Financial Contagion and Systemic Risk: From Theory to Applicable Macroeconomic Model

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Financial contagion and systemic risk: From theory to applicable macroeconomic model[1]

by

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Abstract

This draft working paper is to summarize theoretical contributions in the field of measuring systemic risk and contagion of financial systems. Broad theoretical framework is analysed and empiric approach to a macroeconomic model of global banking system systemic risk and contagion is offered. The model is to use BIS locational statistics as well as national consolidated balance sheets of banking systems to provide some insight into the vulnerability of modern banking system. As to theoretical contributions, three branches of literature are analysed: correlation-based measures, network-based measures and various systemic risk measures.

JEL Classification:
Keywords: *financial contagion, systemic risk, banking system, modeling.*

[1] This is merely a draft working paper, if you have any ideas to discuss or remarks to make please do not hesitate to contact me. My e-mail is snakers4@mail.ru. The empiric part of the paper is expected by **end of August 2012.**

Financial contagion and systemic risk of global financial system: from theory to applicable macroeconomic model

Definition of financial contagions

What is financial contagion? And why is it correlated with the systemic risk of global financial system? How can we exactly measure and define such an intangible entity? What statistical and mathematical methods can we use to measure susceptibility of global financial system to inner and outer shocks? There are no clear straightforward answers to these ambiguous questions. Nevertheless it is worth trying to do it by employing vast arrays of empiric and theoretical literature on this topic.

Kolb (2010) [2] advises that we should first of all consider the very nature of the metaphor used to describe this phenomenon. We should be fully aware of the fact that such notions as *"epidemic"* (which refers to financial crisis) and *"contagion"* are quite different. Not all crises or epidemics may be due to contagion. The main fundamental reason of contagion is the mechanism of transmission of contagion from one financial institution to another. Anticipating the following literature, it is worth noting that the vast majority of researchers in fact analyse the consequences of contagion, i.e. they study various episodes of increased correlation of financial indicators. Such an approach may provide us with a useful to tool for identifying contagious episodes post factum but it remains unclear what underlying mechanisms are involved.

Let us return to the very notion of financial contagion. Different economists have various ideas about definition of contagion:

1. "The theory is that small shocks impacting several institutions or sectors are then spread to the whole financial sector of economy by means of contagion[3]";
2. "The spread of problems in financial sphere from one economy to another in one region or globally, which can be called contagion[4]";

Some provide more complex definitions of contagion:

1. Increase in probability of crisis in one country due to occurrence of crisis in other countries;

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[2] Financial contagion: the viral threat to the wealth of nations / RobertW. Kolb, editor, ISBN 978-0-470-92238-5.
[3] Allen, Franklin, and Douglas Gale. 2000. "Financial Contagion," *Journal of Political Economy* 108:1, 1–33.
[4] Caramazza, Francesco, Luca Ricci, and Ranil Salgado. 2004. "International Financial Contagion in Currency Crises." *Journal of International Money and Finance* 23:51–70.

2. “Spill over” of volatility from one country to another;
3. Contagion occurs when correlated stock price movements cannot be explained by fundamentals;
4. Contagion is a significant increase in covariance between prices and volumes in different markets, which happens as a result of crisis;
5. Contagion occurs when transmission channel is amplified after a shock on one of markets.

For some researchers the speed of contagion is what matters. But for the majority of economists the very notion of contagion is equivalent to increase in correlation between studied markets. There are several specific concerns:

1. As a rule, during crises volatility is usually seen to rise which causes increase in correlations. Therefore researchers employ sophisticated econometric and statistic apparatus;
2. The correlation level must be higher “than is explained by the fundamentals” of “than was expected”;
3. Lack of proper proof of contagion (i.e. stable high correlation) is interpreted as inter-dependence;

Channels of contagion

It is useful to know during which episodes (the majority of researchers agree that contagion took place during Asian financial crisis and the crisis of 2007-2008) took place and to have certain metrics to track it. But in order to shape sensible counteraction policy we are to know the mechanisms of transmission, which can possibly act as means of contagion. We can even point to one popular metaphor[5]: “when America sits in a draught, the rest of the world catches cold”. The following channels are widely agreed to be applicable in this case:

- Trade (during crisis import of the affected country can decrease impacting the rest of the world);
- Direct and portfolio investment;

[5] At least in Russia.

- International liabilities between (or "balance sheet effect", we can actually extend B. Bernanke's financial accelerator theory to international scale[6]);
- The existence of marked to market assets on the balance sheets of banks may lead to fire price sales during crises, which may result in capital deficiency. Margin calls may also be an issue;
- Change in the perception mechanism of investors, i.e. so called wake-up calls when unanticipated negative events changes investors' outlook. Also sometimes investors are known to treat all emerging economies as the whole, which influences their judgment heavily;
- Significant uncertainty issues, unreliability of conventional statistical and mathematical methods during turbulence periods;

The first three channels are quite fundamental (also trade and BOP have long and reliable series of data). These fundamental connection channels can be analysed using network models and calculation widely accepted network metrics. This was done extensively only for trade network.

Correlation analysis of contagion

The bulk part of research dedicated to contagion is based on correlation metrics. They usually do not dwell on analysing the channels of transmission.

In particular researchers from Bank of Italy[7] summarize a few useful stylized facts about financial crises and contagion:

- Drastic asset price changes affect clusters of countries;
- Volatility of asset yields is higher during crises;
- During crises covariance of asset yields is known to rise within one country;
- Correlations between assets from different countries also rise;

[6] Bernanke, B. & Gertler, M. & Gilchrist, S., 1998. "The Financial Accelerator in a Quantitative Business Cycle Framework," Working Papers 98-03, C.V. Starr Center for Applied Economics, New York University.
[7] GIANCARLO CORSETTI, MARCELLO PERICOLI, MASSIMO SBRACIA, 2010, "Correlation Analysis of Financial Contagion", Bank of Italy working paper.

Nevertheless, researchers claim that increase in correlation must be sufficient to identify contagious episode. Also we find IMF research [8] testing new contagion distribution channel of very high interest. Researchers test hypothesis that uncertainty (measured as variation of 1 year GDP forecasts) is correlated with crisis type. They divide crises into "surprise" events (Thailand, Russia and Mexico) and expected events (Brazil, Argentina, Turkey). It turns out that surprise crises have a robust positive effect on uncertainty level, i.e. it grows after crisis. Expected crises on the other hand decrease the level of uncertainty. Researchers claim that these findings are dataset and methodology robust. Also by employing logit-models they find that the uncertainty itself has a positive effect on crisis probability. Therefore uncertainty can act as a self-fulfilling mechanism of crisis transmission to a certain extend. But how the invisible contagion transmission method works? The following mechanism is suggested:

- Some event occurs which undermines faith in traditional informational institutions;
- Uncertainty grows;
- Visible reliability of traditional analysis methods declines, information quality declines;
- Consequently investment in some sphere (or country or sector) decreases;
- Then there is a positive loop of uncertainty;
- Eventually it may facilitate crisis;

It is worth noting that this mechanism of transmission (combined with balance sheet effects and margin calls) is in fact equivalent to financial accelerator on global scale.

Billio, Getmansky [9] et.al. (2010) offer another approach to measuring inter-dependence of markets. The first step of their estimation is calculating a system of simultaneous equations, which have GARCH-based ideology. This system of equations accounts for changes in volatility due to its lagged values and for dependence of volatility between different markets. Then fitted values are subtracted from real values and the dataset acquired as a result of this operation is searched for correlation. In the end, they offer 2 indexes measuring correlation growth strength in the dataset (for 1995-2005).

[8] Prakash Kannan and Fritzi Köhler-Geib, 2009, "The Uncertainty Channel of Contagion", IMF Working paper WP/09/219.
[9] Monica Billio, Mila Getmansky, Andrew W. Lo, and Loriana Pelizzon, 2010, "Measuring Systemic Risk in the Finance and Insurance Sectors", MIT Sloan School Working Paper 4774-10.

According to their metrics, they identify 3 contagious episodes – Asian crisis, 2001 and 2003.

Kleimer, Lehnert,Verschoor (2008) [10] go even further and depart from assumption that contagion (when it is existent) occurs instantly and analyse not close prices but time-aligned data. Such approach allows them to operate on really small time-frames (minutes). Researchers analyse 2 crisis events (Thailand and Hong-Kong) and conclude contagion occurred between Thailand and Australia, Hong-Kong, Indonesia, Japan, Malaysia, Singapore. It is worth noting that synchronized data (close period data) show contagion only between Thailand and Indonesia. The same observations may be derived from Hong-Kong episode.

Some researchers approach this issue from institutional point of view[11] and claim the existing system of regulation and risk dissemination to be inadequate. Their primary concerns are the following:

- Inefficiency or regulating banking entities;
- Lack of transparency when it comes to valuing assets of financial institutions;
- Uncertainty due to inexistence of unified asset valuation techniques;
- Moral hazard connected with corporate governance and deposit insurance;
- Lack of clear government policy regarding bankruptcy of significant financial institutions;

Network analysis of contagion

All the aforementioned usually refers to analysing financial contagion indirectly, i.e. analysing its symptoms. If we continue to use the contagion metaphor, then we need not only to only to identify the infection and its epicentre, but also invent a means of preventing such infections in future. Therefore we will turn to more fundamental disease spread channels. As discussed before we take the following channels into consideration:

- Trade;
- Capital account;

[10] Kleimeier, S., T. Lehnert, and W. Verschoor. 2008. "Measuring Financial Contagion Using Time-Aligned Data: The Importance of the Speed of Transmission of Shocks." Oxford Bulletin of Economics and Statistics 70:4, 493–508

[11] Østrup, Finn, Lars Oxelheim, and ClasWihlborg. 2009. "Origins and Resolution of Financial Crises; Lessons from the Current and Northern European Crises." *Asian Economic Papers* 8:3, 2009.

- Bank liabilities;

Detailed analysis is usually conducted using network models. Kubelec and Sa (2010) gathered a vast array of bi-directional data for 18 developed economies from 1980 to 2005 (direct investment, portfolio investment, debt, official reserves). Their main conclusions are the following: the financial network is getting more and more dense, its central nodes are the USA and Great Britain. Also they observe increase in connectivity of financial and trade network. The distributions of trade and finance connections have long tails, which implies the existence of core-periphery structure. Average path length also decreases.

Hattori and Suda (2007) analysed stocks of banks' claims to each other for 215 countries from 1985 to 2006. Their conclusion is that the network is getting more connected and clustered. Also they find that during such shocks as the LTCM collapse and the Asian crisis the structure of the network does not change. This is an important milestone of thinking about a useful empirical model of crises.

Allan and Gale (2000) in their fundamental monograph drew attention to importance of banking system concentration. They utilize a very stylized banking system model in order to show that high level of connectivity in banking system may foster risk diversification. Nier, Yorulmazer and Alentorn (2008) employ more sophisticated mathematical modelling in order to show that higher capital ratio decreases probability of default in banking system in a non-linear fashion. Researchers generate hypothetic banking network using mathematical modelling and then subject it to outer shocks. If shock is smaller than equity capital of the bank then it's absorbed. If the shock is bigger, then it is transmitted to other banks and depositors, which can cause further amplification. Probability of bank default also depends on the foreign claims ratio (which varies from 15% to 30%). It reaches maximum when this ratio is about 30% and then is stable. The link between the number of nodes in the network (i.e. how full the network is) and the number of defaults is m-shaped. It means that there are few defaults in case of little connections and few defaults in case of abundant connections. The most useful about this paper is its approach for modelling banking networks, shock absorption and transmission mechanisms. This will be adopted by us empirically in future.

Fagiolo, Reyses and Shiavo (2010) [12] provide a significant contribution by analysing world trade network. Their findings include:

- Network has core-periphery structure;
- Major role is played by OECD countries;
- The structure of the network is quite stable and is not susceptible to systemic shocks;
- High involvement in trade network increases the probability of stock market shock during crisis events.

But the most interesting contribution is provided in IMF paper by Minoiu and Reyes (2011) [13] analysing the financial network of flows of banking claims (BIS locational statistics). Their database contains quarterly data for 184 countries from 1978 to 2009. Bank claims include loans, deposits, obligations and other assets. One aforementioned paper had almost the same database, but they analysed stocks of claims, which are by definition less volatile and representative (they found the banking network to be quite stable). In contrast with previous findings, banking flows network appear to be very volatile and have certain interesting properties to be outlined. Minuiu and Reyes analyse 15 lenders and 169 borrowers, which is a dictated by BIS's structure of data.

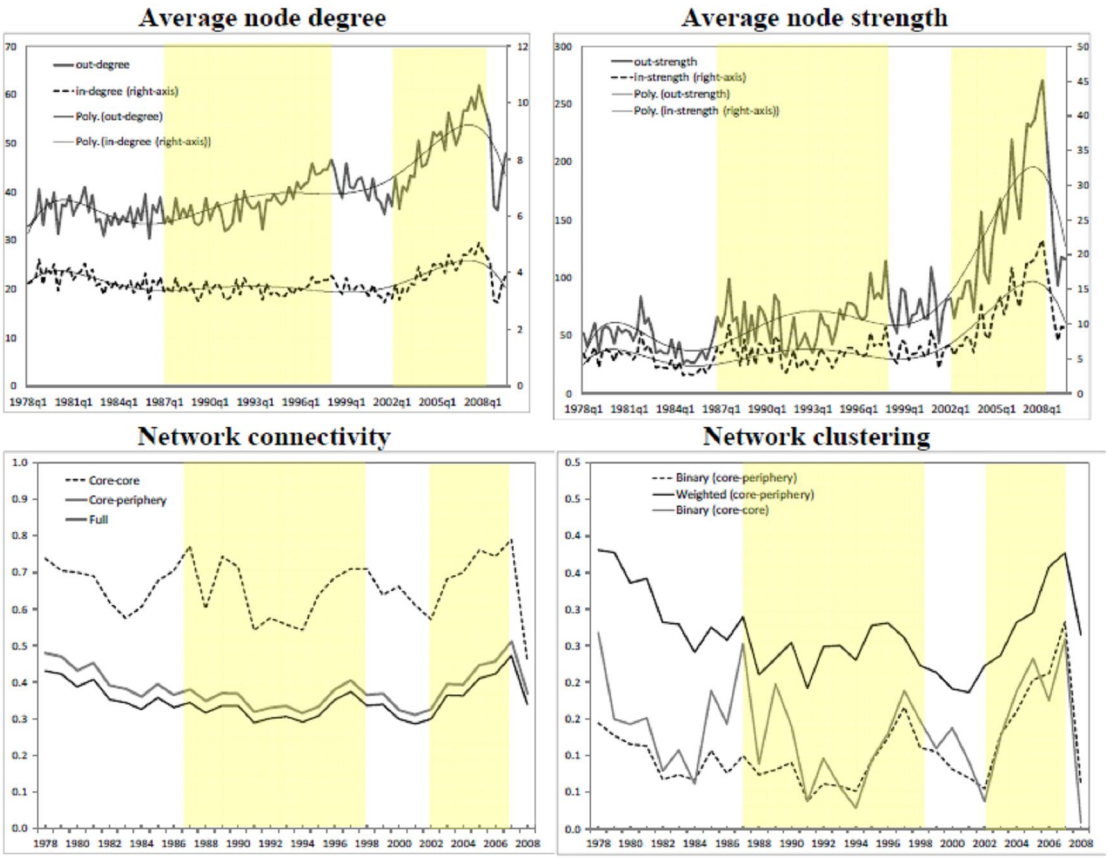
Researchers use the following conventional metrics stemming from graph theory: node degree (number of connections for each country), node strength (sum of inflows or outflows for a given node), relative node strength, connectivity (total number of non-zero connections divided by their potential number) and several clustering metrics.

During 3 decades the financial network underwent several waves of financial globalization. Figure 1 depicts the dynamics of main network metrics. We can clearly see 3 ways of financial globalization on the chart. The first wave ends with debt crisis of early 80s. The second one ends with the Asian financial crisis. The third wave of connectivity growth in GBN (Global Banking Network) ends with the crisis of 2007-2008. Authors also confirm that the network is quite volatile by using empirical distribution tests (Kolmogorov-Smirnov tests).

[12] Fagiolo, G., Reyes, J., and S. Schiavo, 2010, "The evolution of the world trade web: A weighted network analysis," *Journal of Evolutionary Economics*, Vol. 20(4), pp. 479–514

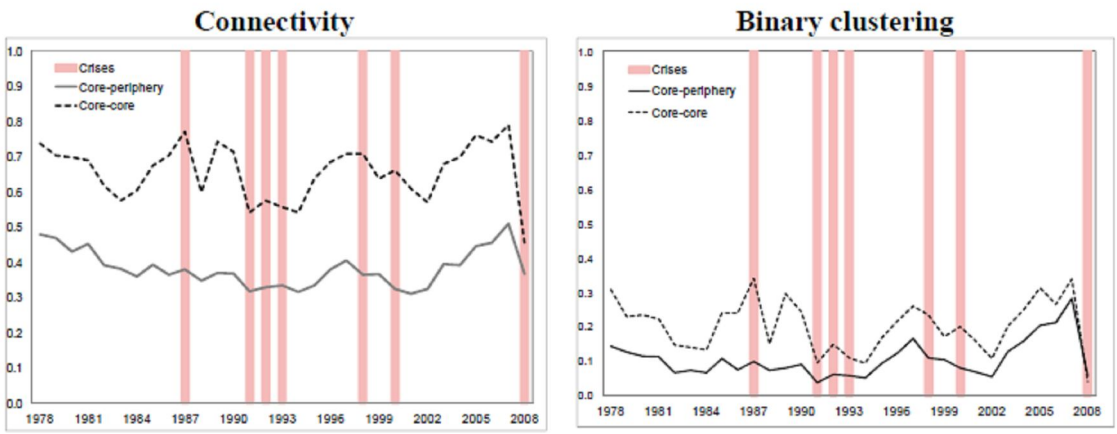
[13] Camelia Minoiu, Javier A. Reyes, 2011, "A network analysis of global banking: 1978–2009", IMF Working Paper WP/11/74.

Figure 1 Financial network metrics



Source: Camelia Minoiu, Javier A. Reyes, 2011, "A network analysis of global banking: 1978–2009", IMF Working Paper WP/11/74

Figure 2 Financial network metrics during crises

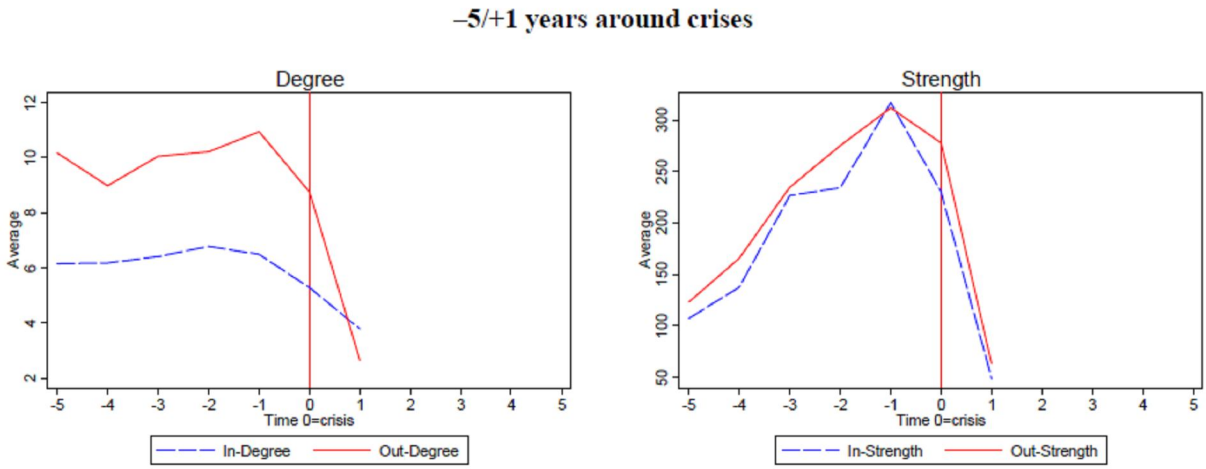


Source: Camelia Minoiu, Javier A. Reyes, 2011, "A network analysis of global banking: 1978–2009", IMF Working Paper WP/11/74

It is also interesting that in a recent paper by Stolbov (2012) [14] the existence of credit cycles in global economy is also confirmed using quite different statistical and mathematical apparatus.

The main interest is behaviour of GBN during crises. Take a look at the figure 2 depicting the following crises: the 1987 stock crash, Scandinavian banking crises of 1991-1992, British currency crisis of 1992-1993[15], LTCM collapse in Q3 1998, the Internet bubble collapse in 2000, the demise of Lehman Brothers in Q3 2008. Authors claim that many connections "die out" after crises and connectivity metrics decrease. It can be seen even more clearly for Latin America and Eastern Asia. Authors also measure average connectivity levels before and after crises and state that crises lead to decrease in connectivity metrics. Inclusion of 2007-2008 crisis amplifies this effect (see figure 3).

Figure 3 Average metrics before and after systemic crises



Analysis is finalized with dummy-based regression model showing that credit is significantly rationed during crisis periods.

[14] Stolbov, Mikhail, International Credit Cycles: A Regional Perspective (April 9, 2012). Available at SSRN: http://ssrn.com/abstract=2037352 or http://dx.doi.org/10.2139/ssrn.2037352.
[15] A notorious episode earning G. Soros £1bn.

Other methods

Analysis of systemic risk is a separate and broad issue in the literature. By definition systemic risk is a situation when there is a probability that a series of connected defaults in the financial system happening during a short time period can decrease liquidity and result in confidence loss. "Systemic crisis can be defined as a systemic event, which influences many financial institutions undermining normal functioning of the financial system. While the special nature of banking institutions plays its role, systemic risk is something more than banks' vulnerability to runs. The notion of financial contagion lies at the root of this concept. In this case contagion means significant spill over of losses from one institution or market to another."[16]

The events of 2007-2009 show us that in the modern economy such phenomena (so called "bank runs") can extend not only on traditional banking institutions but also on insurance companies, hedge funds, non-banking credit facilities and broker/dealer companies via a network of connections between them. Systemic risk can be adequately described as 4 L's:

- Liquidity;
- Leverage;
- Linkages;
- Losses ;

A paper by Billio, Getmansky, Lo et.al. (2010) uses market yields of public companies as a proxy of their operational success in order to measure linkages between them. They analyse a vast array of banks, insurance companies, hedge funds and broker companies.

The main pillars of systemic risk are leverage and linkages. Leverage acts as a magnifying glass, which enlarges losses during adverse market conditions. As financial companies usually have only limited amount of equity capital, they have to sell assets during crises which causes negative feedback loops. Also assets of financial institutions may be quite illiquid (i.e. hedge funds) and lack stable market valuation, which in its turn aggravates the situation. Also the depth of crisis may depend on how asset price is susceptible to market conditions and how companies are interlinked.

[16] De Bandt, Olivier, and Philipp Hartmann, 2000, "Systemic Risk: A Survey," European Central Bank Working Paper No. 35.

In practice data on mutual debt exposures turns out to be proprietary and inaccessible to regulators in most of cases. Therefore systemic risk analysis is frequently conducted using indirect measures. Indirect systemic risk analysis may be useful for crisis prevention if it is based on relevant data. Thus, researchers employ market data assuming that market valuation should react quickly to adverse market conditions. In any case, if financial companies provided such data to regulators, it could be doubted that regulators would act efficiently. In this case we can remember about criticism towards recent Dodd-Frank law[17].

Researchers note that they chose these types of financial institutions deliberately taking into consideration the changes the global financial system underwent recently. Literature on systemic risk can be divided in several broad categories.

The first type of literature deals with contagion on micro level within banking system and studies linkages between bank defaults, bank profitability and amounts of direct losses. Also direct financial links between banks, which can incur losses, are considered.

The second category studies fluctuations of aggregated banking credit activity, banking crises and booms. Such studies usually also utilize banks' financial ratios and volumes of liabilities. The main result is that fundamental macroeconomic factors can actually significantly affect the performance of banking system.

The third group of systemic risk studies uses correlation metrics as a yardstick, which was already covered. A paper by Billio, Getmansky, Lo et.al. (2010) use a variety of approaches:

1. Autocovariance[18] and correlation analysis of aggregated indexes for each financial sector;
2. PCA;
3. Granger causality tests;
4. Analysis of linkages between 25 biggest institutions in each sector;

Figure 4 depicts aggregated 36-month autocovariances of sector indexes. During crises autocovariance is seen to rise. Figure 5 depicts pair correlations between aggregated indexes and figure 6 illustrated PCA for these indexes. All this charts show that systemic fragility and risk is mounting before and during major crises.

[17] http://www.economist.com/node/21547784
[18] Existence of autocovariances of index returns is treated as a proxy of market inefficiency.

Figure 4 36-month autocovariations of aggregates in different sectors

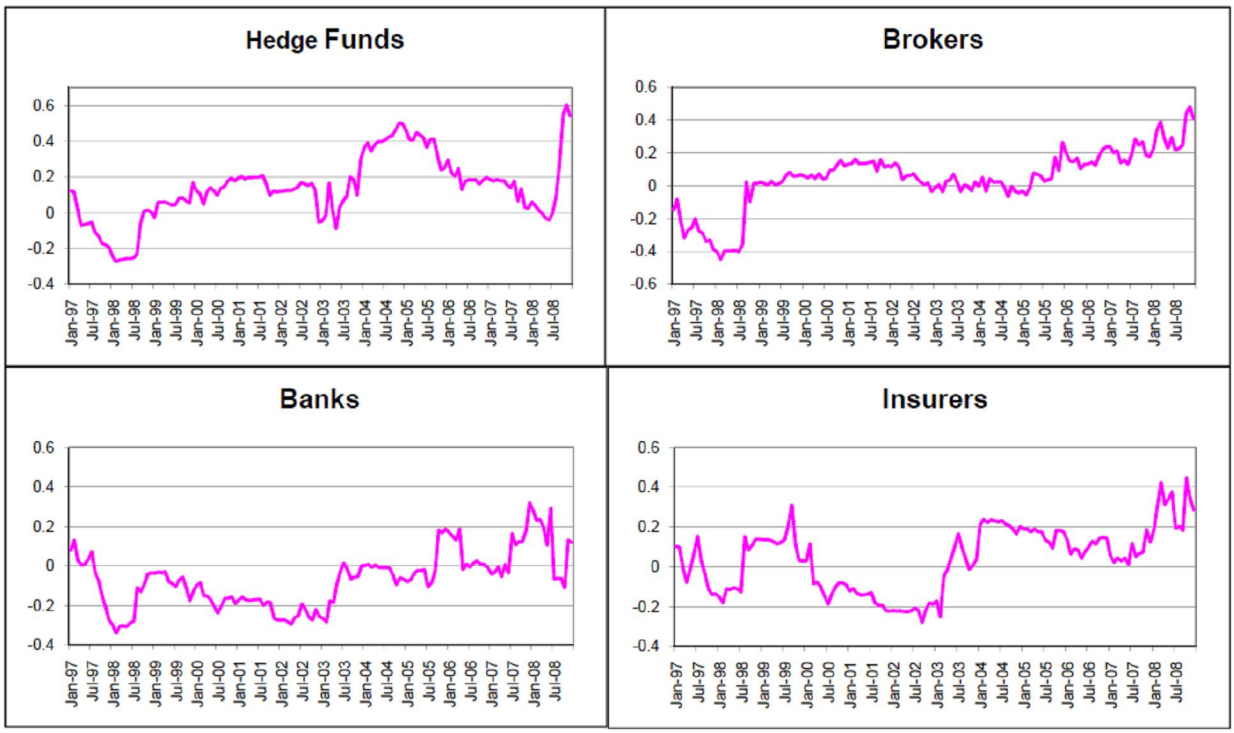
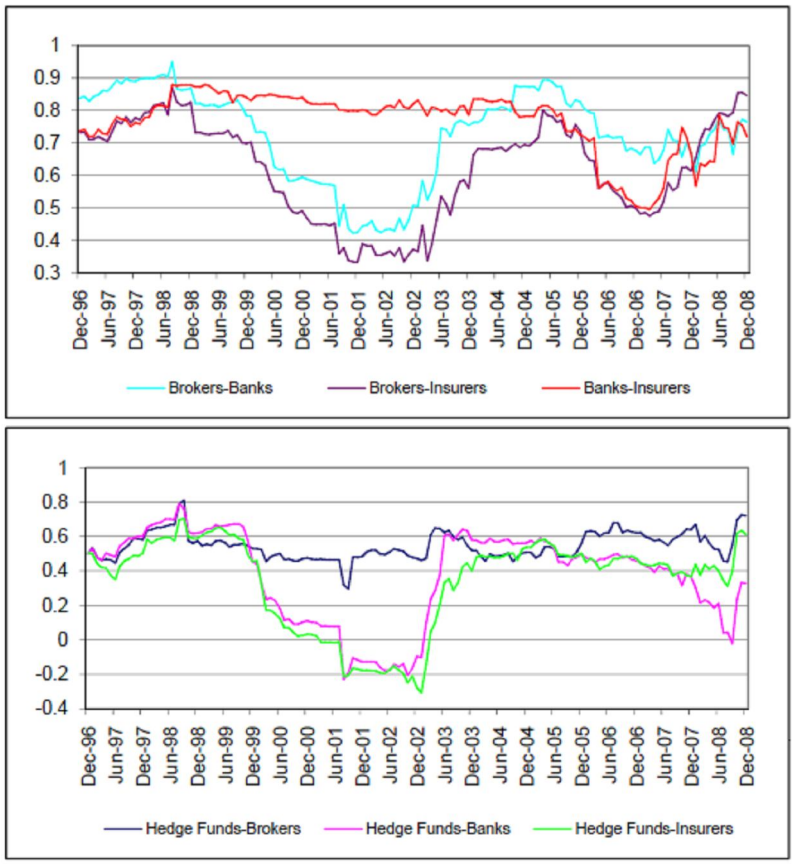
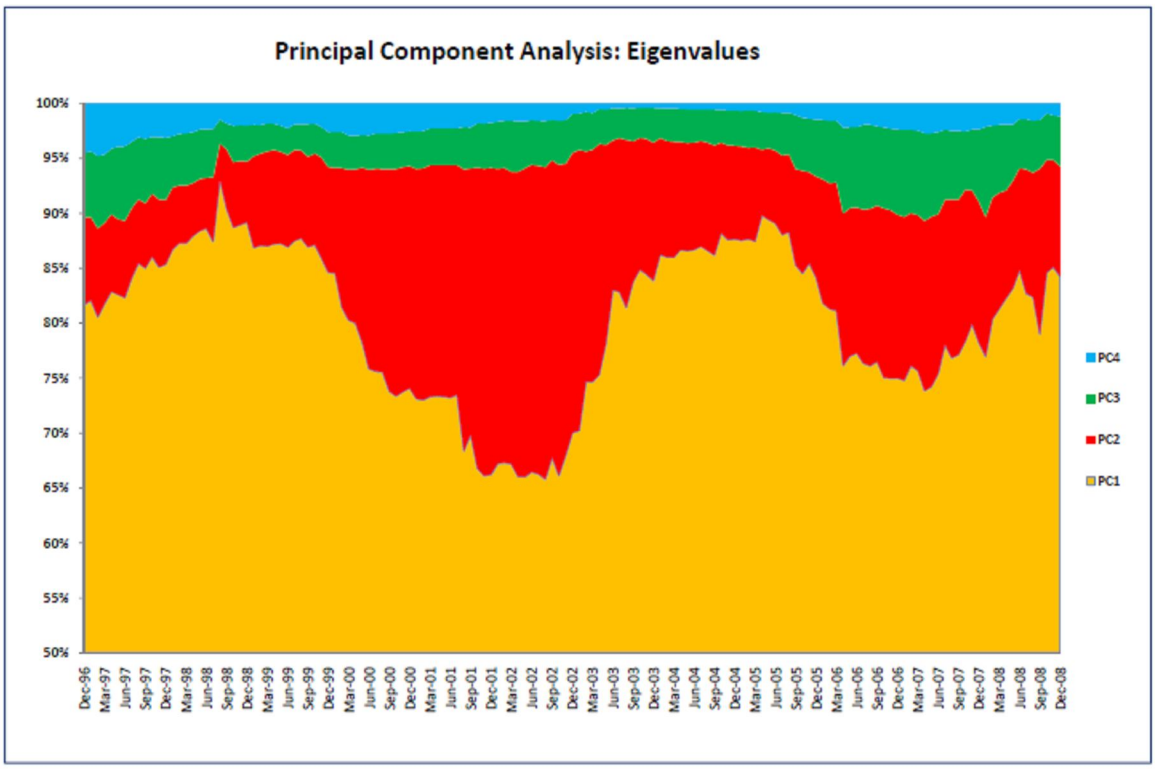


Figure 5 36-month pair correlations



Source: Monica Billio, Mila Getmansky, Andrew W. Lo, and Loriana Pelizzon, 2010, "Measuring Systemic Risk in the Finance and Insurance Sectors", MIT Sloan School Working Paper 4774-10.

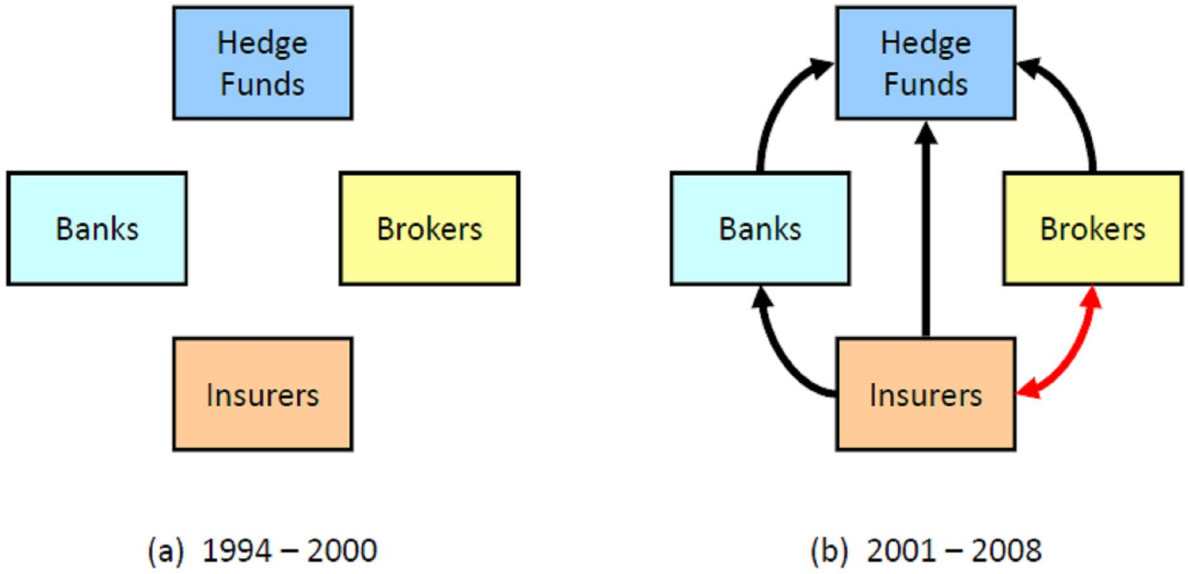
Figure 6 Principal component analysis



Source: Monica Billio, Mila Getmansky, Andrew W. Lo, and Loriana Pelizzon, 2010, "Measuring Systemic Risk in the Finance and Insurance Sectors", MIT Sloan School Working Paper 4774-10.

It is also worth noting that causality links between 100 top institutions from 4 sectors were analysed. Researchers found that the number of statistically significant links between institutions rose from 6% to 14% (of maximal number of links). Also figure 7 depicts a major change in causality relations in the last decade.

Figure 7 Causality links between finance sectors



Source: Monica Billio, Mila Getmansky, Andrew W. Lo, and Loriana Pelizzon, 2010, "Measuring Systemic Risk in the Finance and Insurance Sectors", MIT Sloan School Working Paper 4774-10.

Sketch of applicable macroeconomic model of contagion

The following model of systemic risk and contagion in global financial system (GFS) is to be implemented. It owes its main building blocks to the above literature. It was decided to limit our analysis solely to banking sector and exclude trade and capital movements. Key premises for such decision are the following:

- BIS collects detailed data on banking systems of various countries on unified basis;
- Such banking network is described in literature in detail;
- Central banks provide consolidated balance sheets of their banking systems;
- Researchers point out that banks play pivotal yet not overwhelming role in crises;
- Data on connection and assets of banking systems allows us to validate the potential "threat" and "cushion" to mitigate this threat;
- When current or capital account poses threat to GDP in the long term it is less clear how "cushion" mechanism works;
- Banking data is more frequent (quarterly) and can serve in theory as leading indicator;
- Author's limited capabilities.

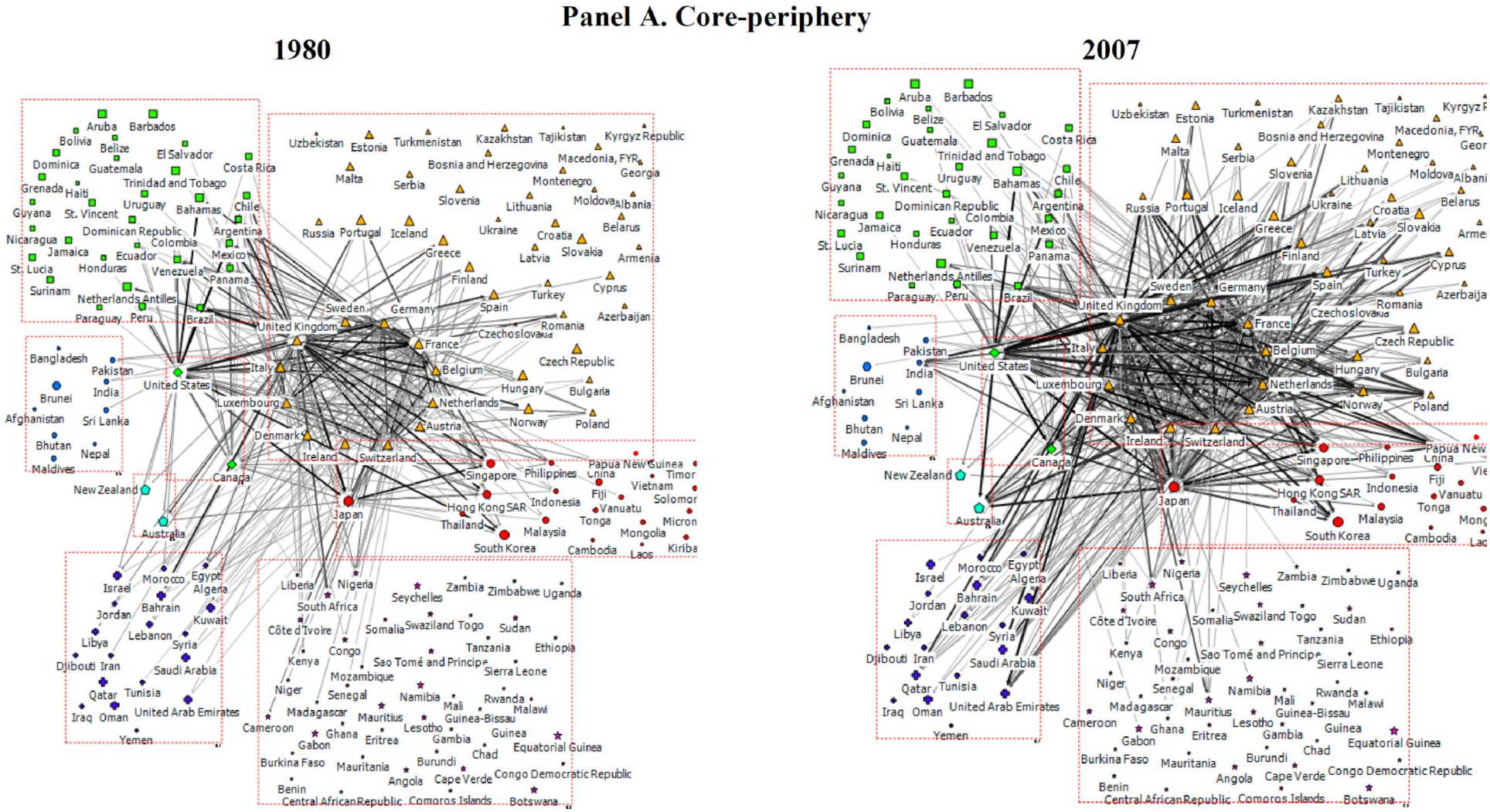
Ideologically the model will look as follows:

- Using data of central banks we construct stylized consolidated banking balances (main entries are equity, foreign assets/liabilities, deposits);
- BIS network data is added;
- Also balance sheets of top 3 largest institutions per country can be added to analysis;
- Fragmentation of banking system can be evaluated using concentration metrics (HHI, CR3 etc);

- We take the assumption that foreign shock occur due to the fact that financial links between countries' banks die out during crises causing losses (now "candidates" are Spain, Portugal and Greece);
- Such shocks are first cushioned using equity capital, then using international assets (which may cause secondary induced defaults and shocks) and only then using deposits;
- Model including balance sheets and network will be subjected to shock via mathematical modeling;

In perfect world such model can be a useful applied instrument to spot problem financial zones and evaluate consequences of financial turmoil.

Figure 7 Stylized connections in GBN



Source: Camelia Minoiu, Javier A. Reyes, 2011, "A network analysis of global banking: 1978–2009", IMF Working Paper WP/11/74

Conclusion

This article summarized different approaches to studying financial contagion and systemic risk. A sketch of applied macroeconomic model was proposed. The next iteration of this paper will include empirical analysis and model evaluation.

The analysis of systemic risk and financial contagion is a relatively new and developing topic. Usually different statistical and mathematical methods are applied, but researchers agree on one thing: we require adequate and timely methods to monitor financial system in order to react on mounting fragility in the system. Also we believe that in the modern world, to which very intertwined financial system is inherent, such analysis should become mainstream. But in this case we are to develop simple and intuitively understandable instruments. It is obvious that systems of simultaneous GARCH equations are not easy understood by the public. Therefore we will also try to develop such an instrument and make it accessible via the Internet.

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