

	Interbank												
	BIS03	BR02	CA01	DE01	DK01	FR01	HU06	IT01	KR01	MX0103	MX0303	MX0602	NL01
Num of links	812	418	29	10675	77	46	131	3084	263	420	129	50	576
Density	87.3	4.1	96.7	3.3	42.3	41.8	14.1	1	85.9	23.3	7.1	2.8	2.4
Avg Degree	26.2	4.1	4.8	18.9	5.5	4.2	4.2	5.6	14.6	9.8	3	1.2	3.7
Med Degree	28	1.5	5	14	5	4	3	3	15	10	2	1	1
Assortativity	-.12	-.36		-.63	-.3	-.42	-.44	-.43	-.17	-.26	-.36	-.2	-.48
Clustering	22.4	3.1	17.8	41.3	21.5	10.8	23	19.7	21.2	16.2	6.5	3.4	7.5
Lender Dep	28.8	63.9	54.4	42.9	37.5	38.7	51.1	74.9	31.6	56.6	76.3	84.4	79.4
Borrower Dep	31.6	60.2	46.3	71	39.6	39	44.9	88.2	24.9	53.4	63.6	78.8	73.1
Mean HHI Assets	.17	.41	.41	.29	.27	.18	.41	.67	.19	.41	.51	.44	.62
Median HHI Assets	.15	.31	.42	.22	.25	.22	.29	.71	.17	.33	.47	.46	.73
Mean HHI Liabilities	.19	.42	.35	.6	.25	.29	.2	.82	.15	.38	.33	.32	.42
Median HHI Liabilities	.15	.35	.28	.6	.23	.26	.08	1	.14	.28	.28	0	.35
Core Size (% banks)	77.4	9.8	66.7	6.5	42.9	36.4	22.6	3.2	77.8	32.6	16.3	7	7
Error score (% links)	4.4	46.7	3.4	11.2	14.3	10.9	17.6	19.9	3.4	23.6	38	76	26.9

◂ Summary of other networks

Results

Country	Type	Code	Hamming	Jaccard	Cosine	Jensen	Accuracy
Brazil	Interbank	BR02	Anan*	Batt*	Maxe	Batt	Anan*
	Payment	BR04	Anan*	Batt	Bara	Maxe	Anan*
BIS	Interbank	BIS03	Dreh*	Bara, Dreh, Maxe	Bara, Maxe	Bara, Maxe	Bara, Dreh, Maxe
Canada	Interbank	CA01	Bara, Dreh, Maxe	Bara, Dreh, Maxe	Bara, Maxe	Bara, Maxe	Bara, Maxe
Denmark	Interbank	DK01	Anan*	Bara, Dreh, Maxe	Bara, Maxe	Batt	Anan*
	Repo	DK02	Anan	Anan	Bara, Maxe	Anan	Anan
France	Interbank	FR01	Bara, Dreh, Maxe	Bara, Dreh, Maxe	Bara, Maxe	Bara	Bara, Dreh, Maxe
Germany	Interbank	DE01	Anan	Batt	Anan*	Batt	Anan
Hungary	Interbank	HU06	Anan	Hala*	Bara, Maxe	Batt	Anan
	FX Swaps	HU07	Hala	Bara, Dreh, Maxe	Bara, Maxe	Bara	Hala
Italy	Interbank	IT01	Hala	Anan*	Bara, Maxe	Batt	Hala
Korea	Interbank	KR01	Bara, Dreh, Maxe	Bara, Dreh, Maxe	Bara, Maxe	Bara	Bara, Dreh, Maxe

Results

Country	Type	Code	Hamming	Jaccard	Cosine	Jensen	Accuracy
Mexico	Interbank	MX0103	Anan*	Bara, Dreh, Maxe	Bara	Batt	Anan*
		MX0303	Anan	Bara, Dreh, Maxe	Hala	Batt	Anan
		MX0603	Anan	Bara, Dreh, Maxe	Bara, Maxe	Batt	Anan
	Repo	MX0203	Anan*	Bara, Dreh, Maxe	Bara	Batt	Anan*
	Equity	MX0403	Anan	Hala	Bara, Maxe	Batt	Anan
	Derivatives	MX0503	Anan	Bara, Dreh, Maxe	Maxe	Batt	Anan*
	Payments	MX0703	Batt	Bara, Dreh, Maxe	Bara, Maxe	Bara, Maxe	Anan*
		MX0803	Anan*	Bara, Dreh, Maxe	Maxe	Batt	Anan
		MX0903	Bara, Dreh, Maxe	Bara, Dreh, Maxe	Bara, Maxe	Maxe	Bara, Maxe
Netherlands	Interbank	NL01	Anan	Anan	Dreh*	Batt	Anan*
United Kingdom	CDS	UK02	Batt, Hala	Anan			Batt*
United States	Payments	US02	Anan	Anan	Bara	Bara	Anan
	CDS	OFR03	Hala	Batt	Maxe	Bara*	Hala

Results

- The "winner" depends the similarity measure
  - Accuracy – Anan
  - Jaccard – Bara, Dreh and Maxe
  - Jensen – Batt
- Results also depend on network sparcity / rules-of-thumb
  - Sparse networks – Anan, Batt and Hala
  - Dense networks – Bara, Dreh and Maxe
- Mast is a strong performer under the Accuracy and Hamming metrics

Conclusion

- Horse race of network reconstruction methods
- Unique dataset of 25 networks from 13 jurisdictions
- Winners depend on the similarity measure
- Simple rules-of-thumb identified

Thank you!

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Networks analyzed

Country	Type	Code	Short Description
Brazil	Interbank	BR02	Interbank market exposures between financial institutions, both banking and non-banking, related to unsecured operations
	Payment	BR04	Payments between banks, on their own account, taken from the Brazilian LVPS and aggregated for one day.
BIS	Interbank	BIS03	Bilateral financial system exposures on banks as given in the BIS International Banking Statistics.
Canada	Interbank	CA01	Aggregate bilateral exposures between Canadian D-SIBs consisting of: banker's acceptances, debt securities holdings, unsecured lending (drawn and undrawn), OTC derivatives (potential future credit exposures), repurchase agreements (before collateral) and deposits.
Denmark	Interbank	DK01	Interbank loans derived from the KRONOS large value payment system
	Repo	DK02	Net bilateral repo exposure between Danish banks
France	Interbank	FR01	Bilateral exposures between French bank holding groups in December 2011 with values higher than 10% of banks' capital or above 300 millions of euro. It is obtained from the quarterly Credit Register report.
Germany	Interbank	DE01	Bilateral exposures between German banks with total assets above 1 billion euro. Data is derived from the national credit register which includes bilateral exposures (loans, bonds, derivatives, guarantees) above 1.5 million euro.
Hungary	Interbank	HU06	HUF interbank unsecured deposit transactions between Hungarian banks. All institutions and all transactions are included
	FX swap	HU07	All the transactions on the HUF/FX currency swap market where at least one participant is Hungarian

Networks analyzed

Country	Type	Code	Short Description
Italy	Interbank	IT01	Interbank unsecured market exposures (short term loans - up to one year)
Korea	Interbank	KR01	Interbank exposures with a remaining maturity of less than 3 months. These bilateral exposures, which include all on-balance sheet items such as deposits, loans and debt securities, are estimated using flow of funds data and a survey of bilateral interbank holdings.
Mexico	Interbank	MX0103 MX0303 MX0603	Total bilateral exposures (MX01..), Outstanding deposits and loans (MX03..), and Transacted deposit and loans (MX06..)
	Repo	MX0203	Repo amounts lent and borrowed between banks without considering the risk mitigation associated with the collateral
	Equity	MX0403	Cross Holding of securities
	Derivatives	MX0503	Outstanding derivatives
	Payment	MX0703 MX0803 MX0903	Total flow of payments (MX07..), Participant to participant payments (MX08..), and Third party to third party payments (MX09..).
Netherlands	Interbank	NL03	Using data for the payment system TARGET2, i1nterbank loans are inferred including all loans involving a Dutch bank.
UK	CDS	UK02	DTCC's Trade Information Warehouse data. Including all exposures on single names CDS contracts where the reference entity or at least one of two counterparties is UK domiciled. UK02 is the 30% largest in volume.
US	Payments	US02	Fedwire large value payment system for two time periods.
	CDS	OFR03	See UK. In addition index with a majority formed by UK firms

Return

Summary of other networks

	Payments					CDS			Repo		Other	
	BR04	MX0703	MX0803	MX0903	US02	MX0503	OFR02	UK01	DK02	MX0203	HU07	MX0403
Num of links	1396	800	149	302	169027	70	3267	2004	18	74	221	99
Density	13.3	43.3	8.3	16.3	.5	3.9	.6	1.8	13.6	4.1	2.3	5.5
Avg Degree	13.6	18.6	3.5	7	29.4	1.6	4.4	6	1.5	1.7	2.2	2.3
Med Degree	6	18	0	0	10	1	2	1	.5	1	1	1
Assortativity	-.52	-.45	-.37	-.26	-.27	-.15	-.79	-.72	-.73	-.16	-.57	-.31
Clustering	12.2	17.9	5.8	9.5	14.7	2.8	18.2	13.4	3.5	3.2	1.3	5.9
Lender Dep	62.9	52.2	63.9	39.2	60.8	74.4	69.4	59.7	71.4	75.2	77	67.1
Borrower Dep	59.3	53.5	63.7	49.1	61.4	71	69.1	63.4	95.1	69.7	74.1	60
Mean HHI Assets	.5	.38	.27	.12	.46	.44	.51	.36	.32	.45	.39	.31
Median HHI Assets	.41	.3	0	0	.38	.38	.44	.2	.11	.45	.12	.12
Mean HHI Liabilities	.47	.41	.24	.17	.49	.3	.31	.51	.84	.3	.47	.21
Median HHI Liabilities	.39	.3	0	0	.42	0	0	.46	1	0	.35	0
Core Size (% banks)	20.4	44.2	18.6	32.6	2.6	9.3	2	5.4	16.7	9.3	7.1	11.6
Error score (% links)	10.7	4	12.1	2.6	27.4	61.4	5.2	.9	22.2	55.4	33.5	56.6

◂ Return