

Further Analysis on the European Interbank Market during the credit crunch period

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Bank of England FS Seminar
18 September 2009

Agenda

- Introduction
- Research questions
- Data and market description
- Methodologies
- Results

Introduction

- A search on Google News on "start of credit crunch" comes up with the first entry in Moneyweek, 11th July 2007 which had a piece titled "Is this the start of a global credit crunch."
- According to Google News, the BBC was using the term a month later, with insights from leading financial analysts.
- The Independent on Sunday has a good timeline and a major survey this August looking back to the start of the credit crunch in August 2007, going so far as to name August 9th 2007 and the closing of several funds by BNP Paribas due to sub-prime problems in the US as the starting point.

Introduction

- The BNP Paribas press announcement (English version) announcing the development still reads rather shockingly even with the benefit of hindsight. "The complete evaporation of liquidity in certain market segments of the US securitisation market has made it impossible to value certain assets fairly regardless of their quality or credit rating."
- Full marks to BNP Paribas for their transparency over the situation at that point – how many banks would have been so honest?
- So what did the Financial Times have to say on those events back in August 2007? What is interesting is the potential severity of the situation was understood immediately by the Financial Times and its article the following day seem remarkably prescient. Bear Stearns the month before (July 2007) and then BNP Paribas were the first two markers in a timeline which leads to Fannie Mae and Freddie Mac.

Introduction

- Interbank markets play at least two crucial roles in modern financial systems.
- First and foremost, it is in such markets that central banks actively intervene to guide their policy interest rates.
- Second, well functioning interbank markets effectively channel liquidity from institutions with a surplus of funds to those in need, allowing for more efficient financial intermediation.
- Thus, policymakers have an interest in having a financial system with a well functioning and robust interbank market, that is, one in which the central bank can achieve its desired rate of interest and one that allows institutions to efficiently trade liquidity.

Introduction

- The set of internal loans and debts has a structure that can be naturally described by means of a network, that is a system consisting of vertices (banks) connected by one or more oriented edges (debts/loans). The aggregate characteristics of the entire set of transactions can thus be studied in terms of the statistical and topological properties of this network.
- This enables us to use well-established methodologies to assess the stability, self-organization and redundancy of the various relationships between banks as well as the overall robustness of the financial system to external shocks
- A part of this study compares results published in Iori et al. (2008) with post crisis data

Research questions

1. Have trades, volumes and interest rates within the interbank market changed their patterns as an effect of the crisis? And how?
2. Did the structure of selling and buying banks changed?
3. Are banks preferring domestic networks during financial turmoil?
4. Did the network analysis and interbank market data provided early warnings of the crisis?

The E-MID market

- Market players are 246 members from 29 EU countries and the US, of which:
 - 30 central banks acting as market observers
 - 2 Ministries of Finance
 - 108 domestic banks
 - 106 international banks
- Participants requirements are as follows:
 - for Credit Institutions (i.e. Banks and Electronic Currency Institutions): total net assets of at least \$ 10 million; membership to the Payment System of the relevant currency (€, \$, £, PLN), directly or via Agent Banks
 - for Investment Companies: total net assets of at least € 300 million; membership to the Payment System of the relevant currency (€, \$, £, PLN), also via Agent Banks
- More than 14 billion euros traded daily in 4 currencies (daily average 2008)

The E-MID market

MARKET PHASES:

- Pre Trading	N.A.
- Trading (all maturities are tradable)	08:00 - 18:00
- ON Close (all maturities are tradable except ON and BD starting ON)	18:00 - 18:30
- Post Trading	18:30 - 20:00
- Closure	20:00 - 07:00

CURRENCY

EUR

TRADING CALENDAR

TARGET BUSINESS DAYS

SETTLEMENT CALENDAR

TARGET BUSINESS DAYS

SETTLEMENT SYSTEM

TARGET, TARGET2

SETTLEMENT METHOD

MANUAL, AUTOMATED

AUTOMATED SETTLEMENT (overnight 1ST PAYMENT)

IMMEDIATE

AUTOMATED SETTLEMENT (OTHER PAYMENTS)

9.00 am, 11.30 am

BASE

360

LOT SIZE

1.000.000

MIN QUOTE QUANTITY

1,5

MIN QUOTE QUANTITY LARGE PRODUCT

100

QUANTITY TICK

0,01

MIN ORDER QUANTITY

0,05

MIN ORDER AUTOACCEPTANCE

0,5

VOLUME CAP ON PROPOSAL PRIORITISATION

N.A.

RATE TICK

0,005

The E-MID market

**MAX QUOTE NUMBER
MATURITIES**

3

ON, ONL, TN, TNL, SN, SNL, 1W,
1WL, 2W, 3W, 1M, 2M, 3M, 4M, 5M,
6M, 7M, 8M, 9M, 10M, 11M, 1Y - BD

TIME DEPOSIT VALUE DATE

SECOND BUSINESS DAY

FOLLOWING THE TRADE DATE

**ACCEPTANCE ORDER TIME OUT
RECALL ACTIVATION TIME**

90 SEC

N.A.

Bank nationality in the E-MID

AT AUSTRIA
BE BELGIUM
CH SWITZERLAND
DE GERMANY
DK DENMARK
ES SPAIN
FR FRANCE
GB UNITED KINGDOM

GR GREECE
IE IRLAND
IT ITALY
LU LUXEMBOURG
NL NETHERLANDS
NO NORWAY
PL POLAND
PT PORTUGAL

Types of Trades

- The *Market* trades the following *Trades* whose object is the temporary transfer of funds:
- **Overnight (O/N):** *Trades* for a transfer of funds to be effected on the day of the trade and to return on the subsequent *Business Day*;
- **Tomorrow next (T/N):** *Trades* for a transfer of funds on the first *Business Day* following the day of the trade and to return on the second *Business Day* following that of the trade;
- **Spot next (S/N):** *Trades* for a transfer of funds on the second *Business Day* following the day of the trade and to return on the third *Business Day* following that of the trade;
- **Time Deposits:** *Trades* for an initial transfer of funds and to return at a predetermined maturity (from 1 week to 12 months);
- **Broken Date Deposit:** *Trades* with freely agreed *Initial Value Date* and *Final Value Date* between parties without standardization obligations provided that both dates do not coincide with the previous ones and that the two days are not separated by a period superior to a calendar year

Microstructure of the market

- Trading in e-MID starts at 8 a.m. and ends at 6 p.m. Trades are settled in real time, thanks to the “straight through processing” facility: once a deal is made, an automatic procedure makes the lending bank immediately deliver the amount due through a Target payment.
- Another important aspect of the market microstructure is the fixed maturity of the overnight contract. In particular, deals between Italian banks matures at 9 a.m. (next day). At this time, previous day trades are settled in real-time, as the borrowing bank has to repay the amount due through a Target payment.
- Deals involving (at least) a foreign bank mature by noon (next day). These features enable us to apply the framework introduced in the previous section, where the starting time of an overnight contract unambiguously determines the length of the loan, which is known by both participants in the deal.

Data

- We consider trades (tick-by-tick data) that occurred in the e-MID market from 2006:01:02 to 2008:12:31, for a total of 322.213 observations
- We divided the day into 10 hourly time bands, from 8 a.m. to 6 p.m.
- We used as
 - pre crisis the period up to 09/08/2007
 - mid crisis the period up to 15/09/2008 (Lehman failure)
 - and post crisis the period after 15/09/2008

Research question no. 1

Have trades, volumes and interest rates within the interbank market changed their patterns as an effect of the crisis?

And how?

- Interest rates: level and volatility
- Transactions
- Volumes

Daily interest rate (1999 – 2002): previous study

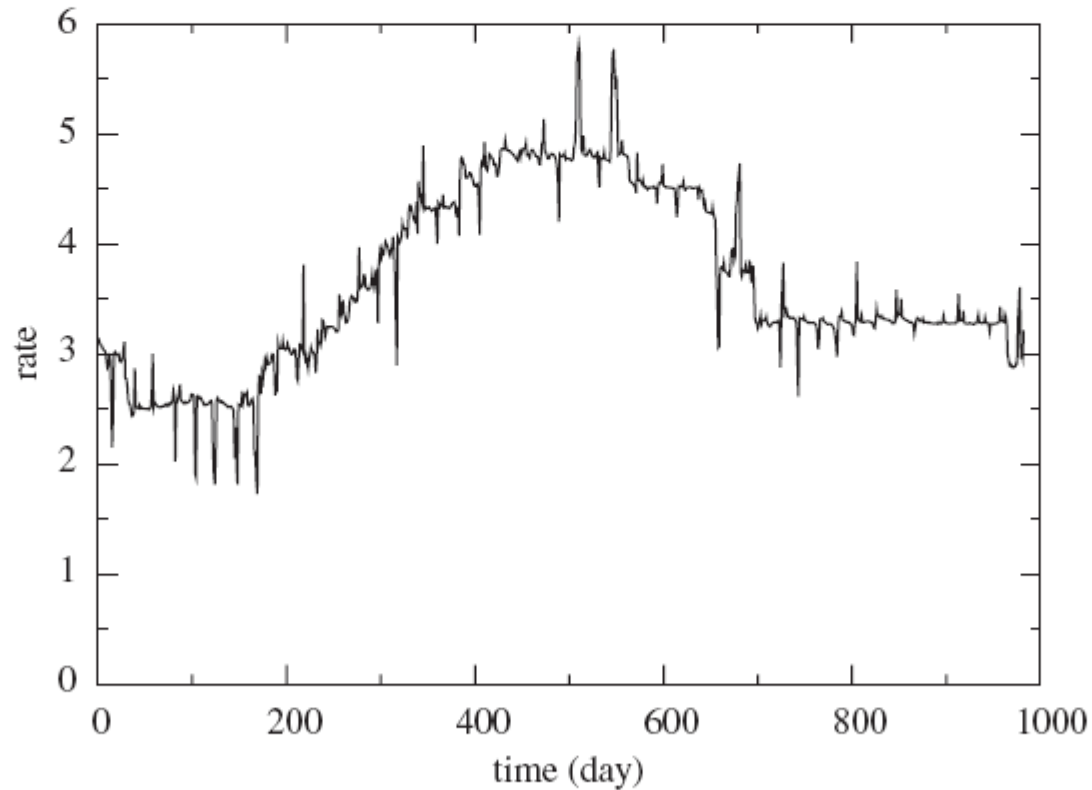
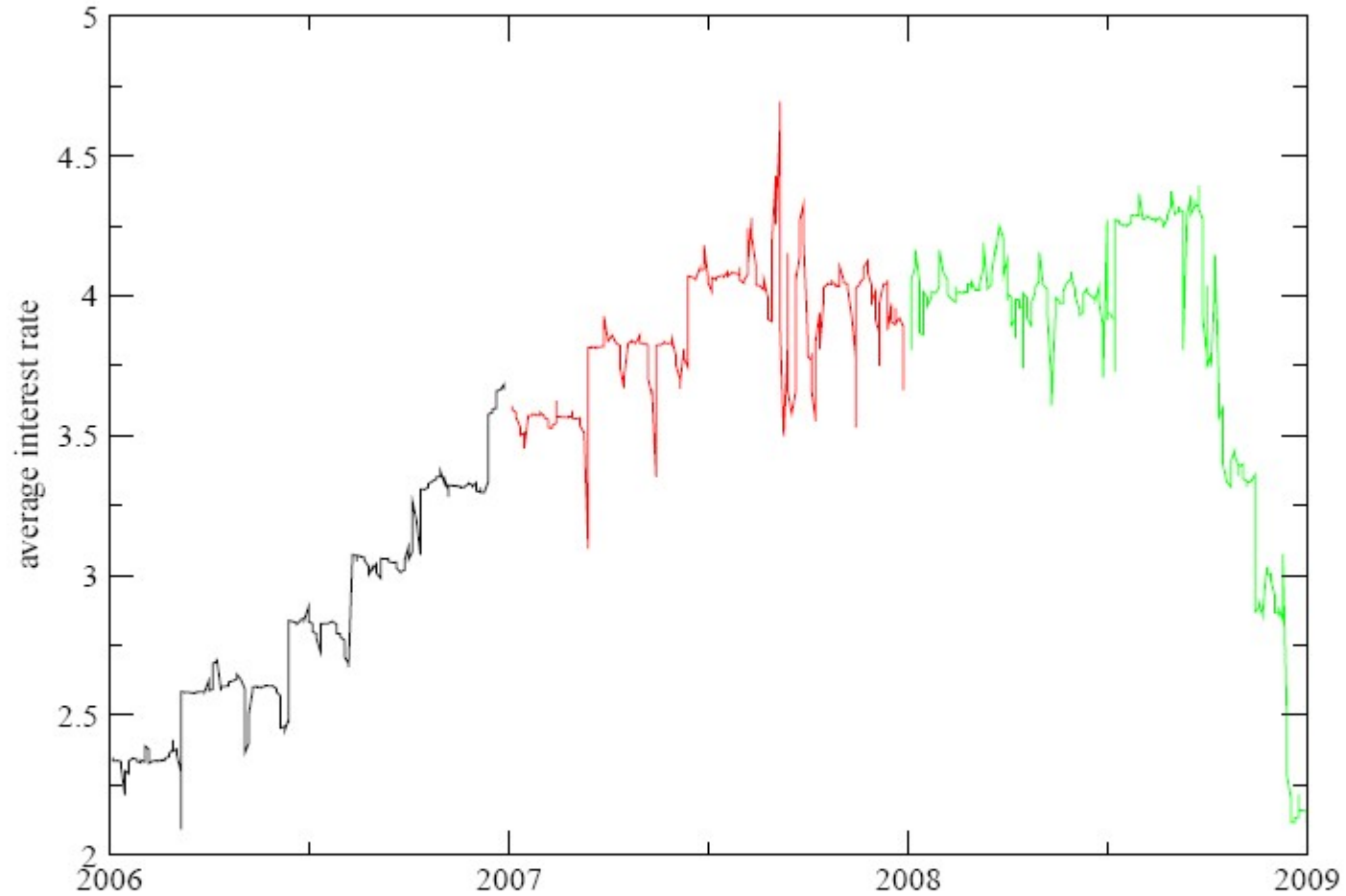
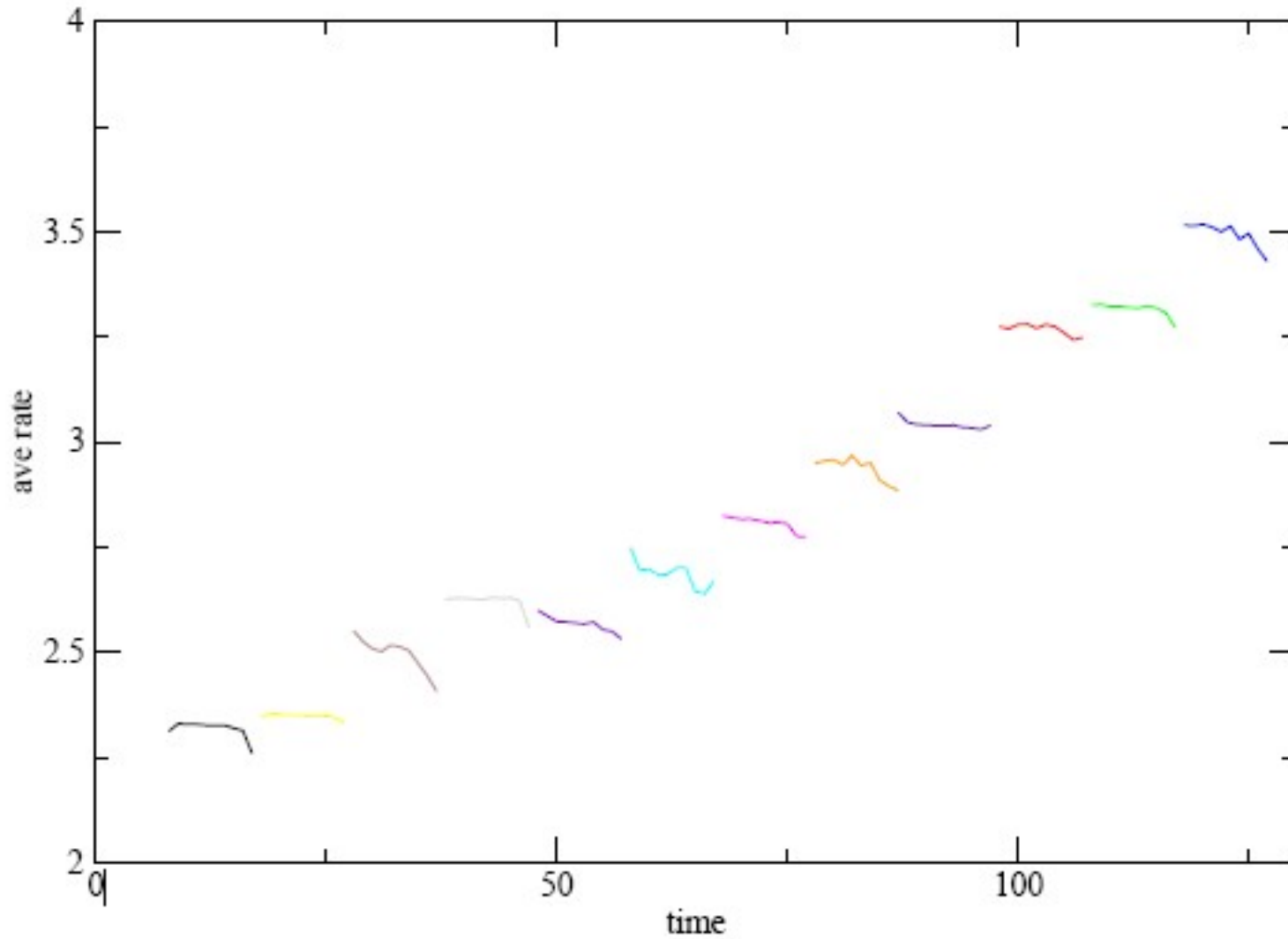


Fig. 1. Time series of daily interest rates from January 1999 to December 2002.

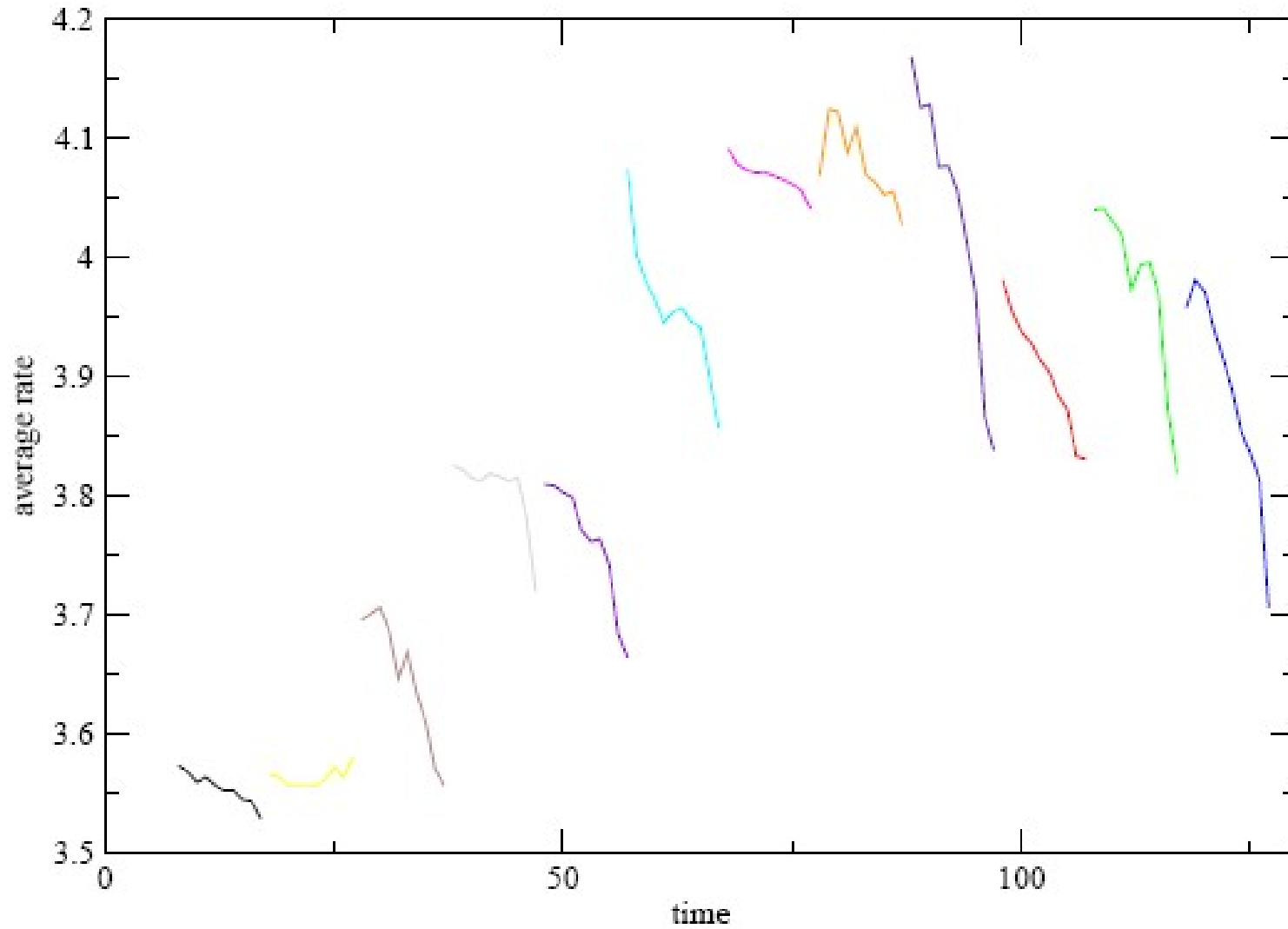
Daily interest rate (2006 – 2008)



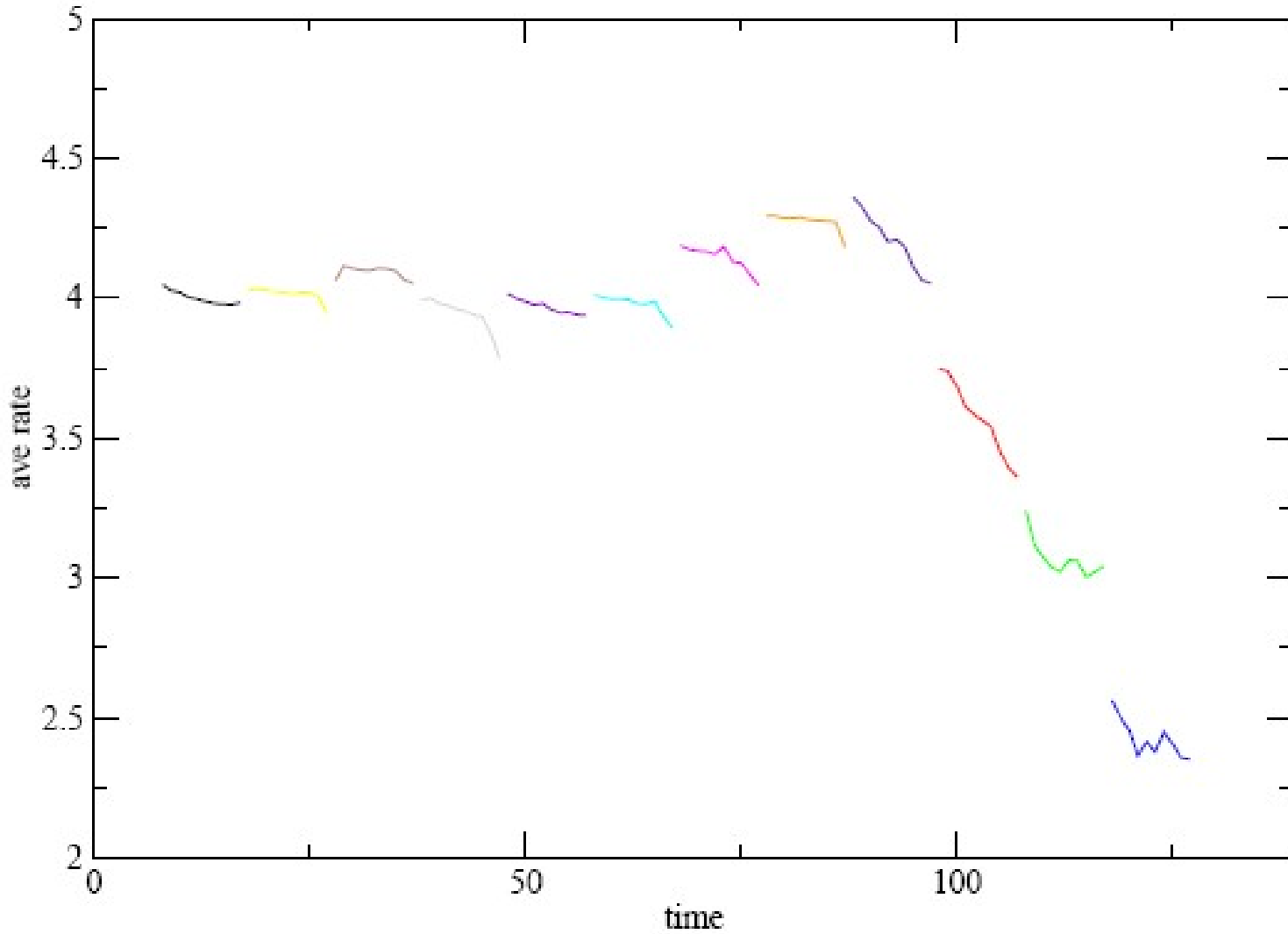
Intra-day interest rate (2006)



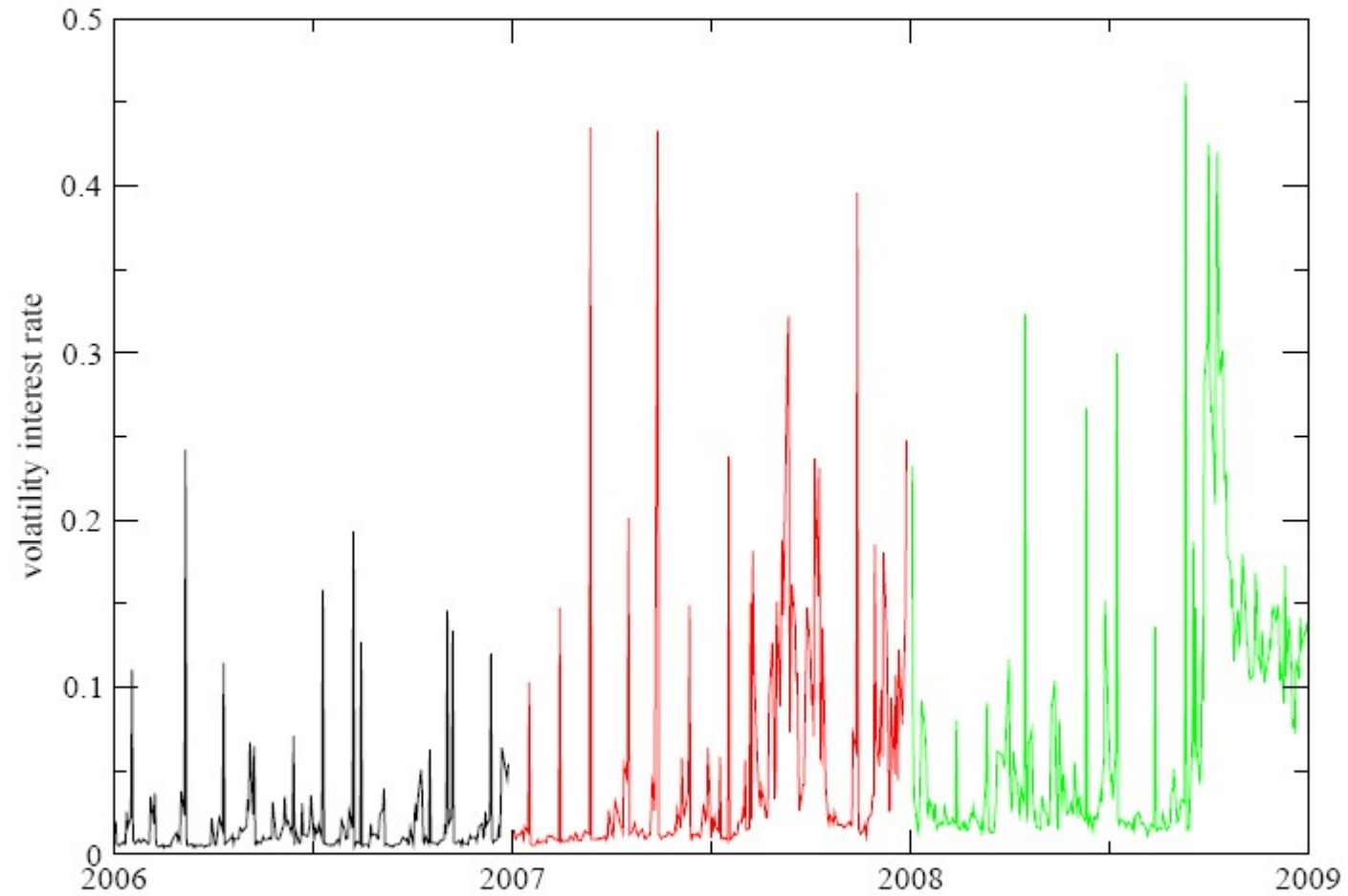
Intra-day interest rate (2007)



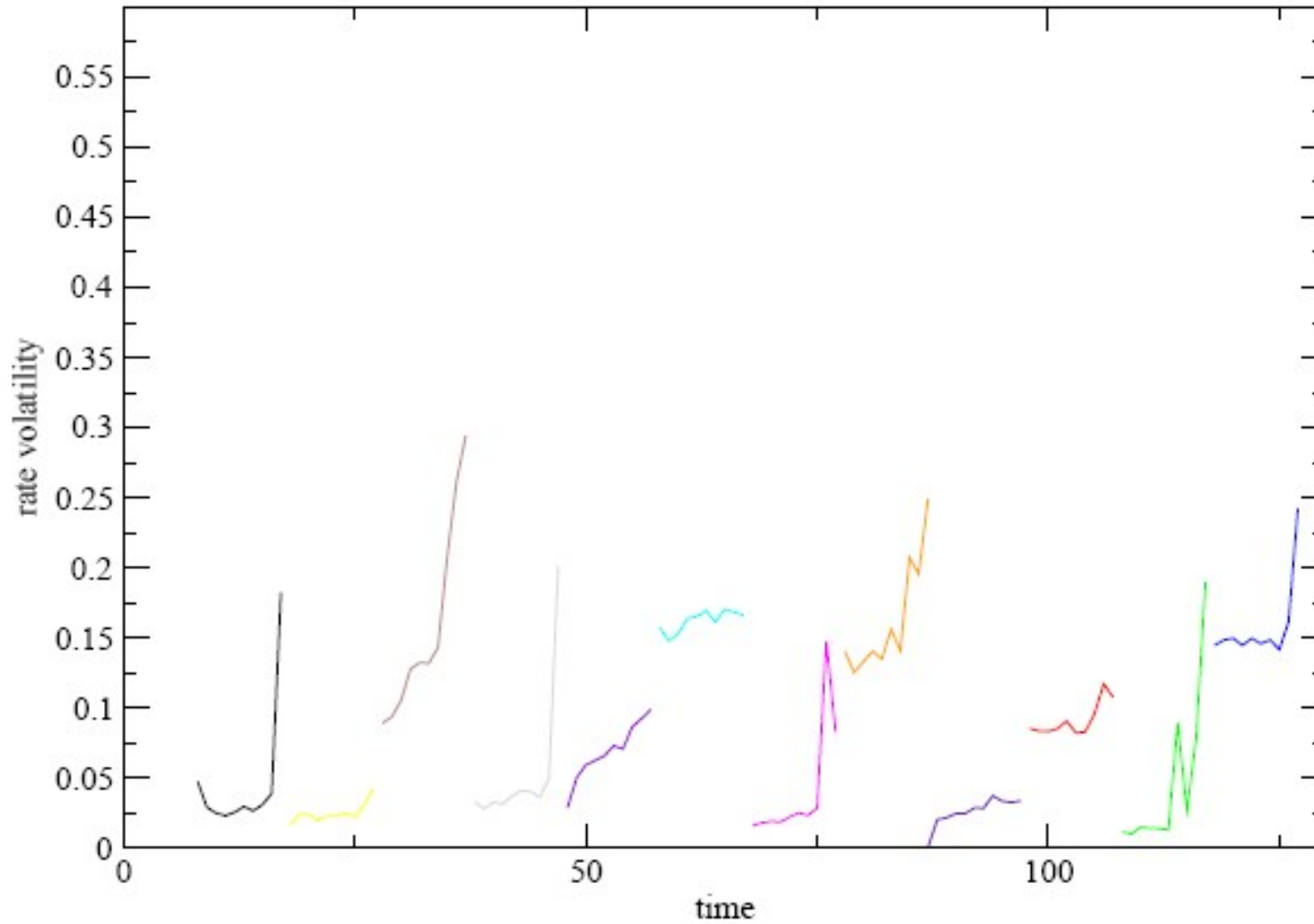
Intra-day interest rate (2008)



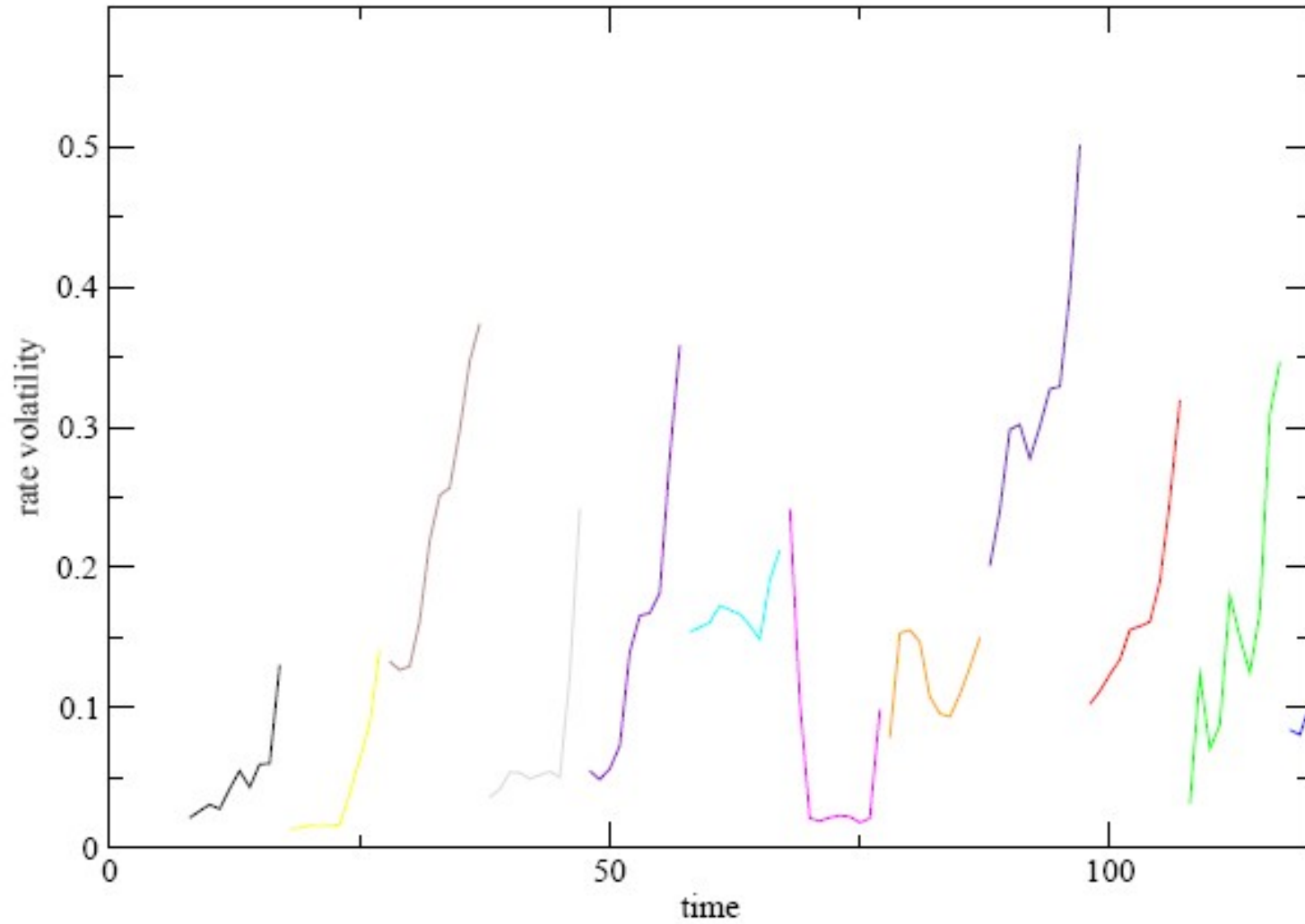
Daily interest rate volatility (2006 – 2008)



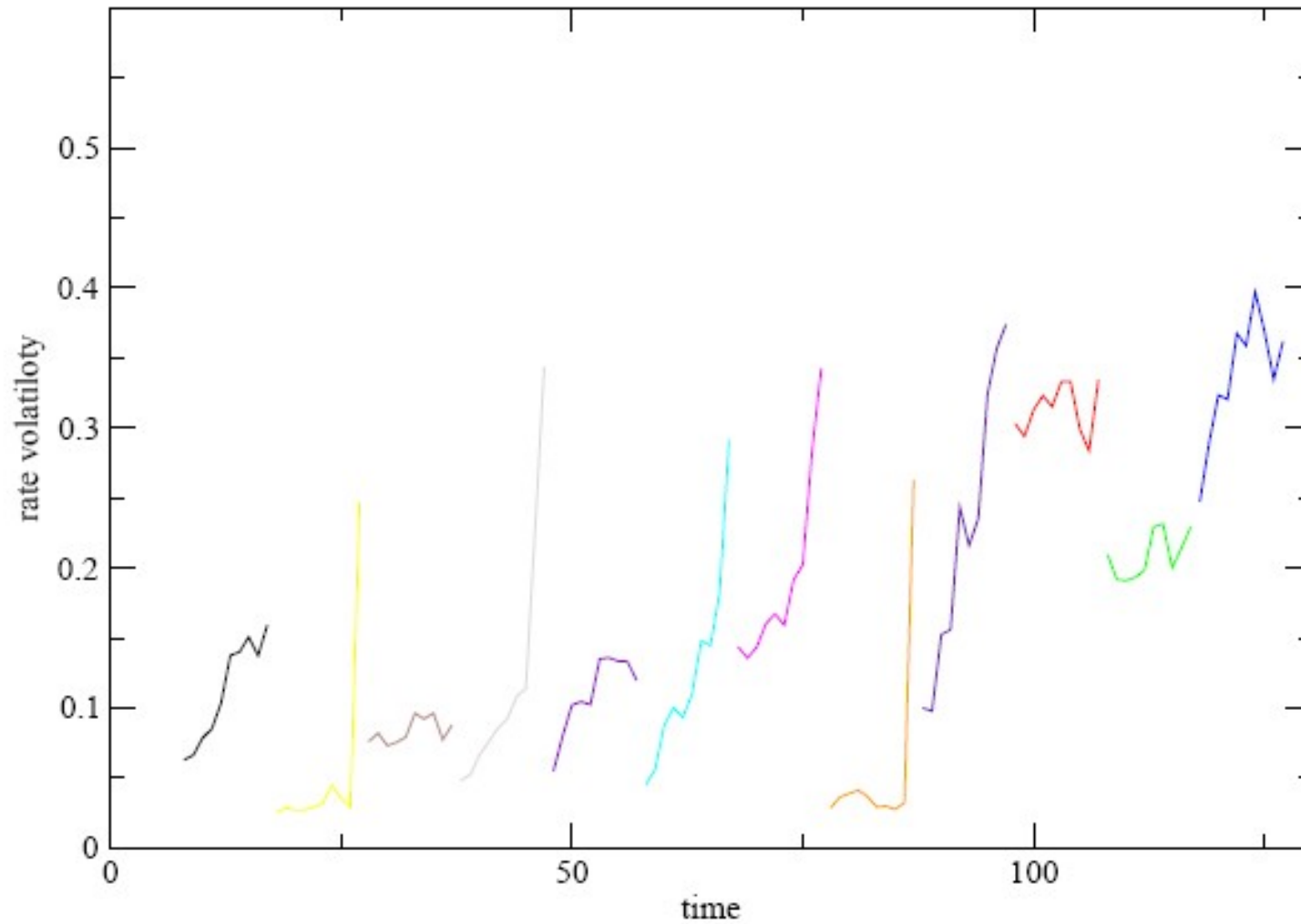
Intra-Day interest rate volatility (2006)



Intra-Day interest rate volatility (2007)



Intra-Day interest rate volatility (2008)



Volume and trades by contract (pre crisis)

BEFORE THE CRISIS: (1/1/2006 - 8/9/2007)

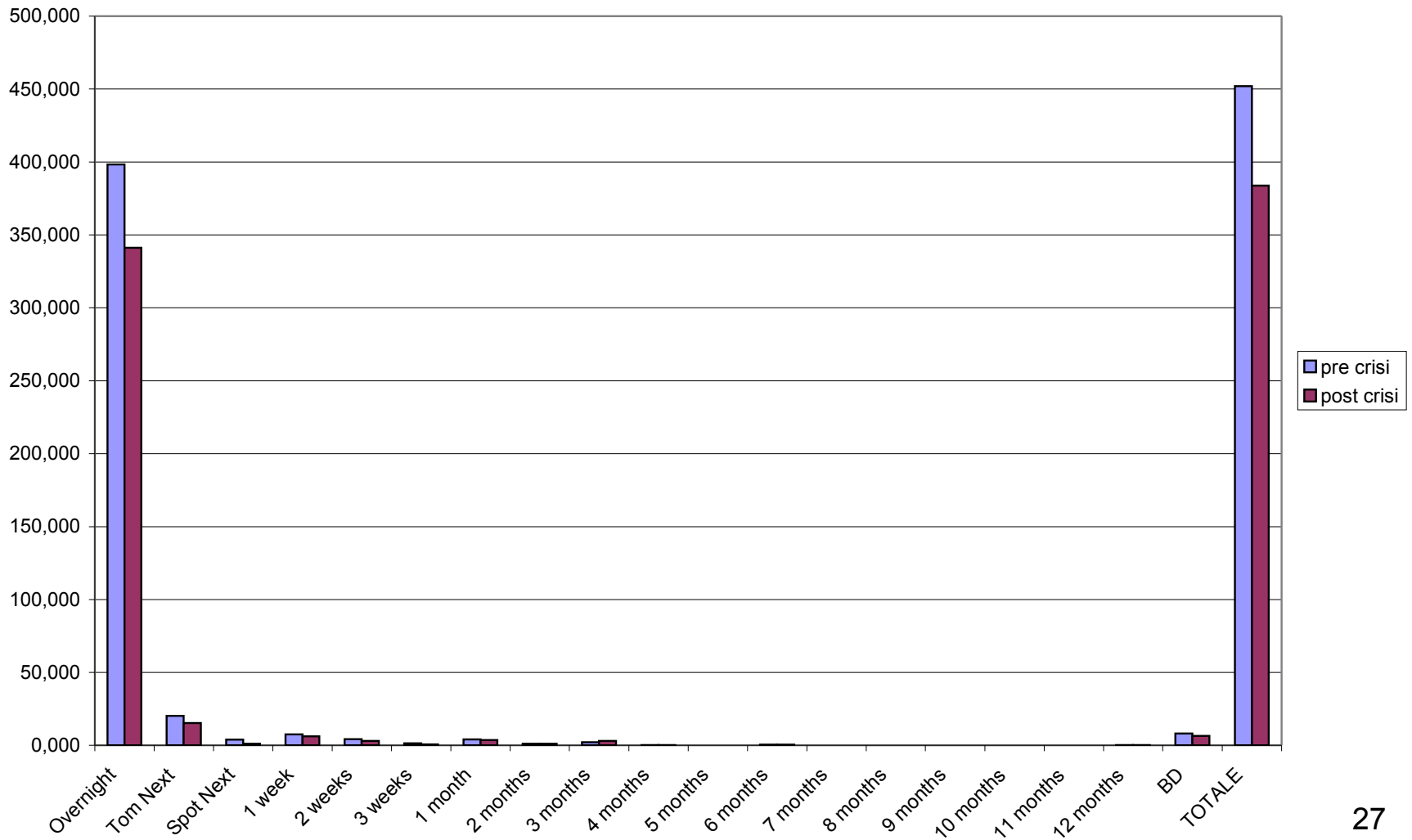
VOLUME ARE MEASURED IN EUROS

Interbank Contract	Total Volume	No. Transactions	No. Transactions per day	Volume per transaction
Overnight	907.182.856.000	162866	398,205	5.570.118
Tom Next	41.392.960.000	8254	20,181	5.014.897
Spot Next	8.129.453.000	1582	3,868	5.138.719
1 week	10.138.835.000	3055	7,469	3.318.768
2 weeks	6.576.936.000	1716	4,196	3.832.713
3 weeks	2.102.563.000	618	1,511	3.402.206
1 month	4.451.632.000	1681	4,110	2.648.205
2 months	1.475.952.000	457	1,117	3.229.654
3 months	2.637.134.000	889	2,174	2.966.405
4 months	109.140.000	55	0,134	1.984.364
5 months	94.670.000	30	0,073	3.155.667
6 months	678.848.000	228	0,557	2.977.404
7 months	26.018.000	6	0,015	4.336.333
8 months	1.150.000	4	0,010	287.500
9 months	48.350.000	15	0,037	3.223.333
10 months	2.600.000	4	0,010	650.000
11 months	1.000.000	1	0,002	1.000.000
12 months	113.325.000	59	0,144	1.920.763
BD	23.284.992.000	3319	8,115	7.015.665
TOTALE	1.008.448.414.000	184.839	451,929	5.455.821

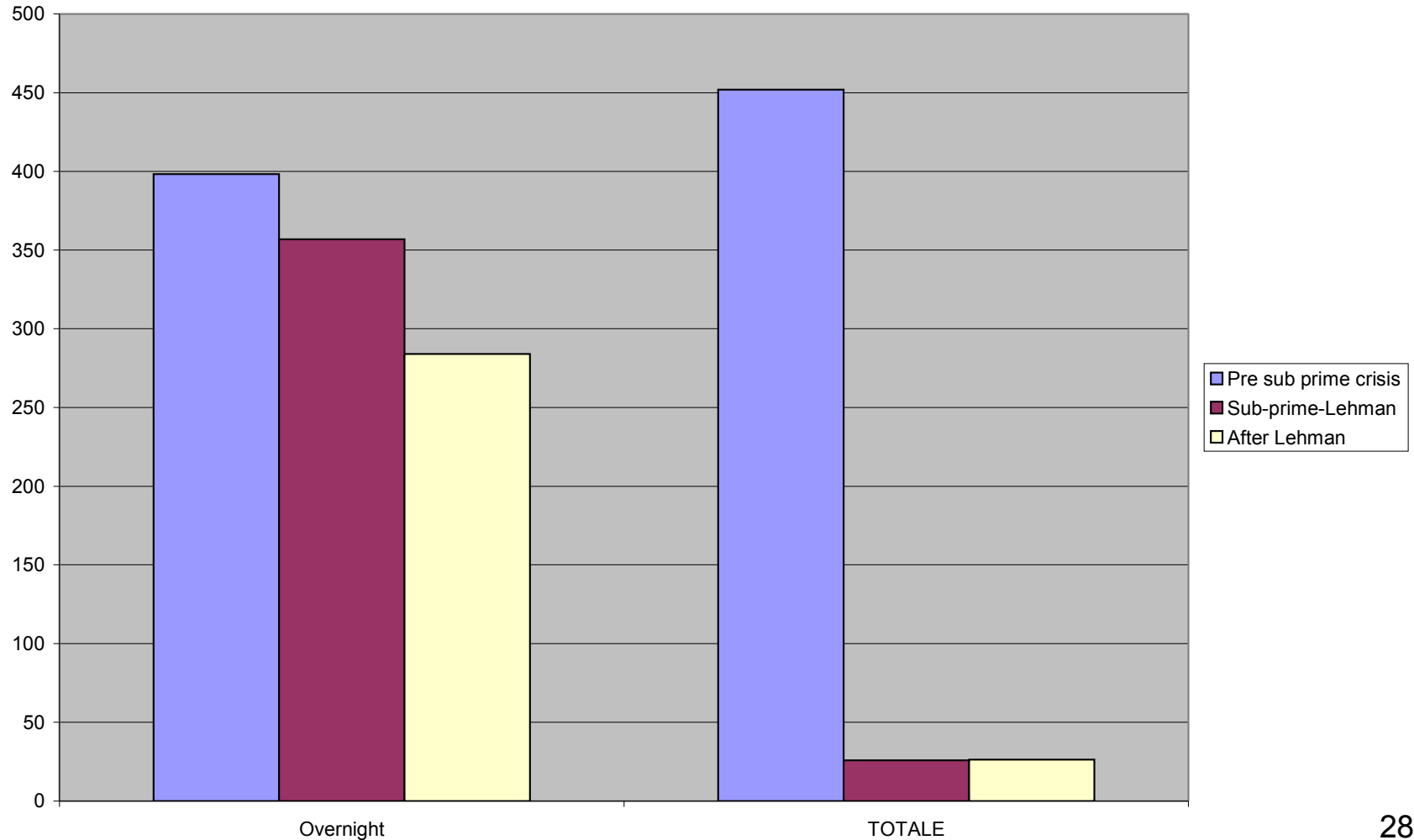
Volume and trades by contract (post crisis)

CONTRACT	TOTAL VOLUME	NO. TRANSACTIONS	NO. TRANSACTIONS PER DAY	VOLUME PER TRANSACTIONS
OVERNIGHT	466.588.549.000	121850	341,317	3.829.204
TOM NEXT	21.456.625.000	5478	15,345	3.916.872
SPOT NEXT	2.035.960.000	432	1,210	4.712.870
1 WEEK	9.686.965.000	2191	6,137	4.421.253
2 WEEKS	4.582.070.000	1098	3,076	4.173.106
3 WEEKS	799.250.000	226	0,633	3.536.504
1 MONTH	3.717.109.000	1293	3,622	2.874.794
2 MONTHS	959.290.000	397	1,112	2.416.348
3 MONTHS	2.325.371.000	1090	3,053	2.133.368
4 MONTHS	179.200.000	53	0,148	3.381.132
5 MONTHS	89.400.000	24	0,067	3.725.000
6 MONTHS	373.952.000	166	0,465	2.252.723
7 MONTHS	6.500.000	3	0,008	2.166.667
8 MONTHS	0	0	0,000	0
9 MONTHS	11.260.000	3	0,008	3.753.333
10 MONTHS	4.000.000	1	0,003	4.000.000
11 MONTHS	0	0	0,000	0
12 MONTHS	113.230.000	39	0,109	2.903.333
BD	11.935.110.000	2667	6,521	4.475.107
TOTALE	524.863.841.000	137.011	383,784	3.830.815

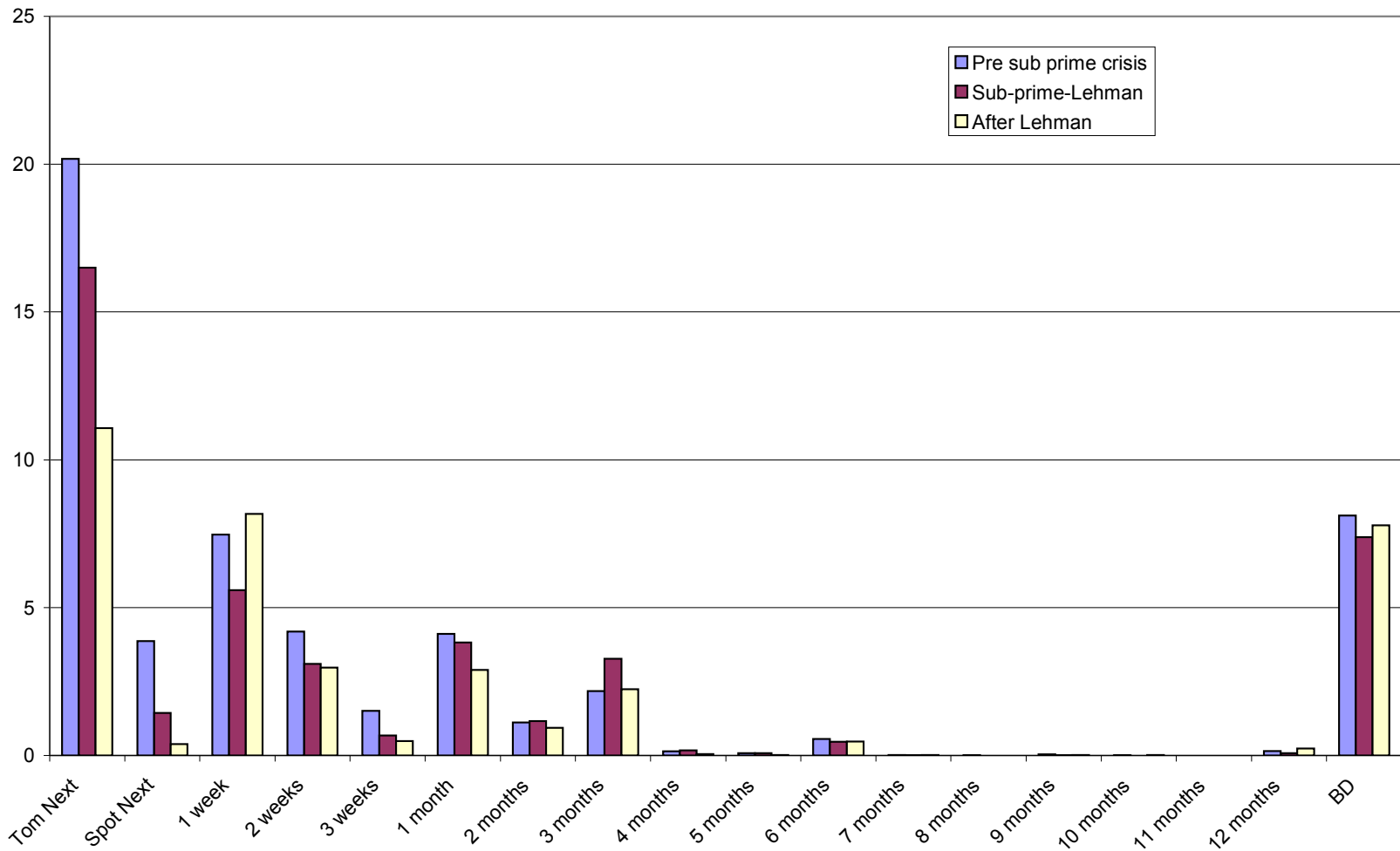
Daily transactions by contract



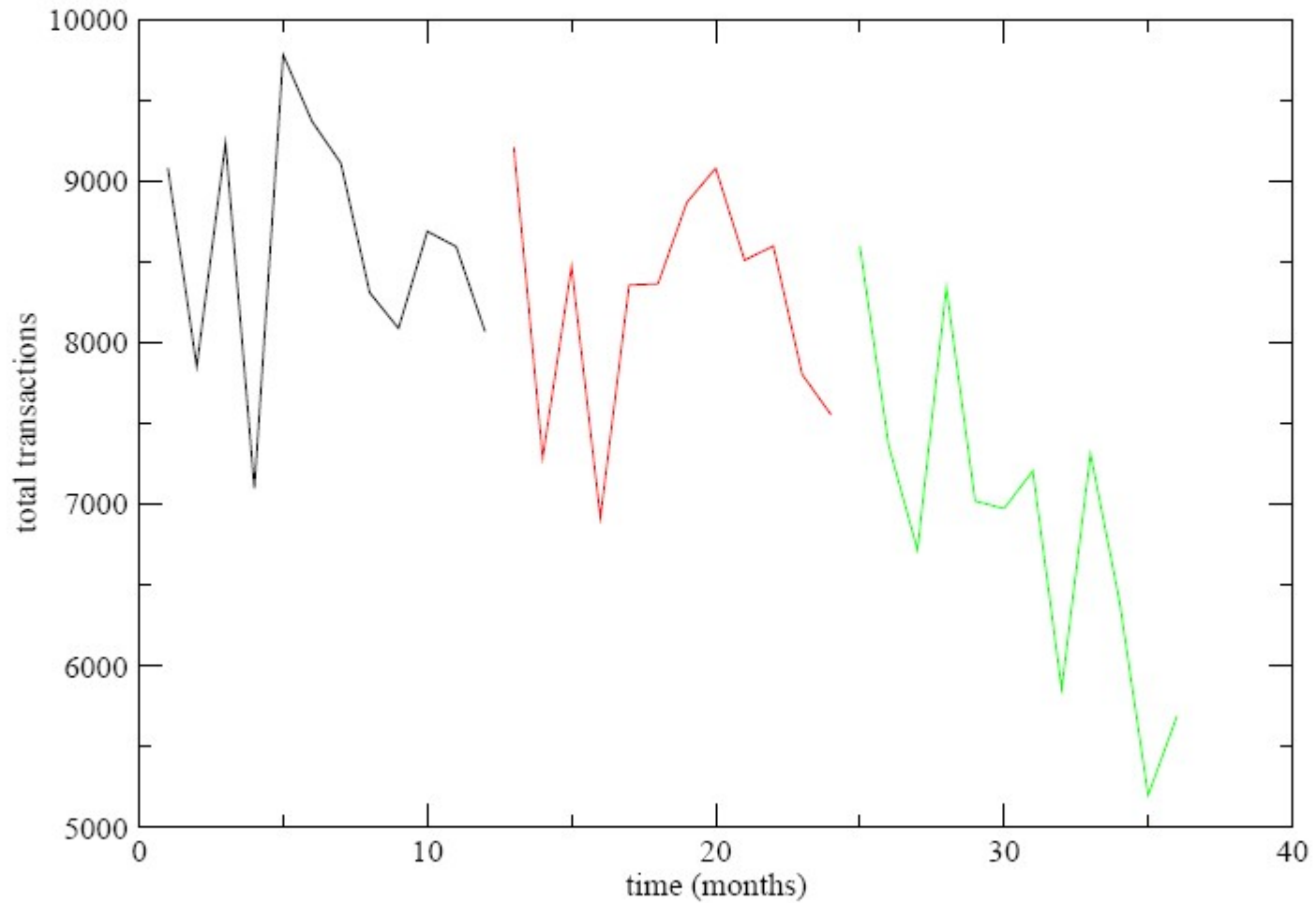
Daily transactions by contract



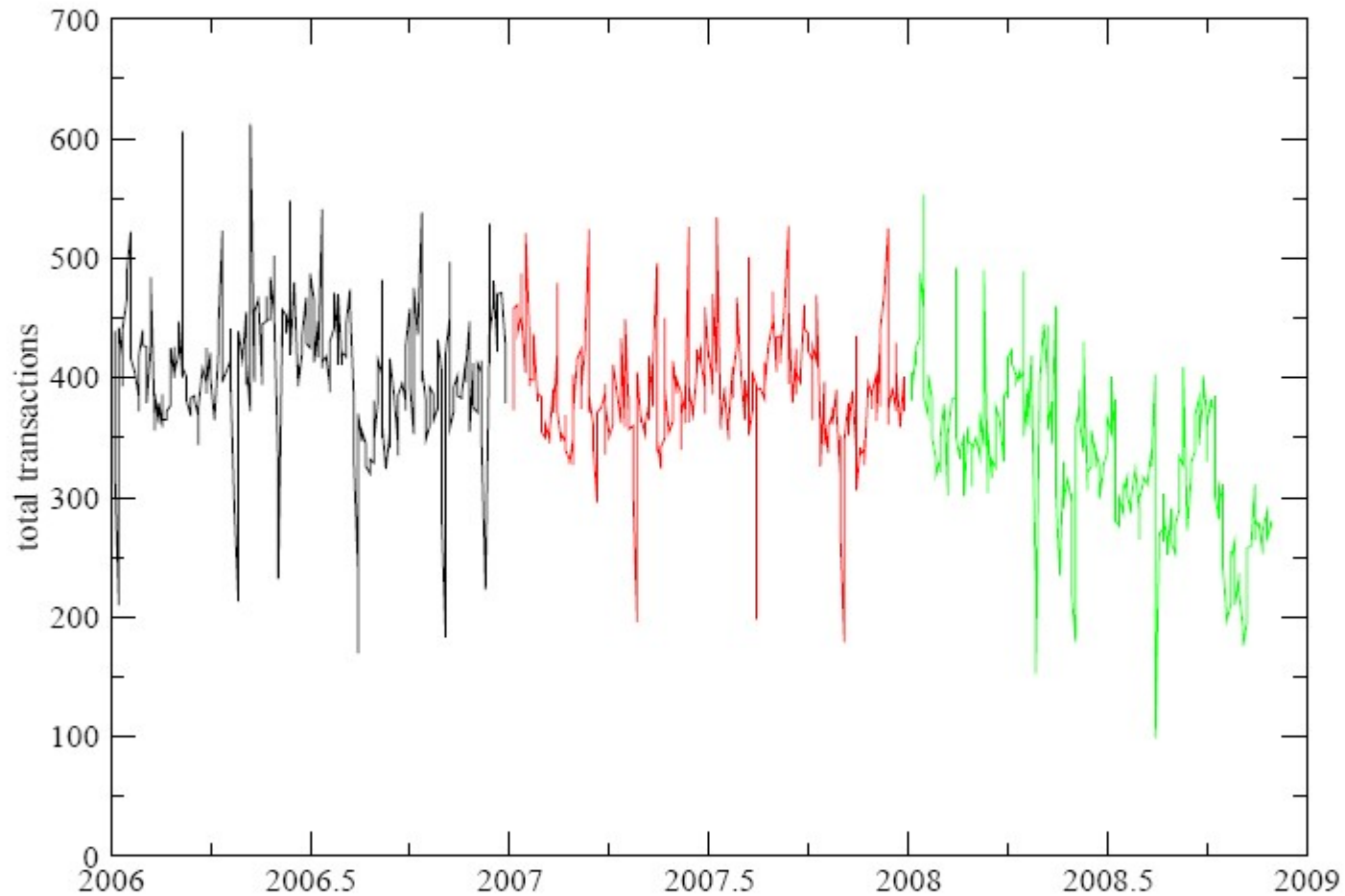
Daily transactions by contract



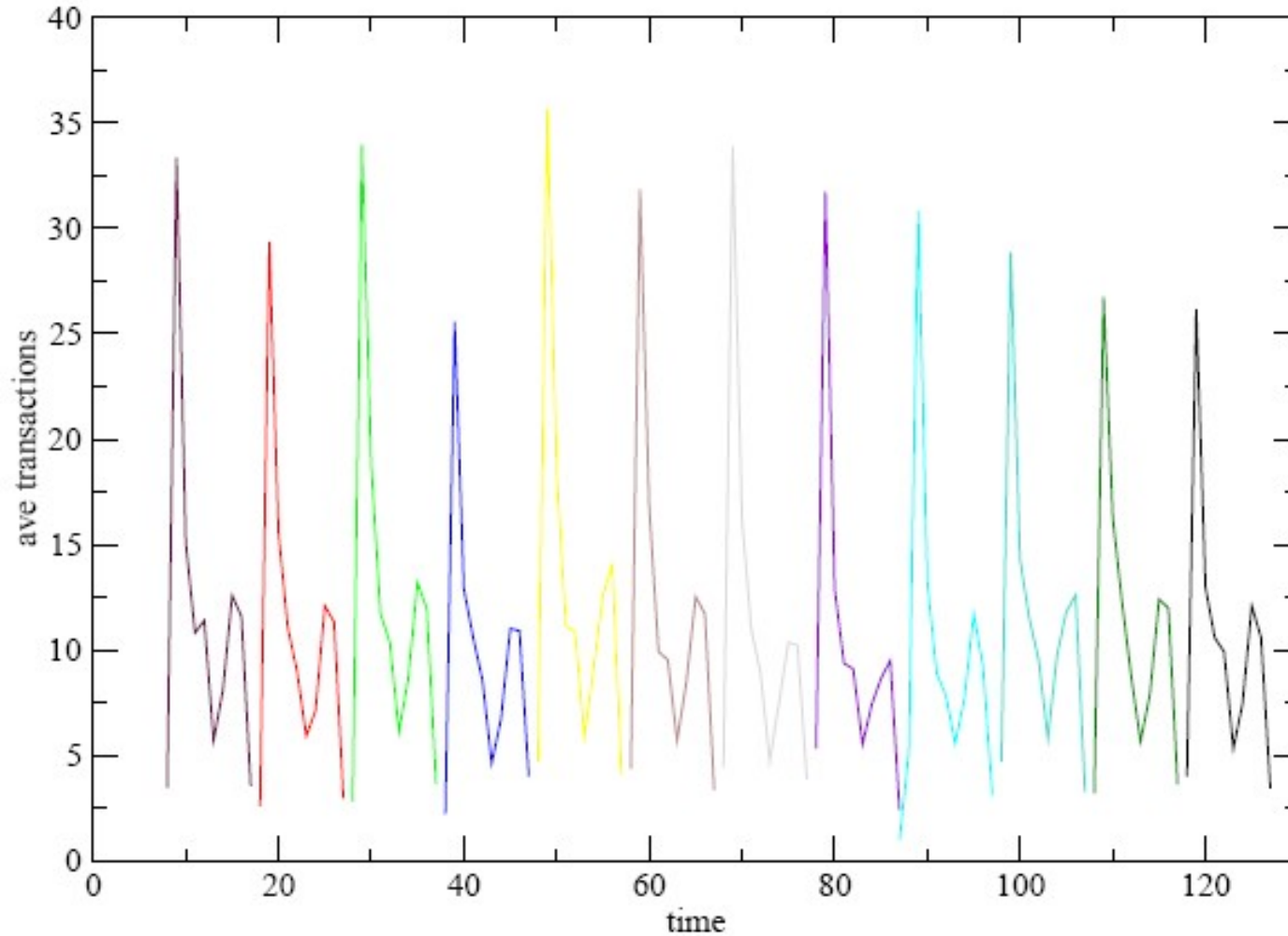
Monthly transactions 2006 - 2008



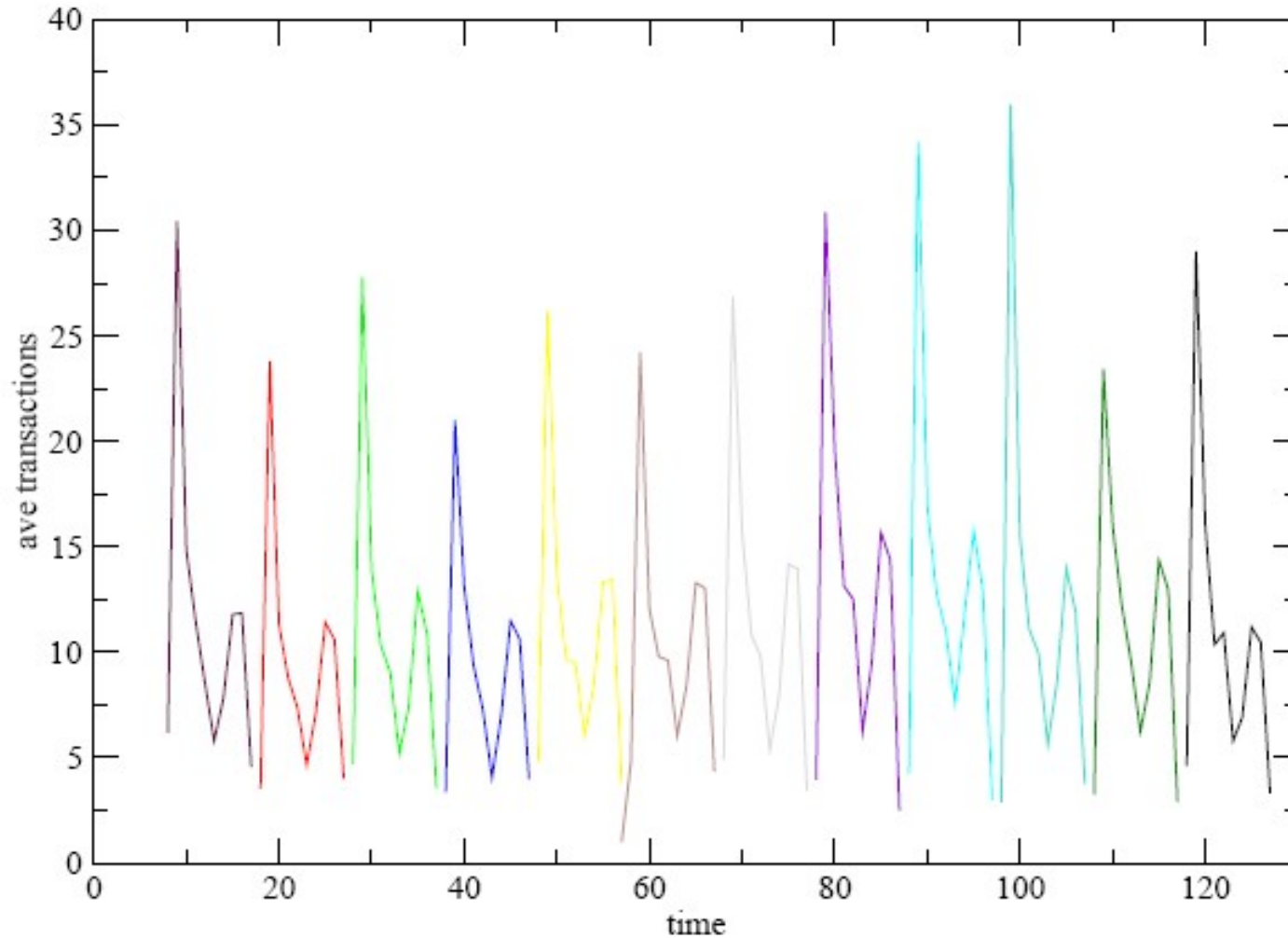
Daily transactions 2006 - 2008



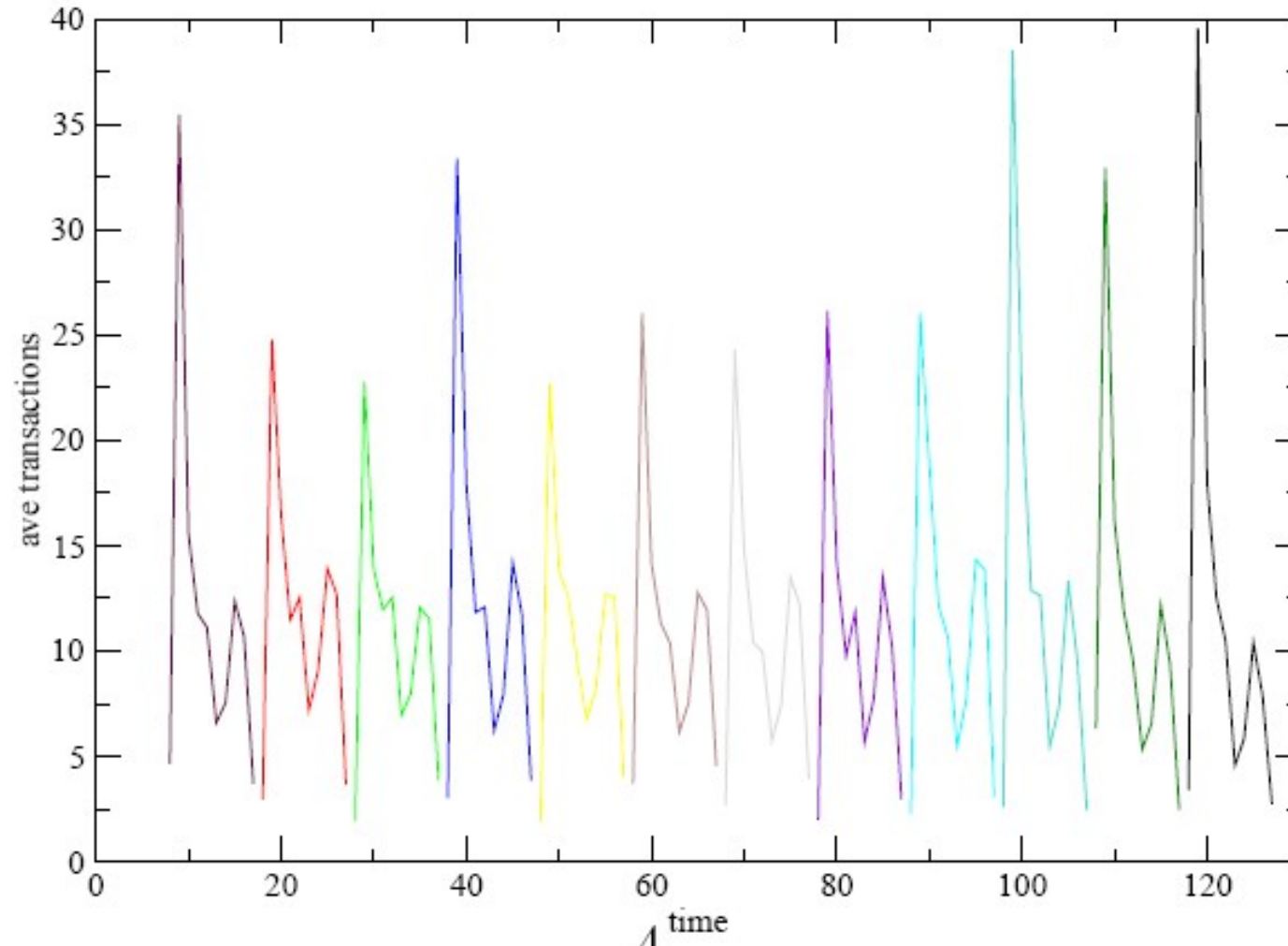
Average sell transactions per active bank (2006)



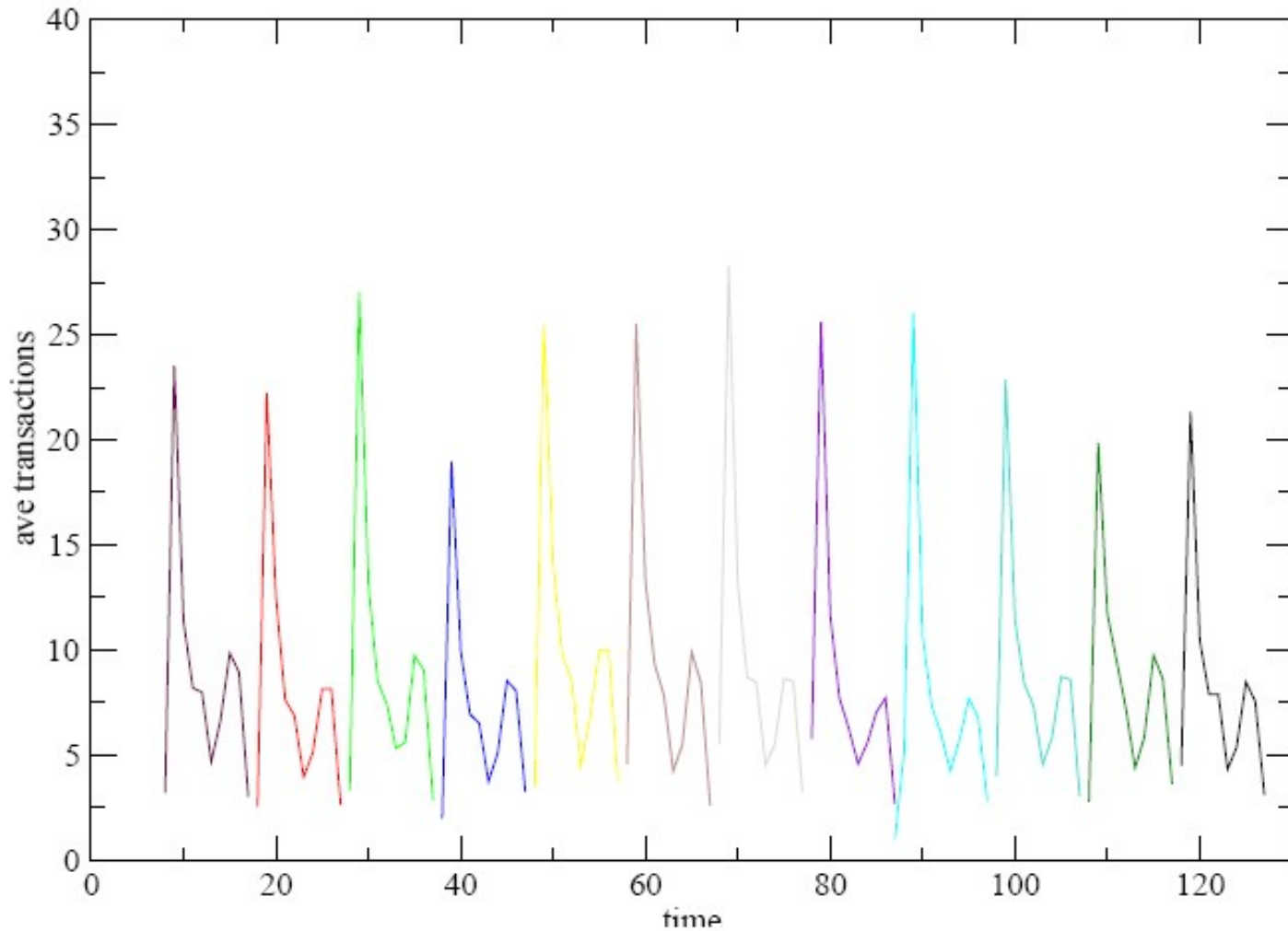
Average sell transactions per active bank (2007)



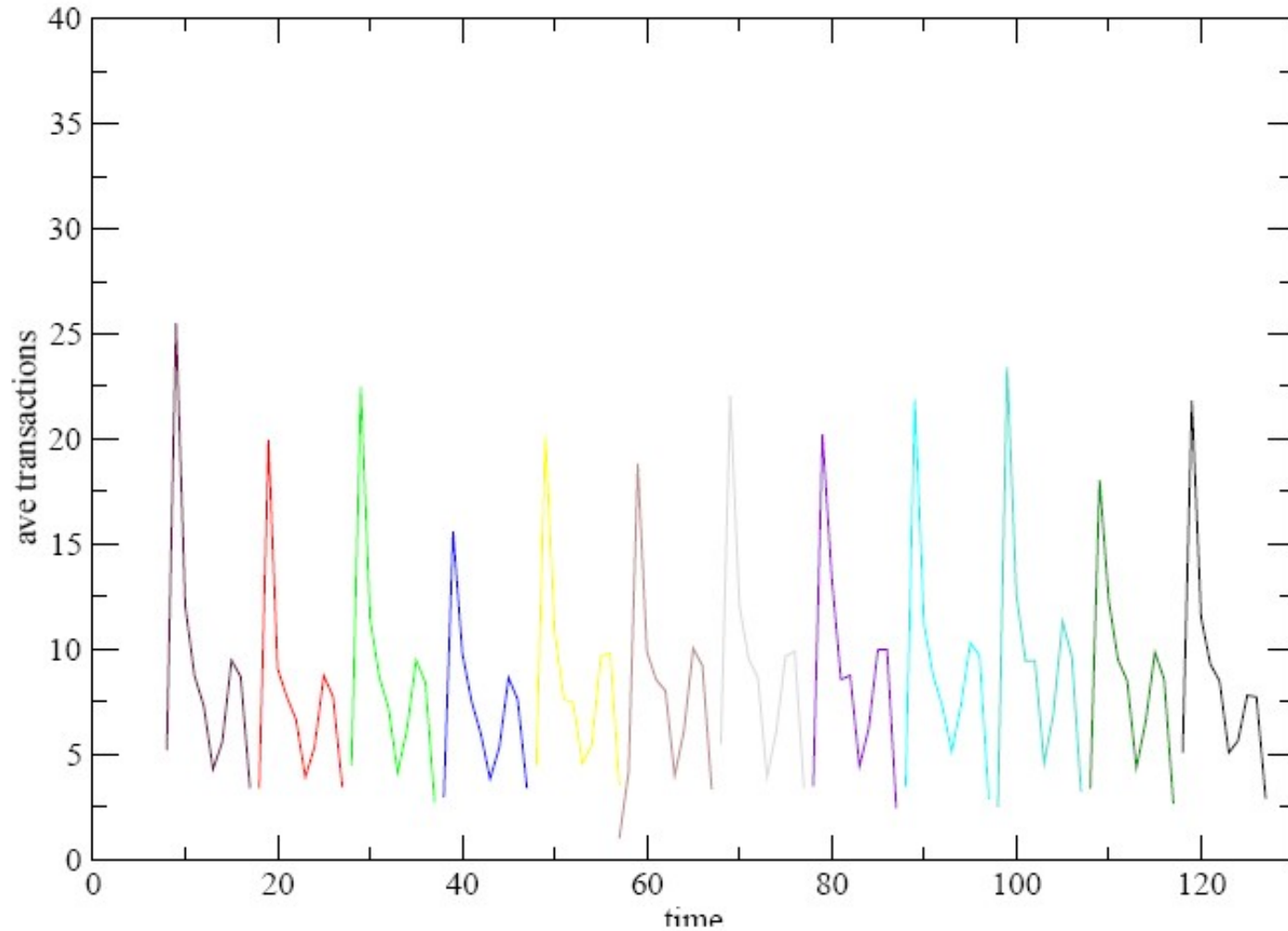
Average sell transactions per active bank (2008)



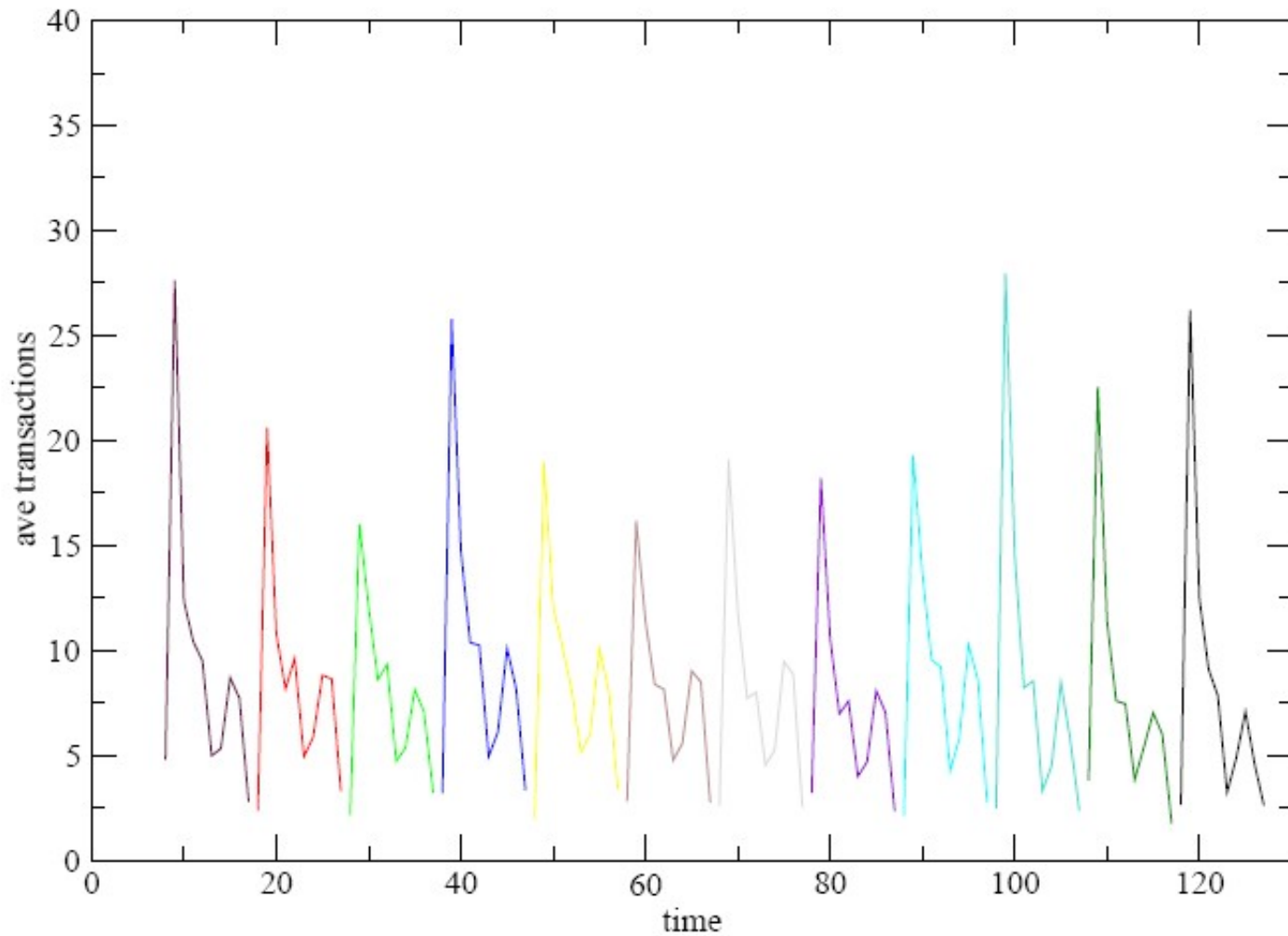
Average buy transactions per active bank (2006)



Average buy transactions per active bank (2007)



Average buy transactions per active bank (2008)



Volumes (1999 – 2002): previous study

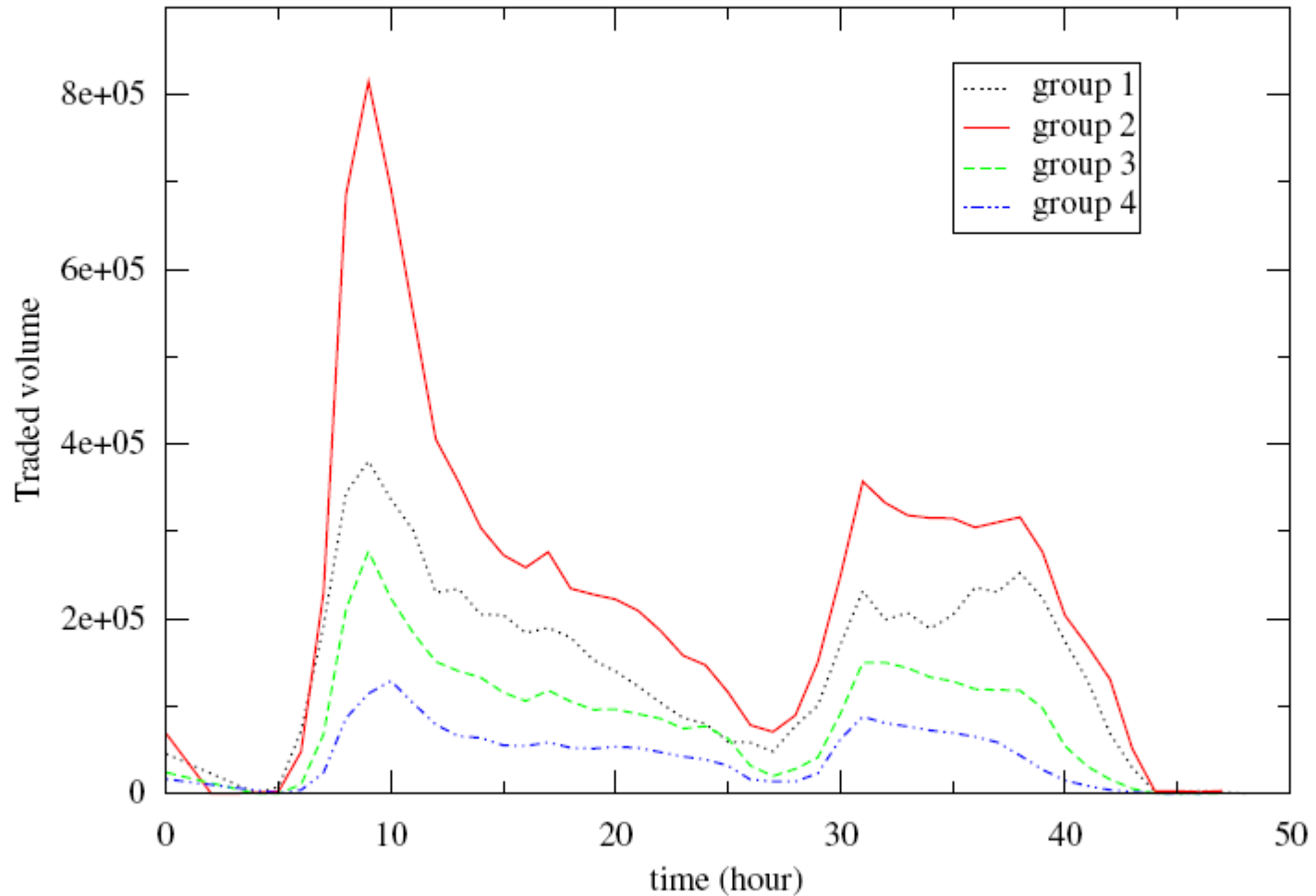
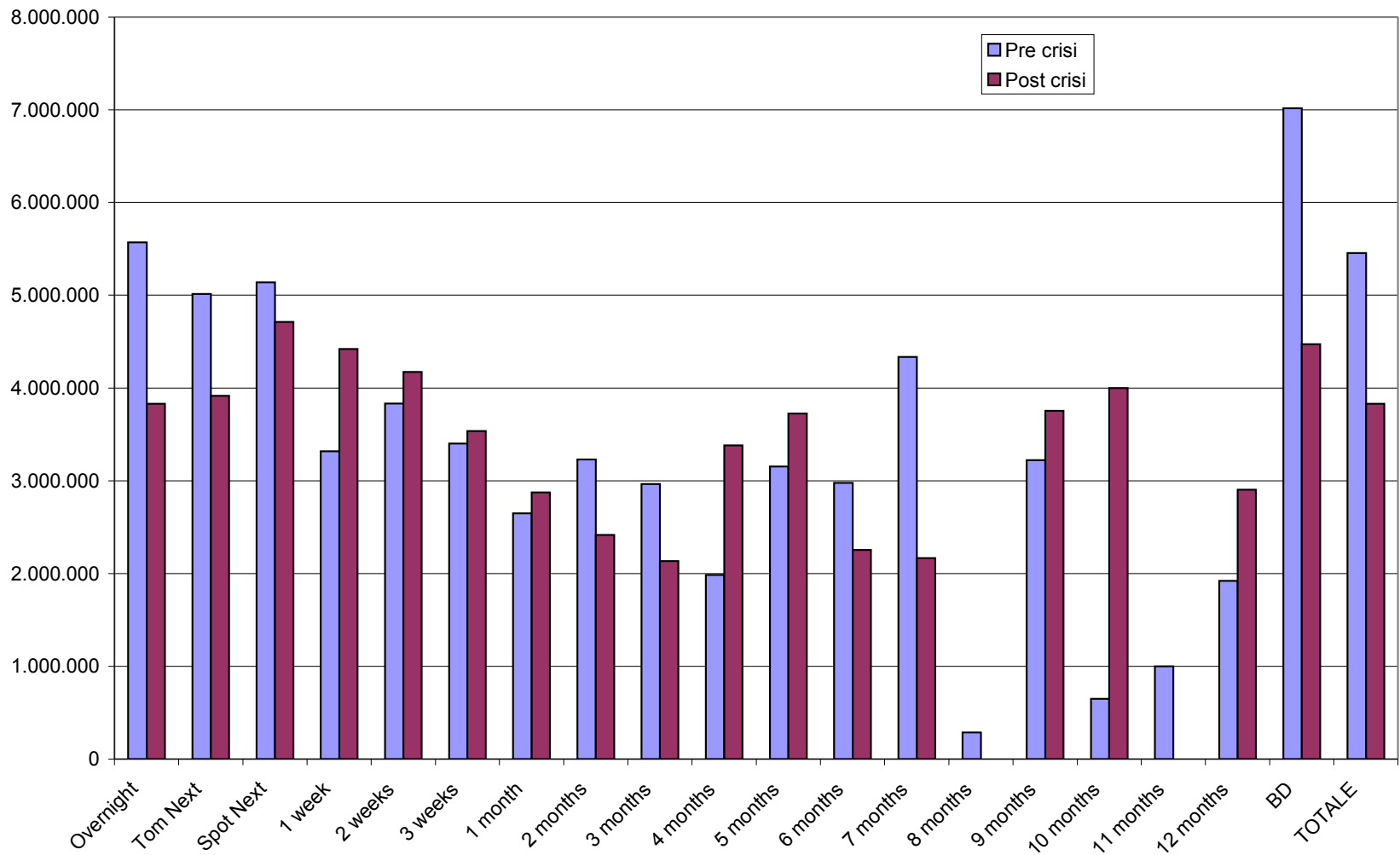


Fig. 2. Average intra-day pattern per group of banks, over the period 1999–2002; group 1 (black-dotted), group 2 (red-solid), group 3 (green-dashed), group 4 (blue-dotdashed).

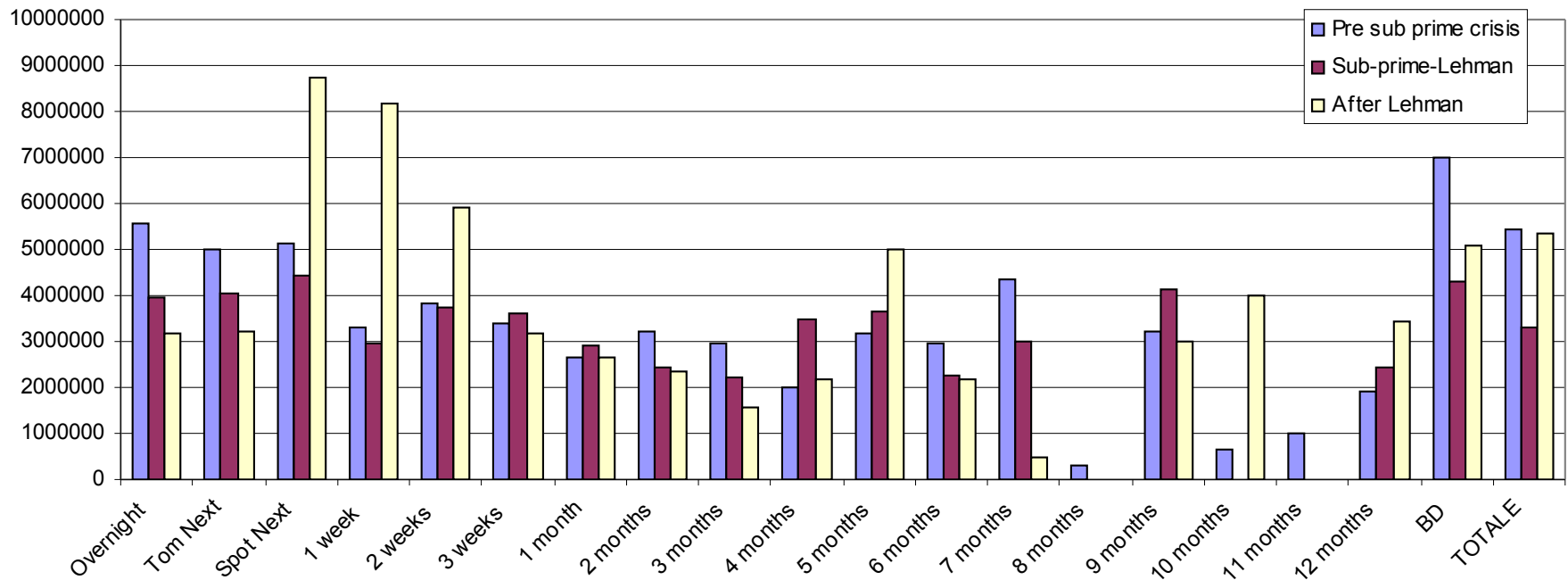
Daily volumes by contract

Pre and post sub prime

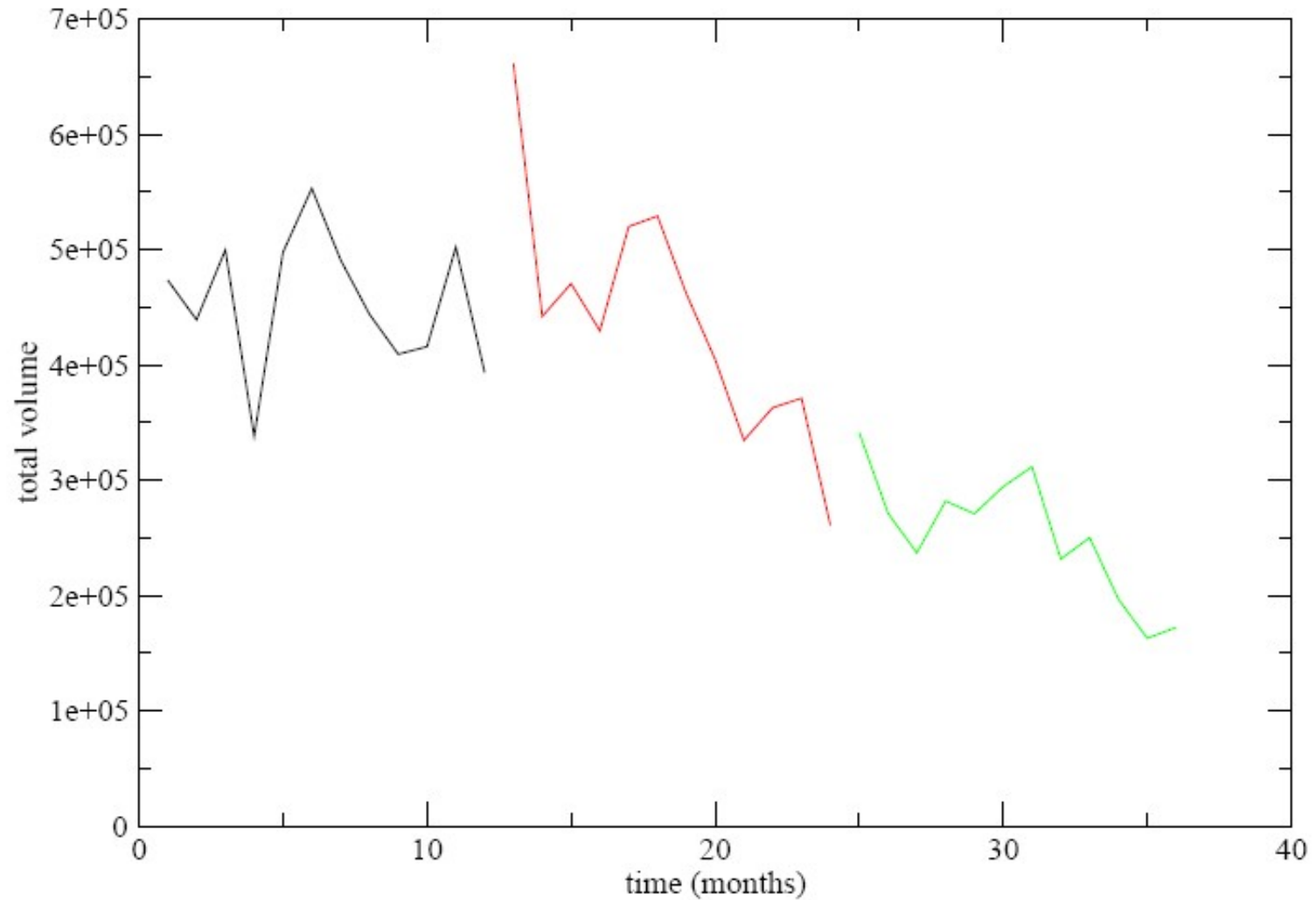


Daily volume by contract

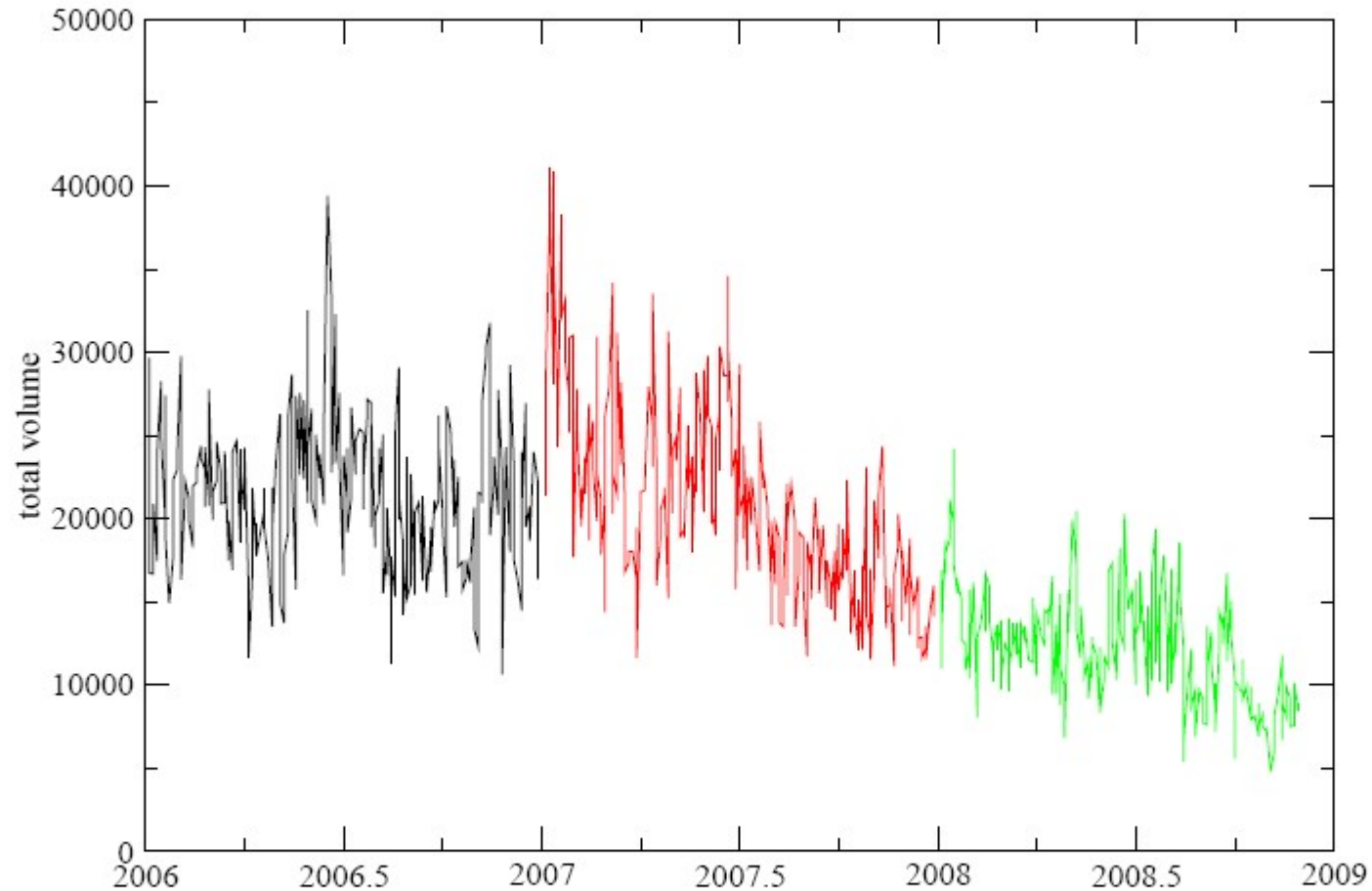
Pre, post sub prime and after Lehman



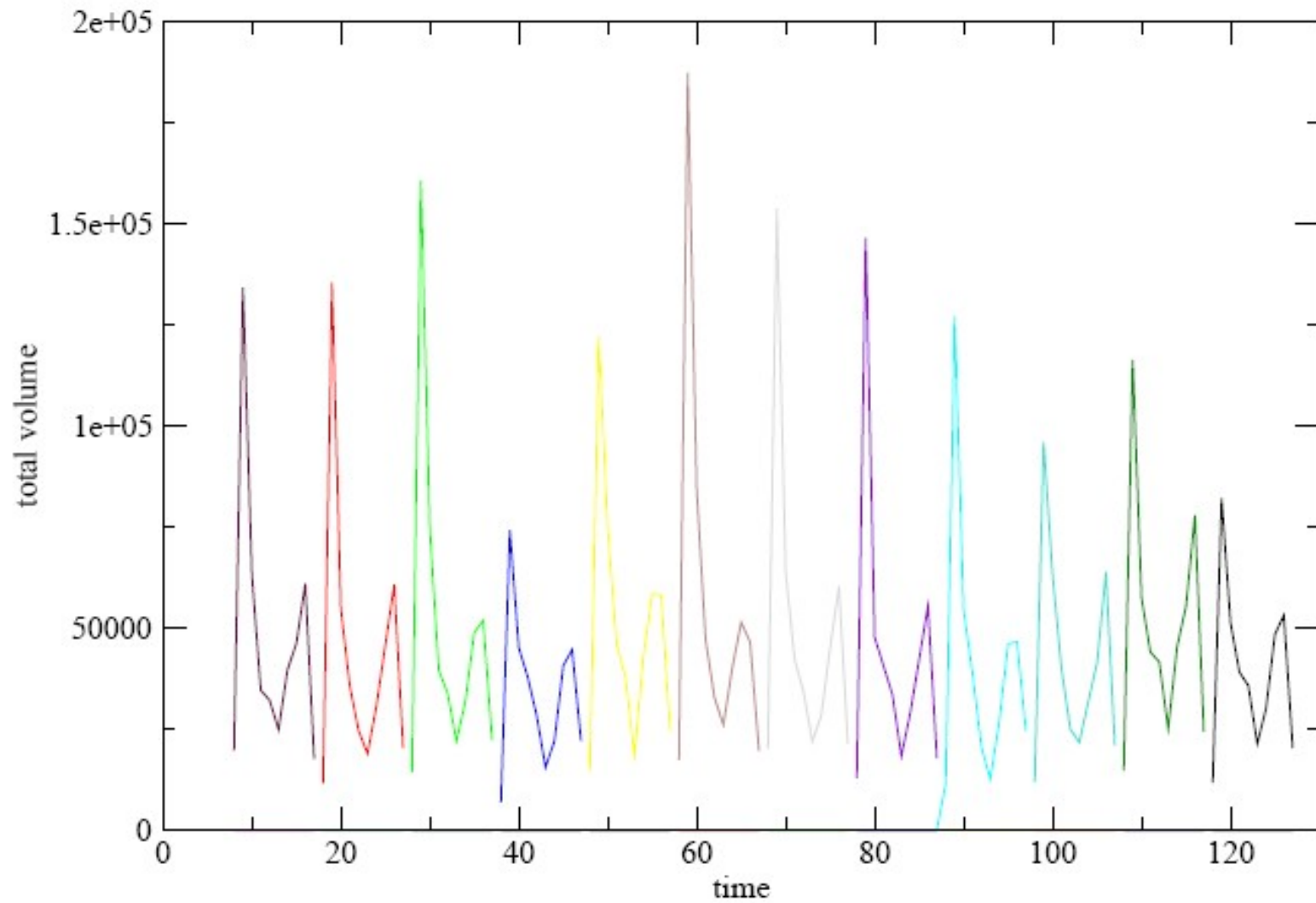
Volume of monthly transactions 2006 - 2008



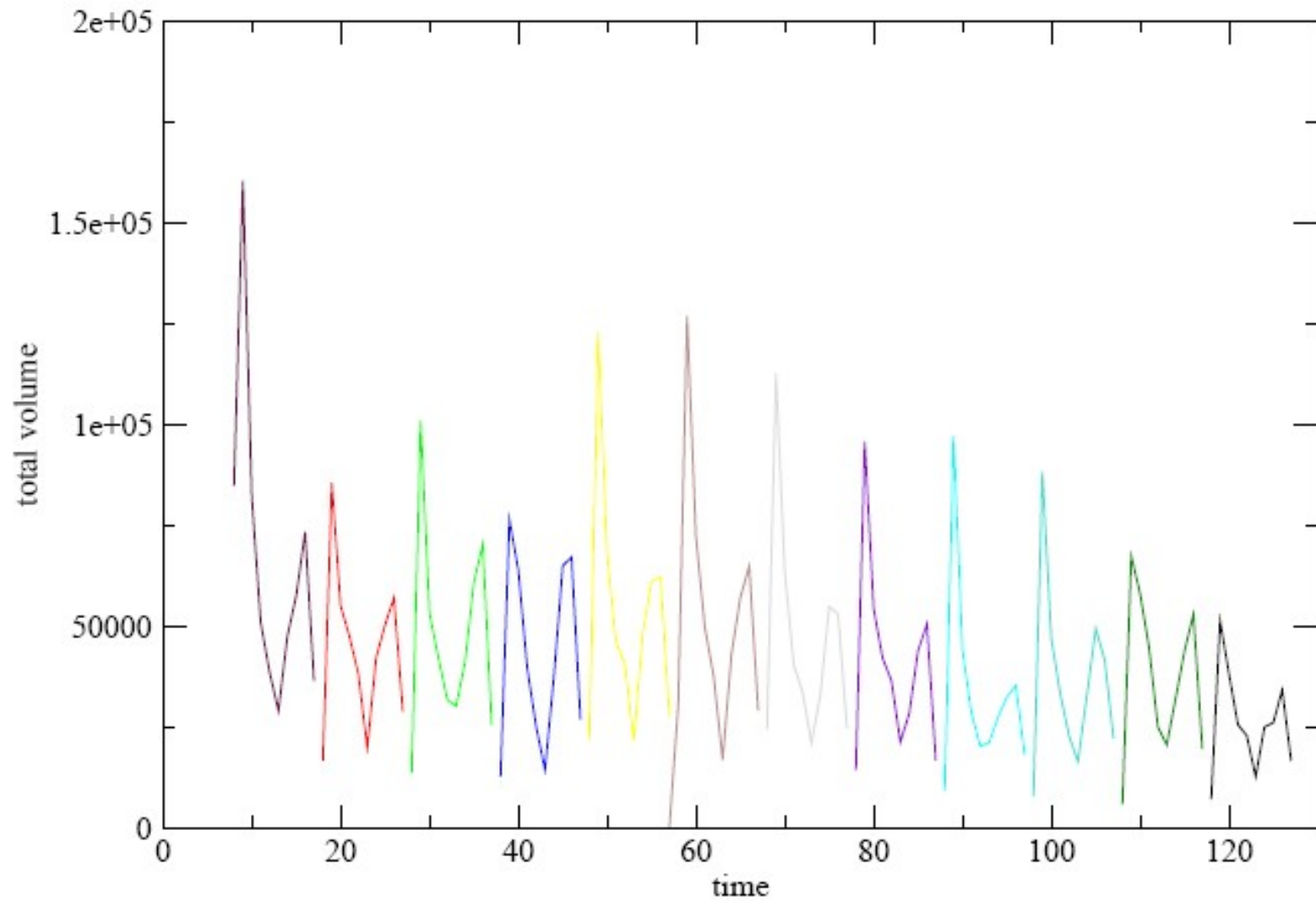
Volume of daily transactions 2006 - 2008



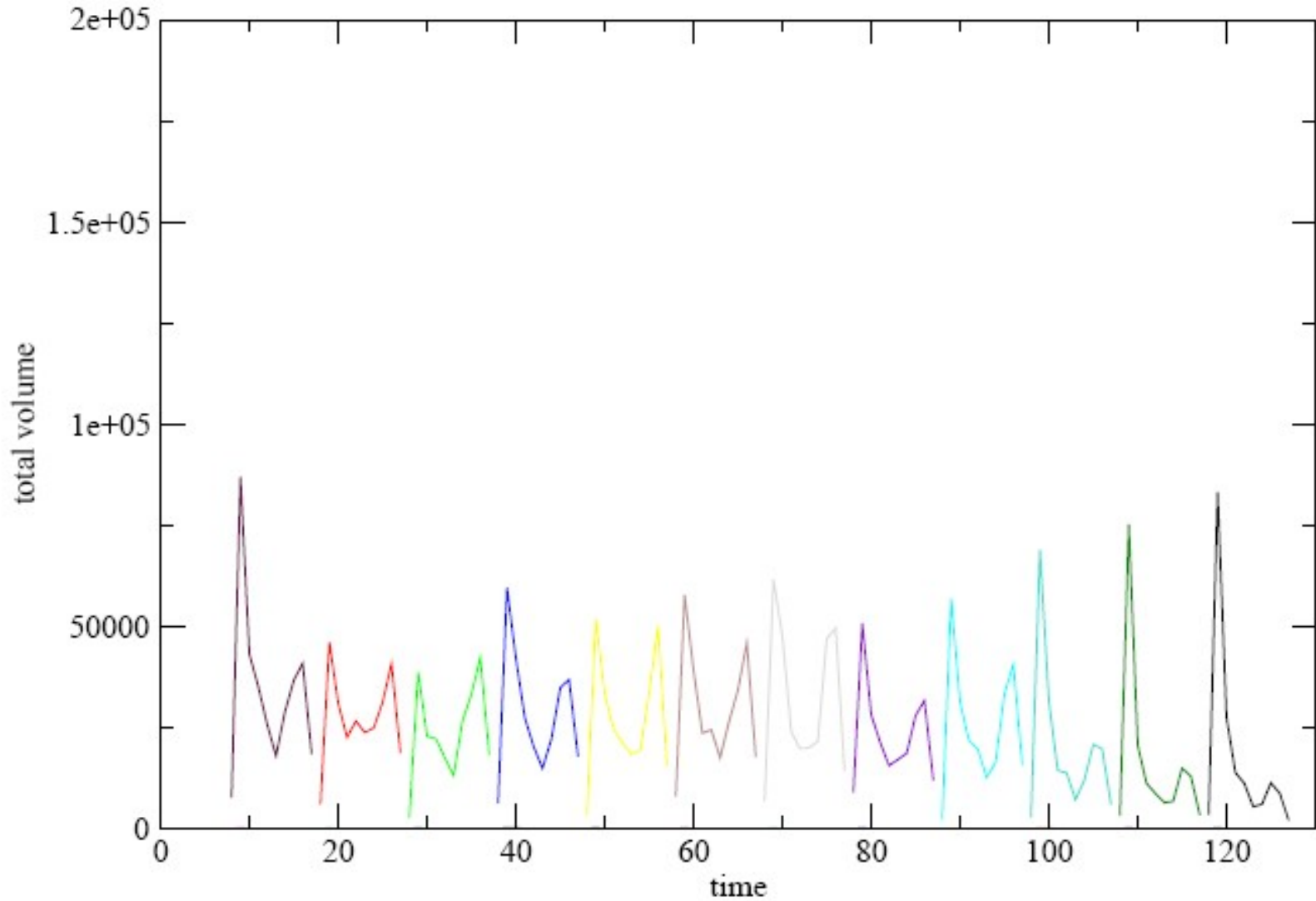
Intra-day volume of transactions 2006



Intra-day volume of transactions 2007



Intra-day volume of transactions 2008



Findings question no. 1

- Intra day interest rates dramatically changed their pattern since March 2007
- Their behaviour returned to the pre sub prime situation after the ECB intervention and, above all, the confidence of a public collateral for interbank positions after Lehman
- Interest rate volatility (daily and hourly) was extremely high since spring 2007
- Daily transactions dropped after the first crisis, particularly in the O/N contract. Only 3 months increased. Lehman crisis affected a more significant decrease in transactions
- Daily volumes per trade decreased especially in the short maturities. Banks showed a preference for long deposits
- On balance, volumes began to collapse in spring 2007
- In conclusion, the structure of the interbank market was significantly affected by the crisis, both in amounts and volatilities; some signals of turbulence could be found some months before the crisis

Research question no. 2

Did the structure of selling and buying banks changed?

Selling and buying players behaviour

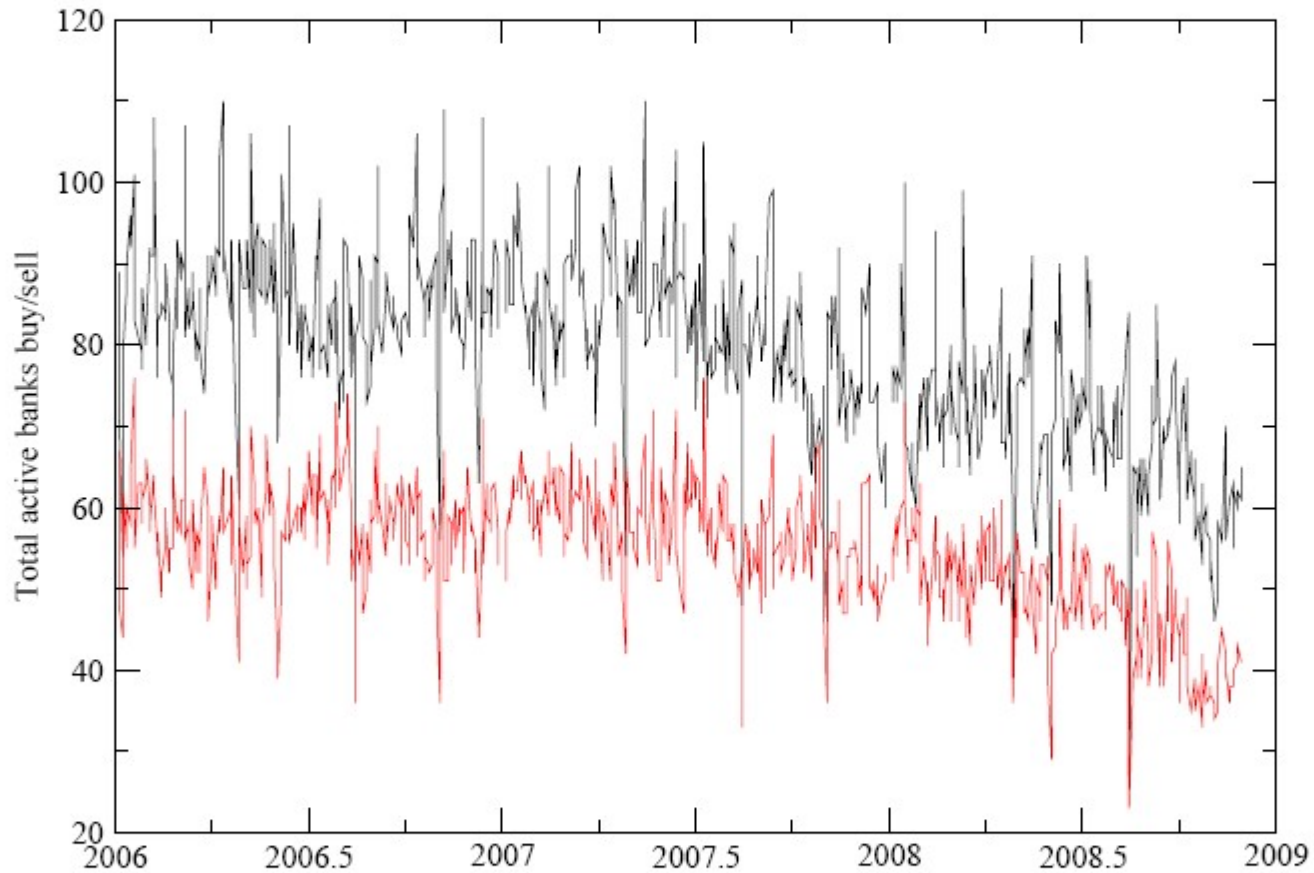
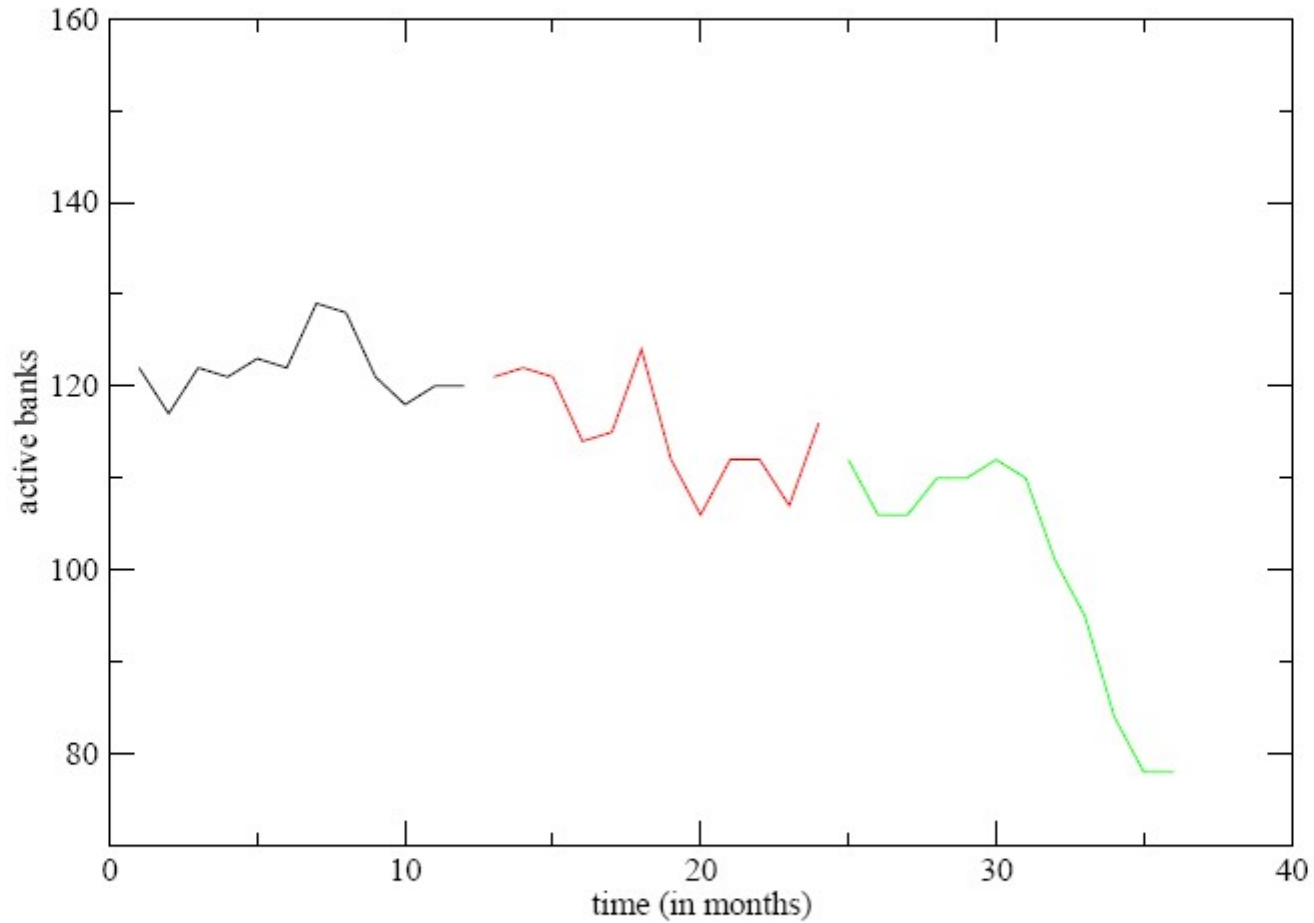


Figure 5: Number of active buy banks (black) and sell banks (red).

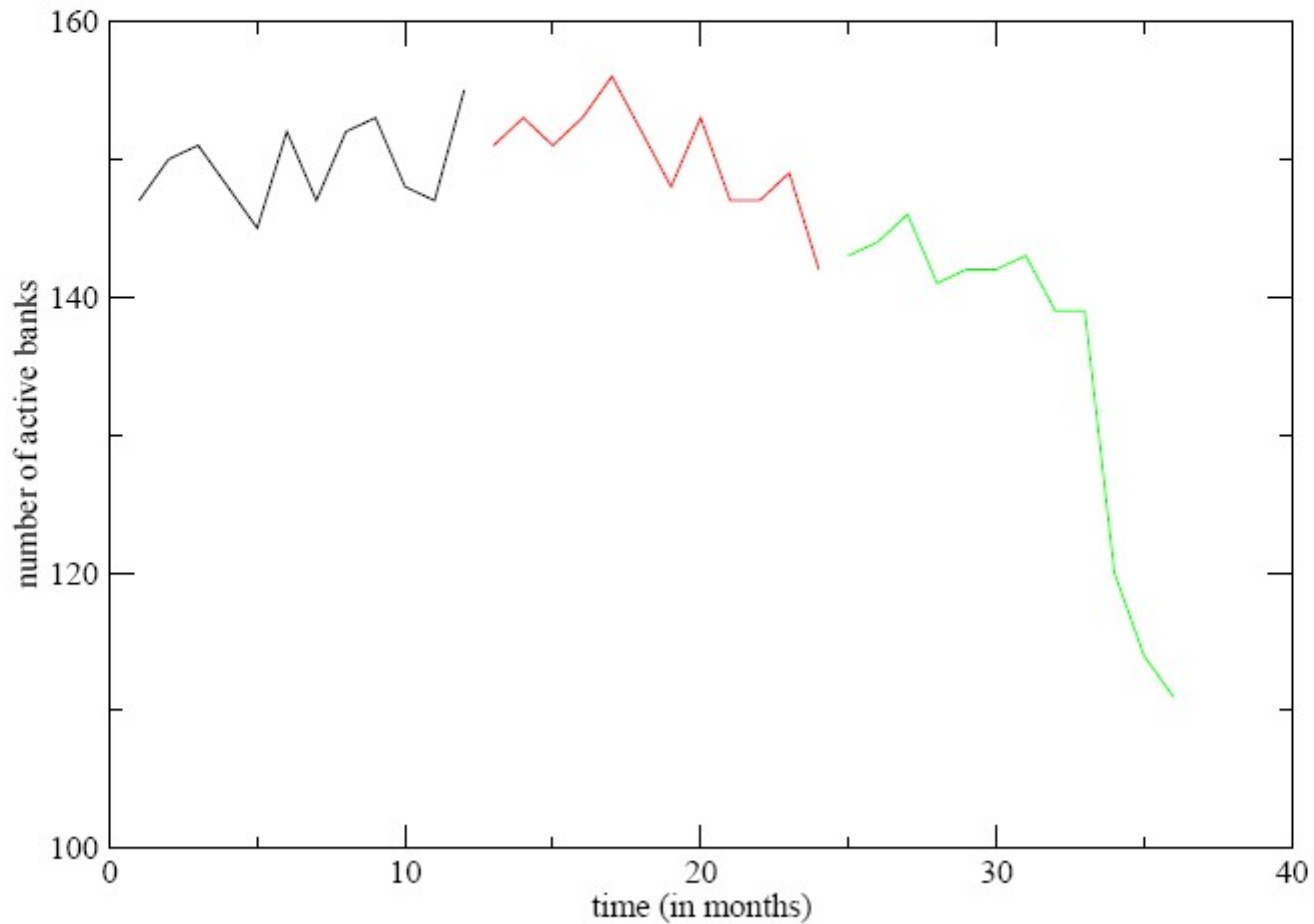
Selling players behaviour

Number of active sell banks in 2006, 2007, 2008, aggregated over a month

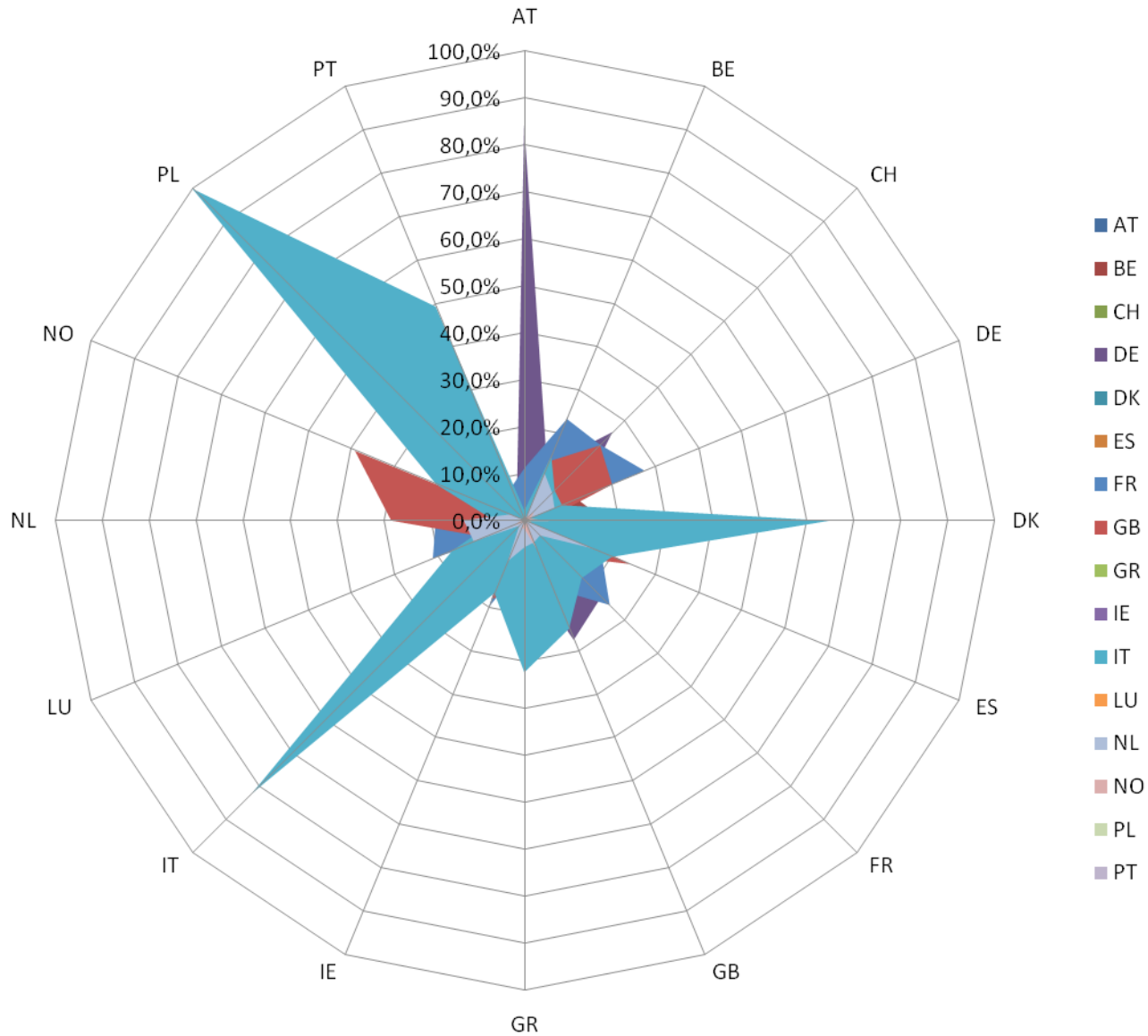


Buying players behaviour

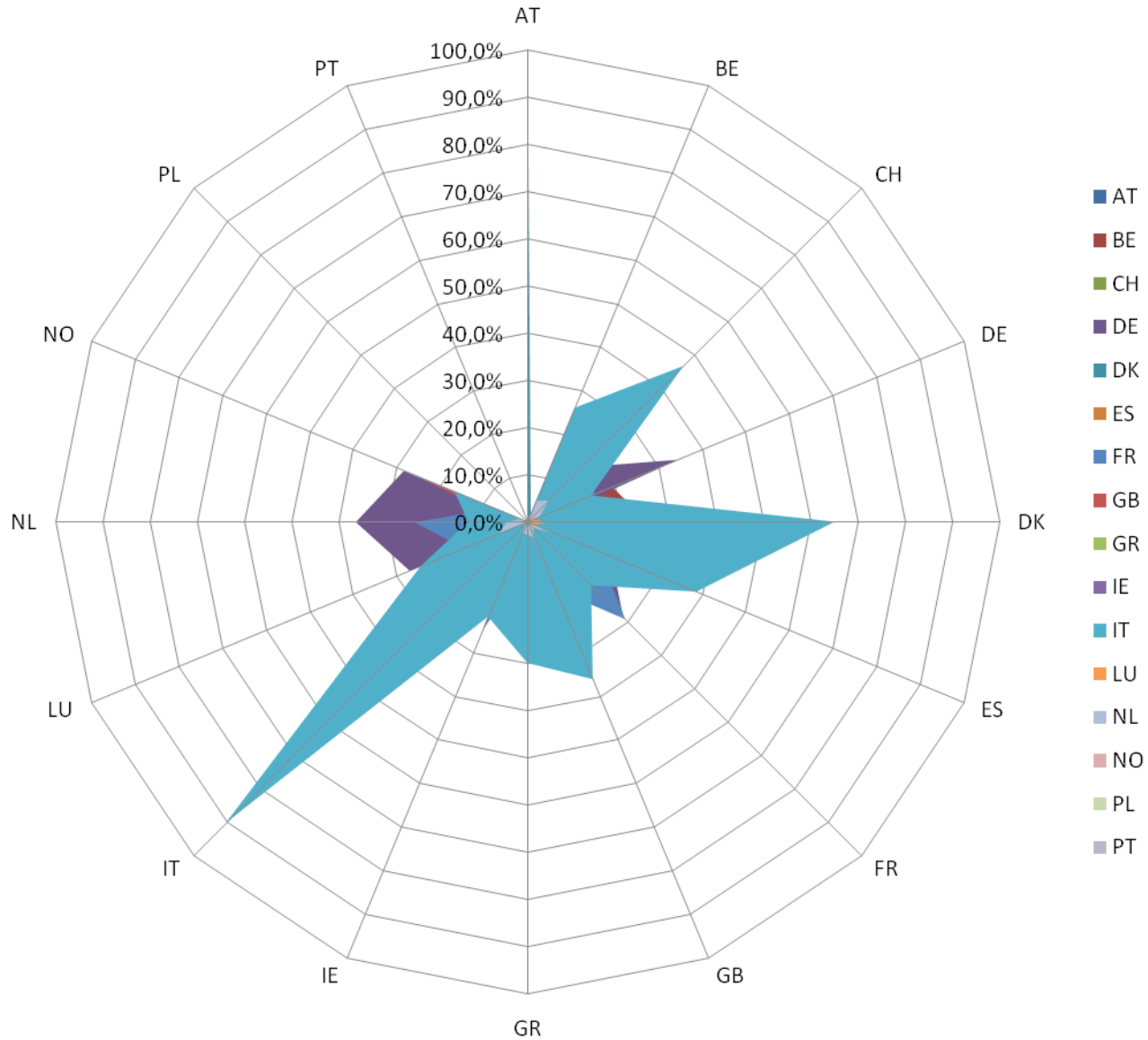
Number of active buy banks in 2006, 2007, 2008,
aggregated over a month



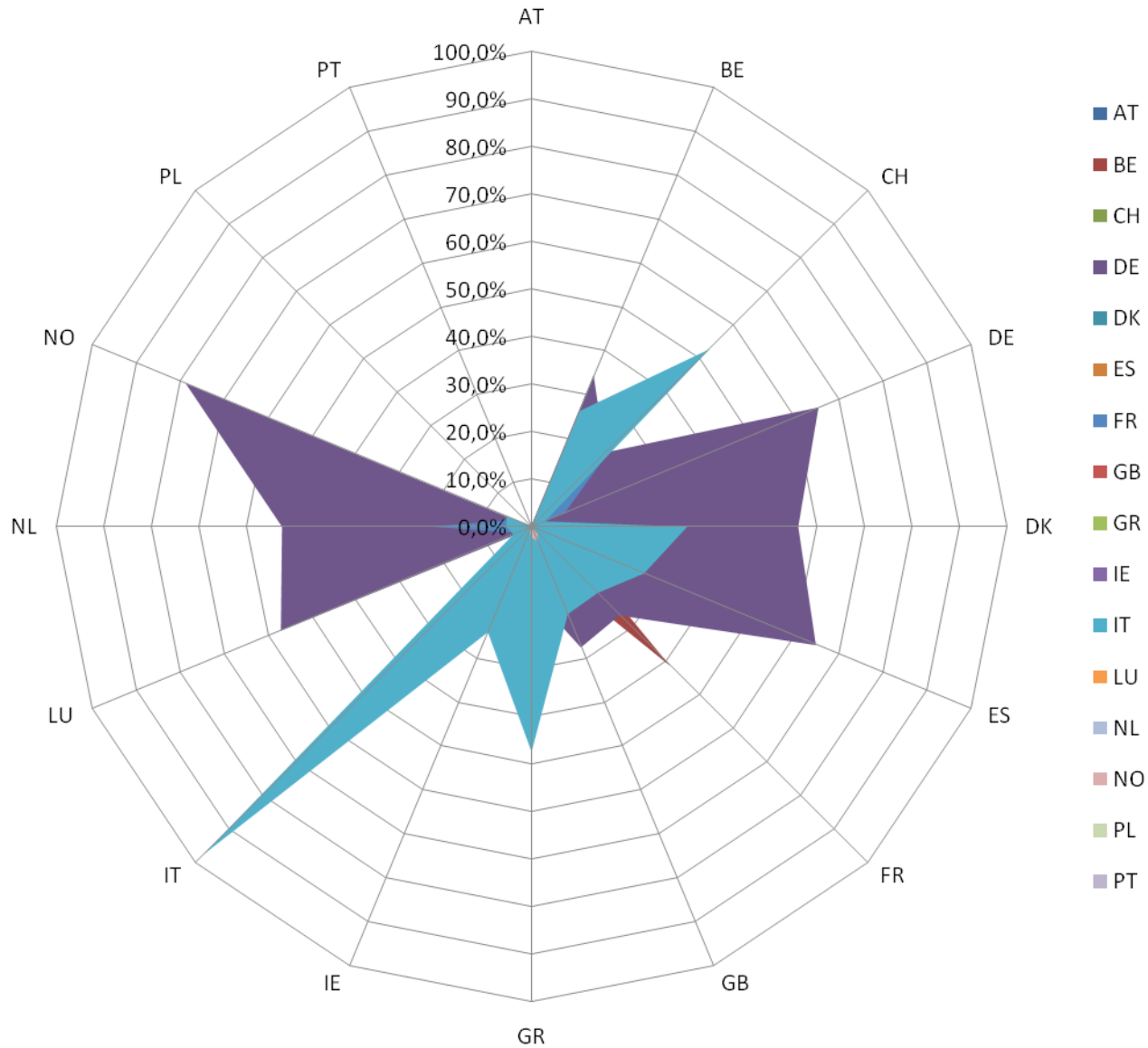
Ordering banks (PRE)



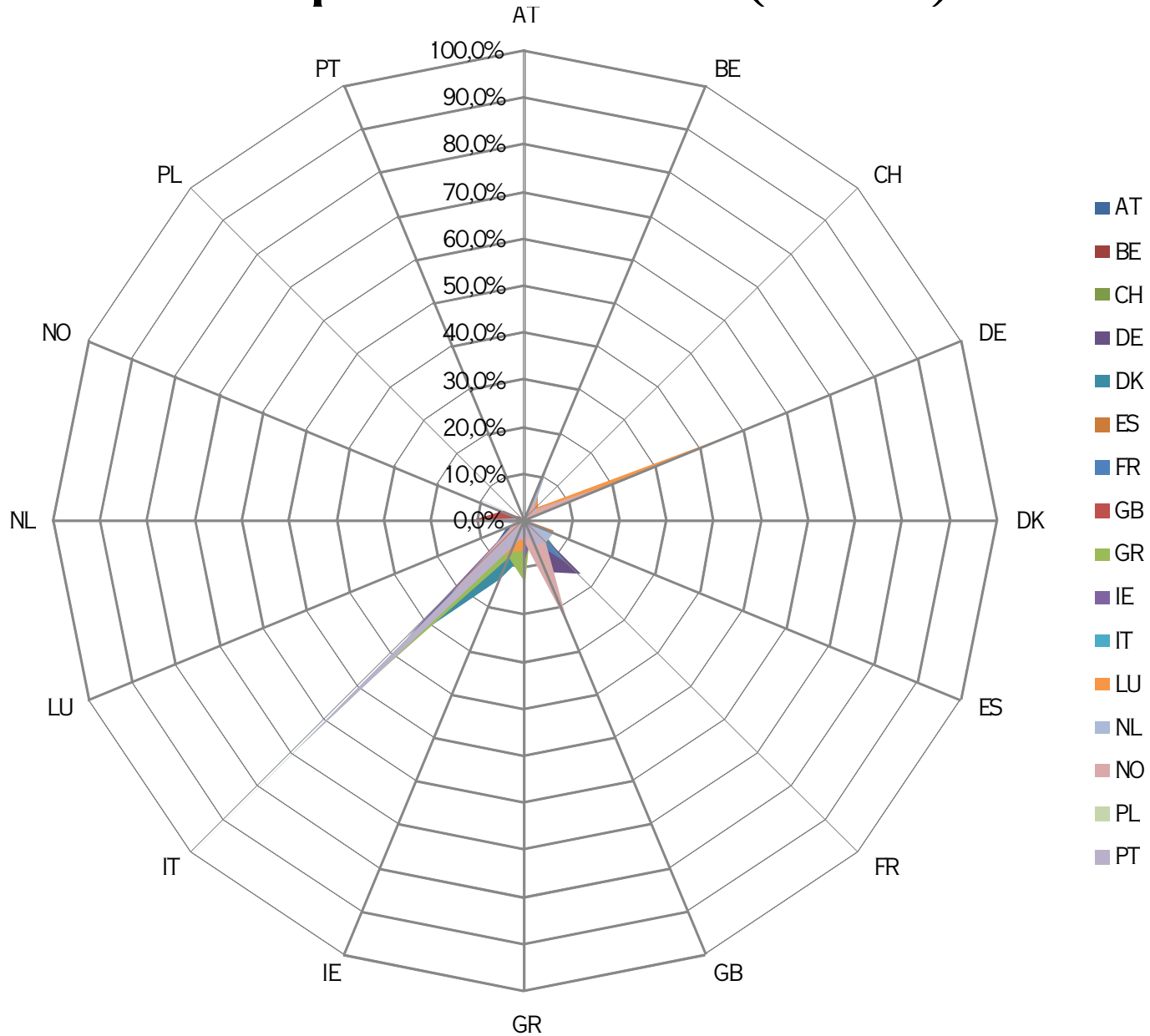
Ordering banks (MID)



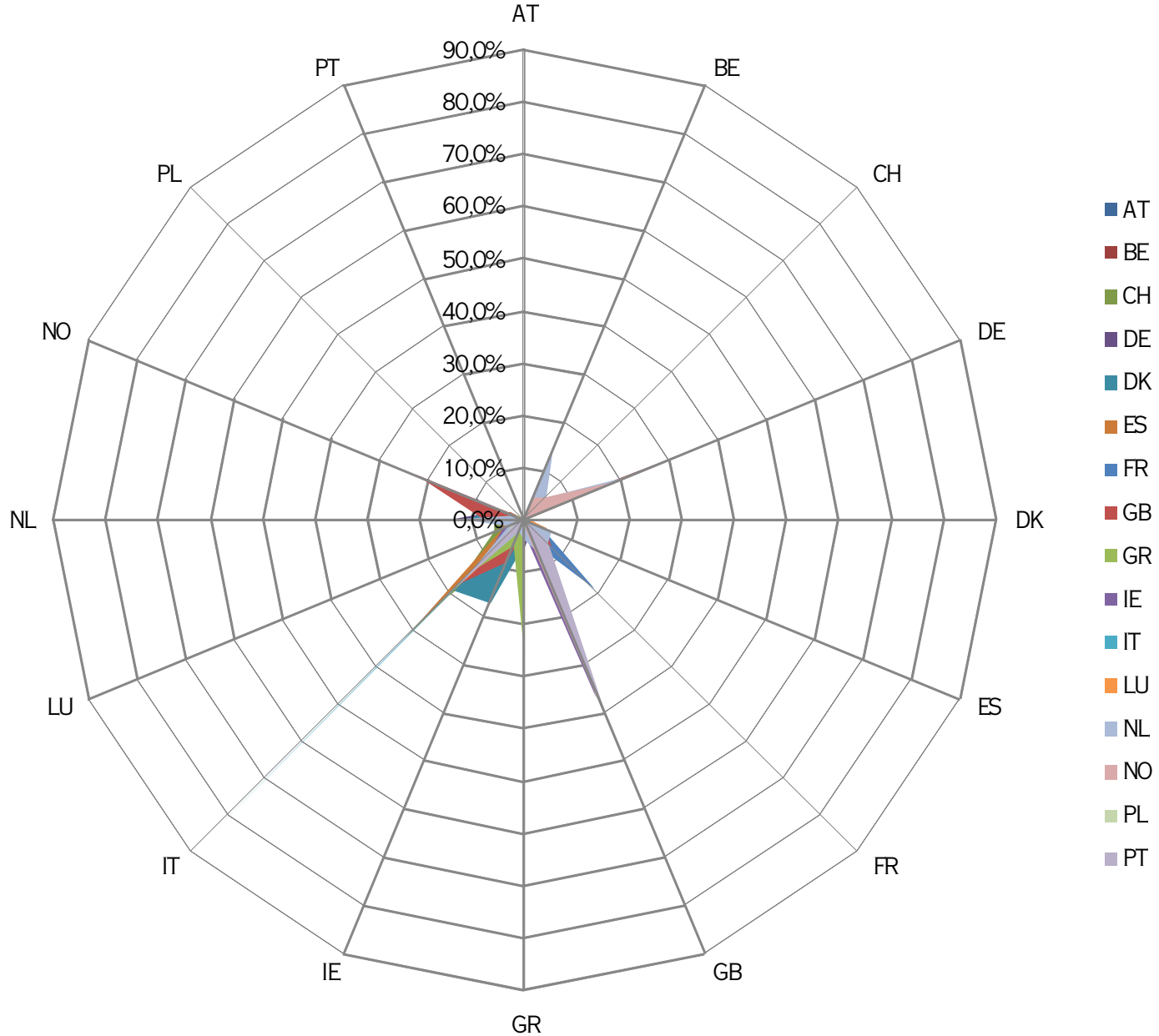
Ordering banks (POST)



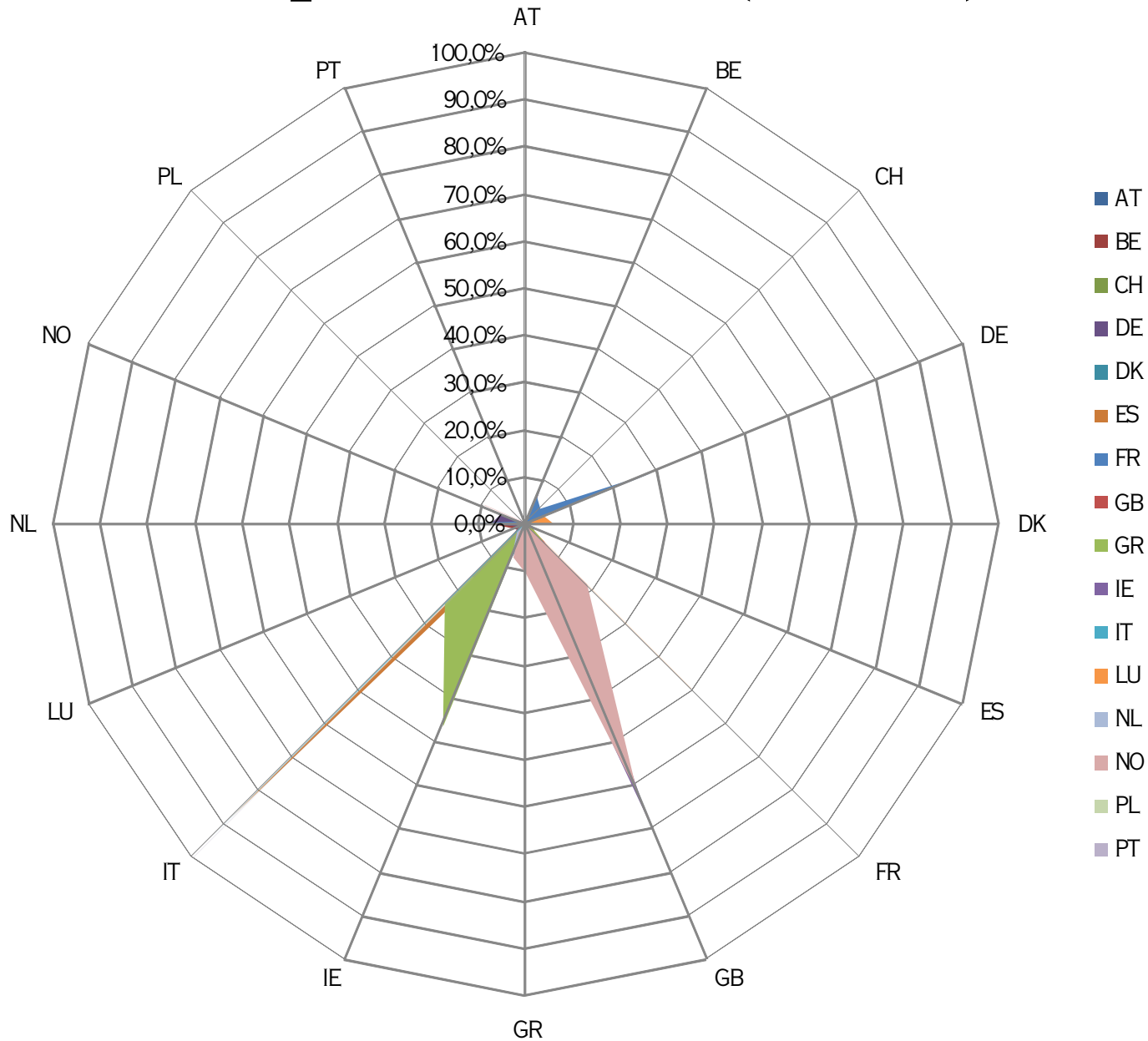
Proposal banks (PRE)



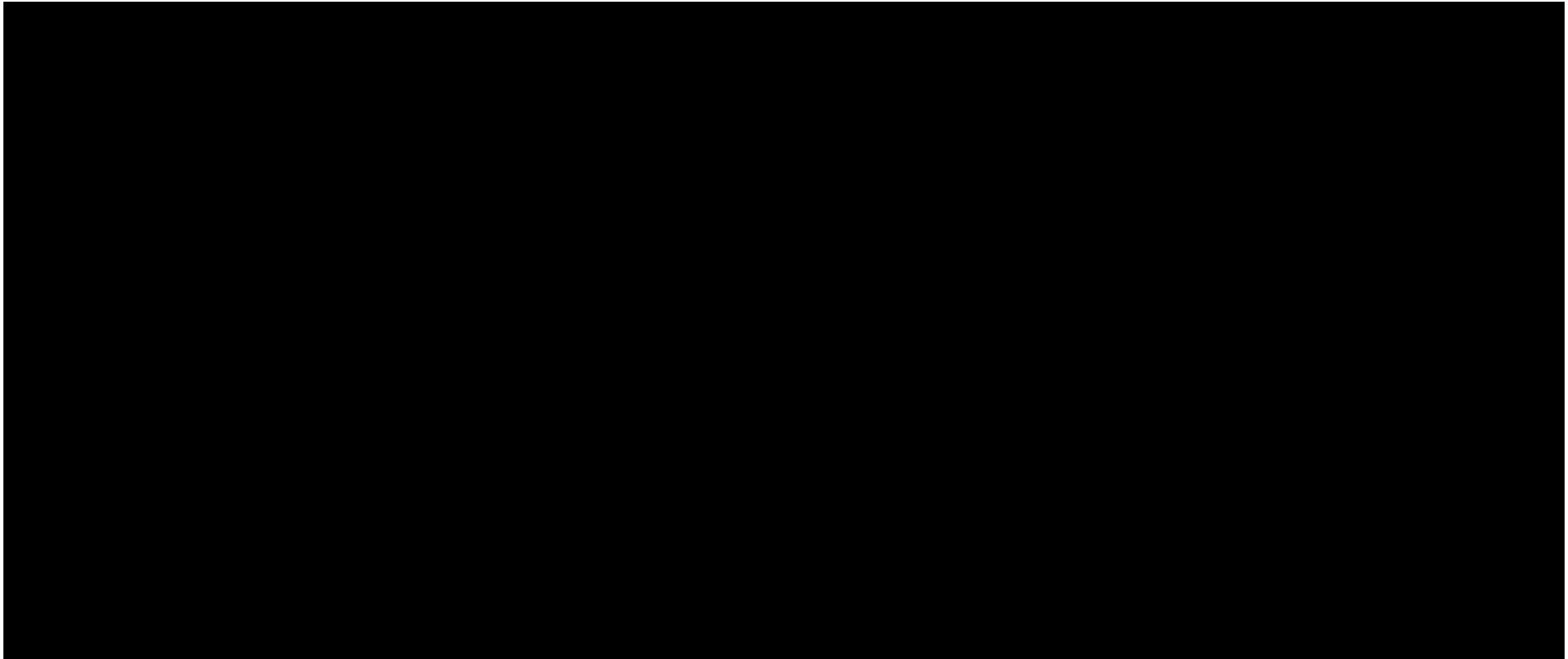
Proposal banks (MID)



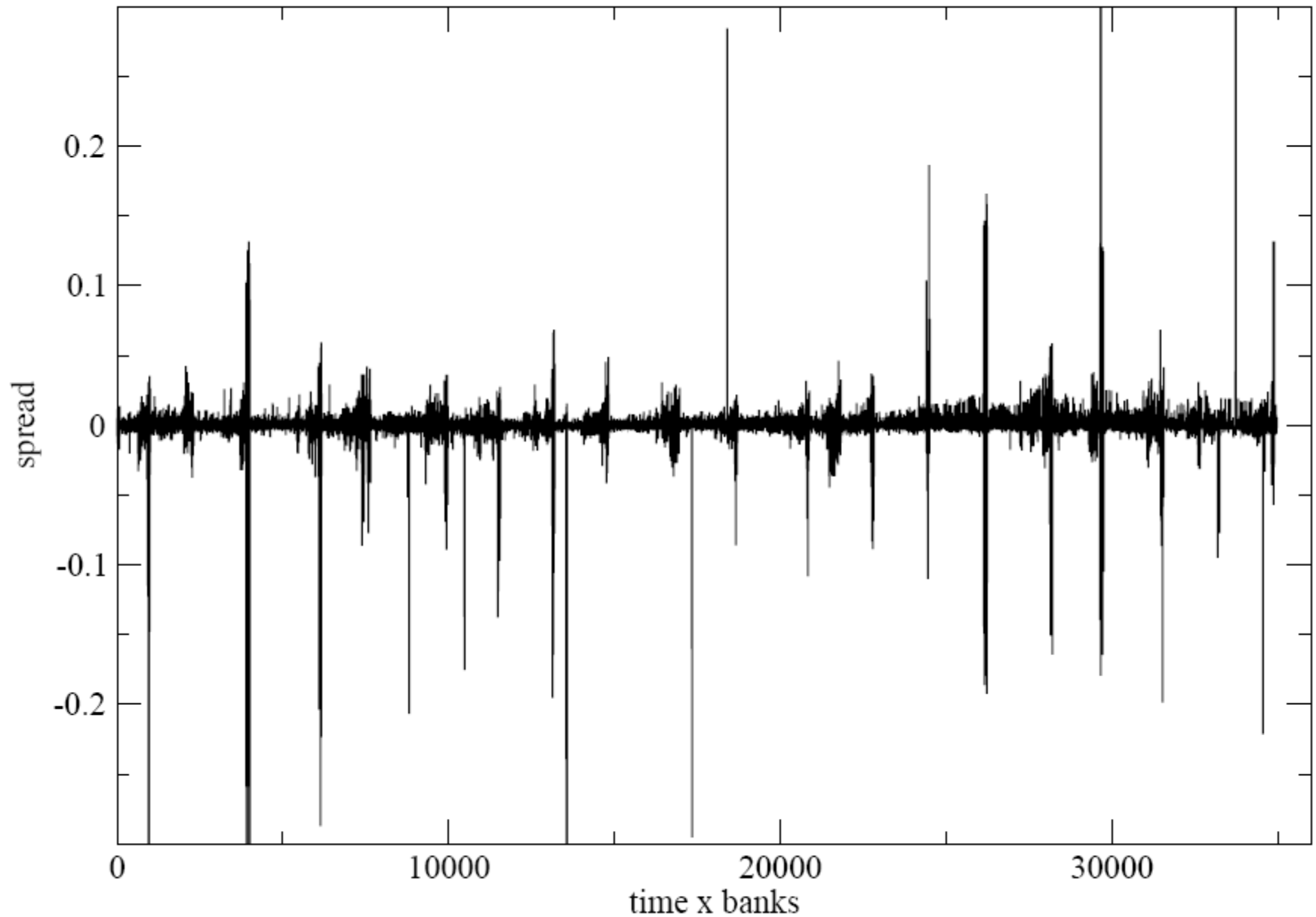
Proposal banks (POST)



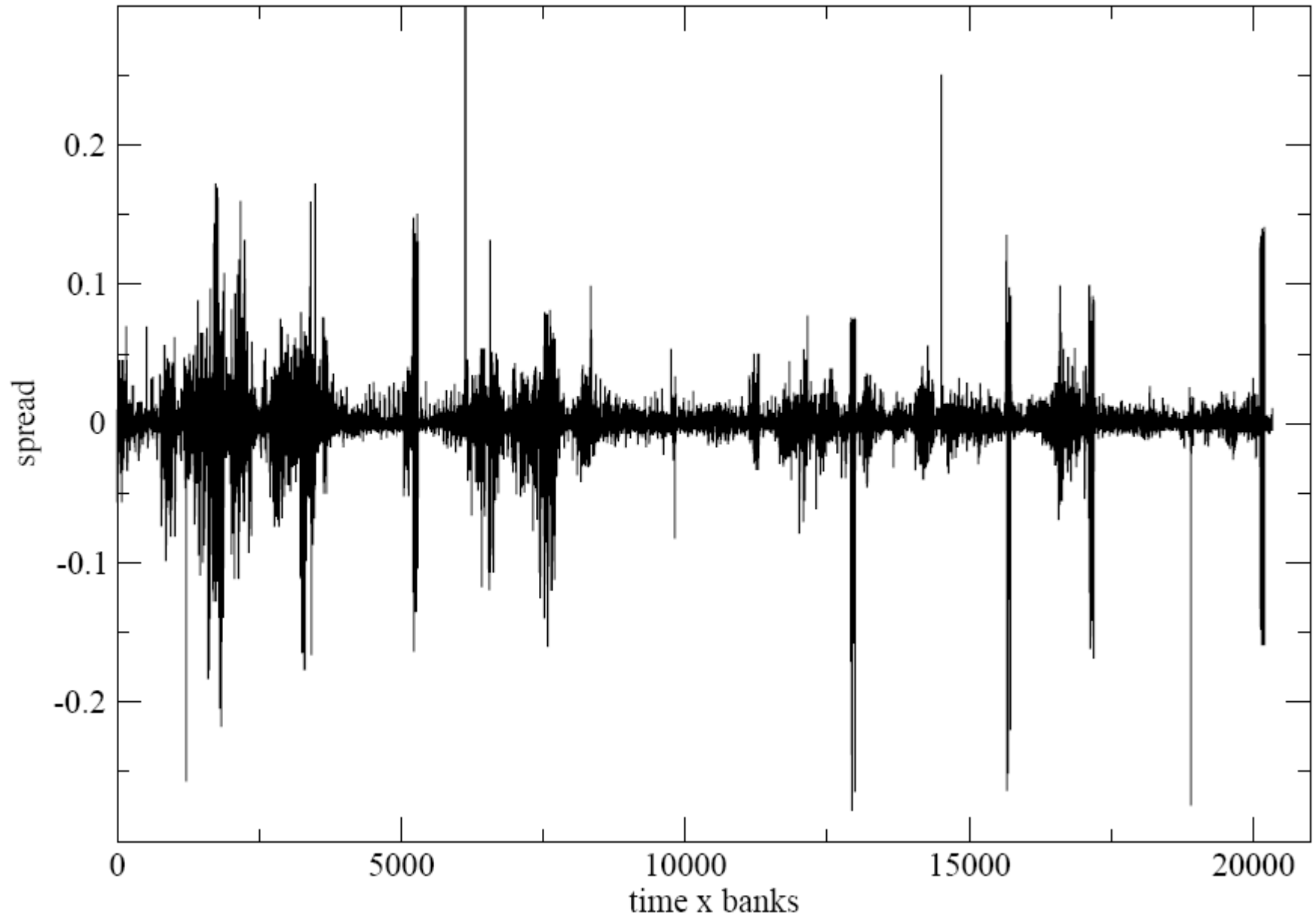
Interbank correlation coefficients



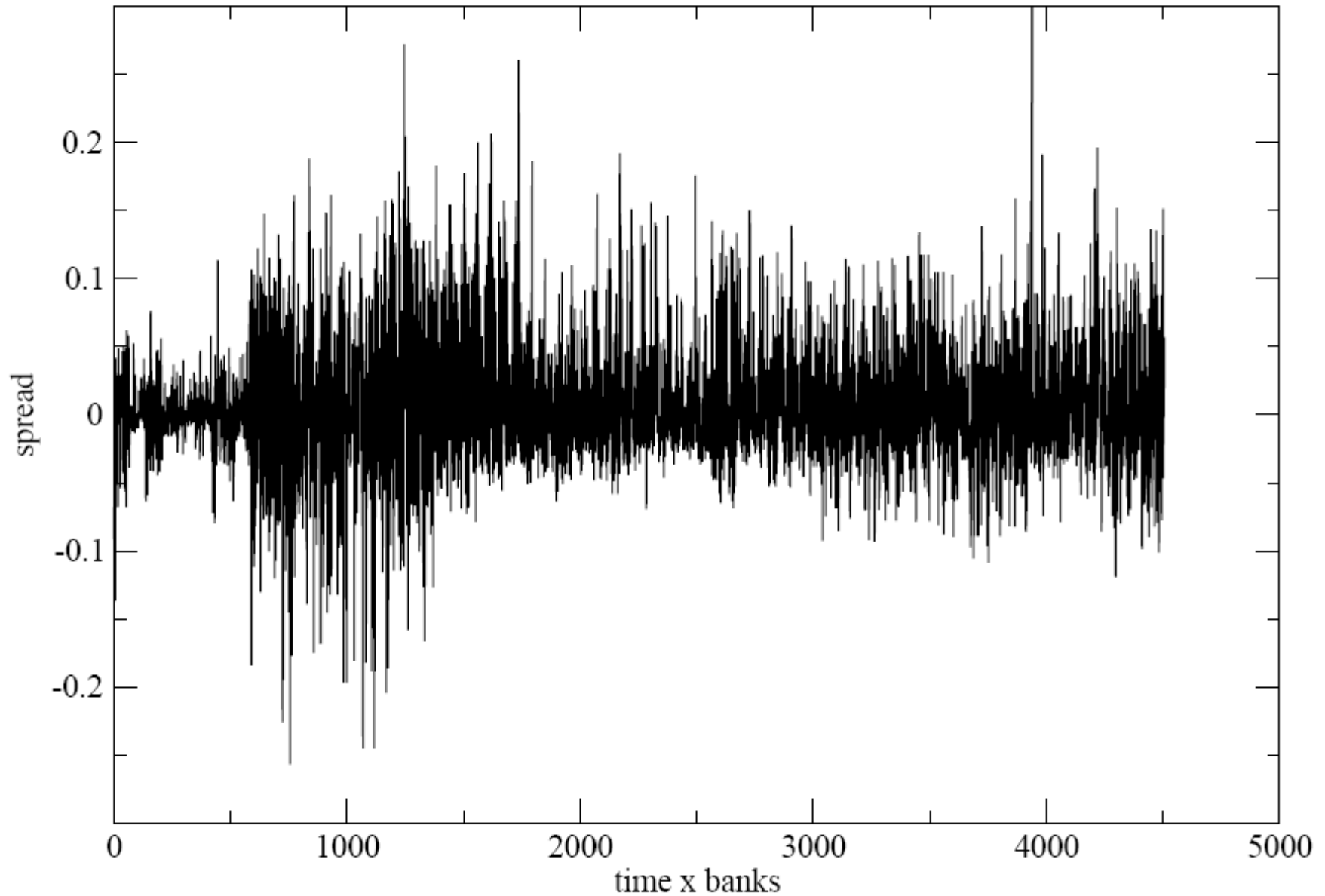
Daily buy spread for each bank (in order of bank) for the pre crisis period



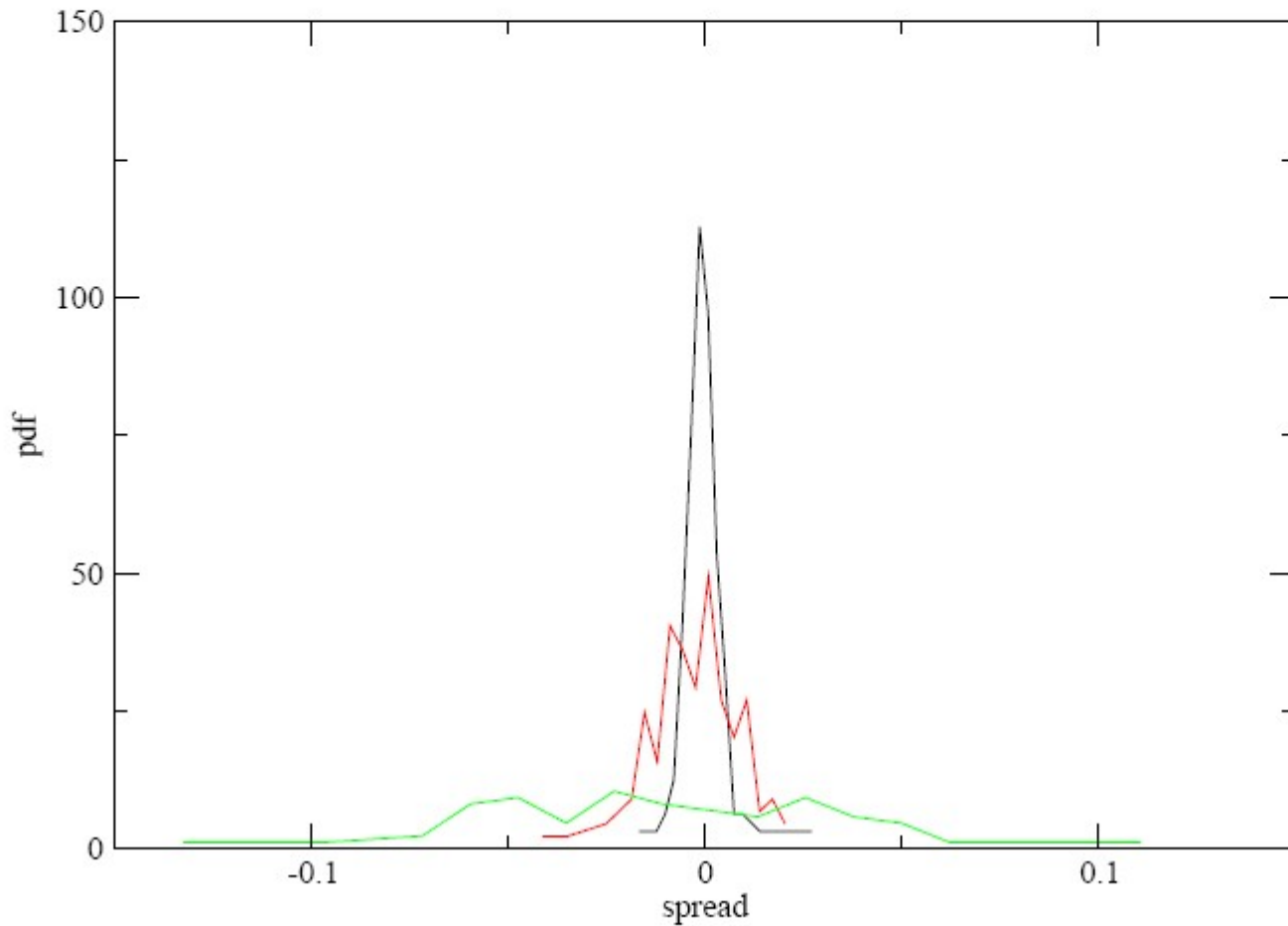
Daily buy spread for each bank (in order of bank) for the mid crisis period



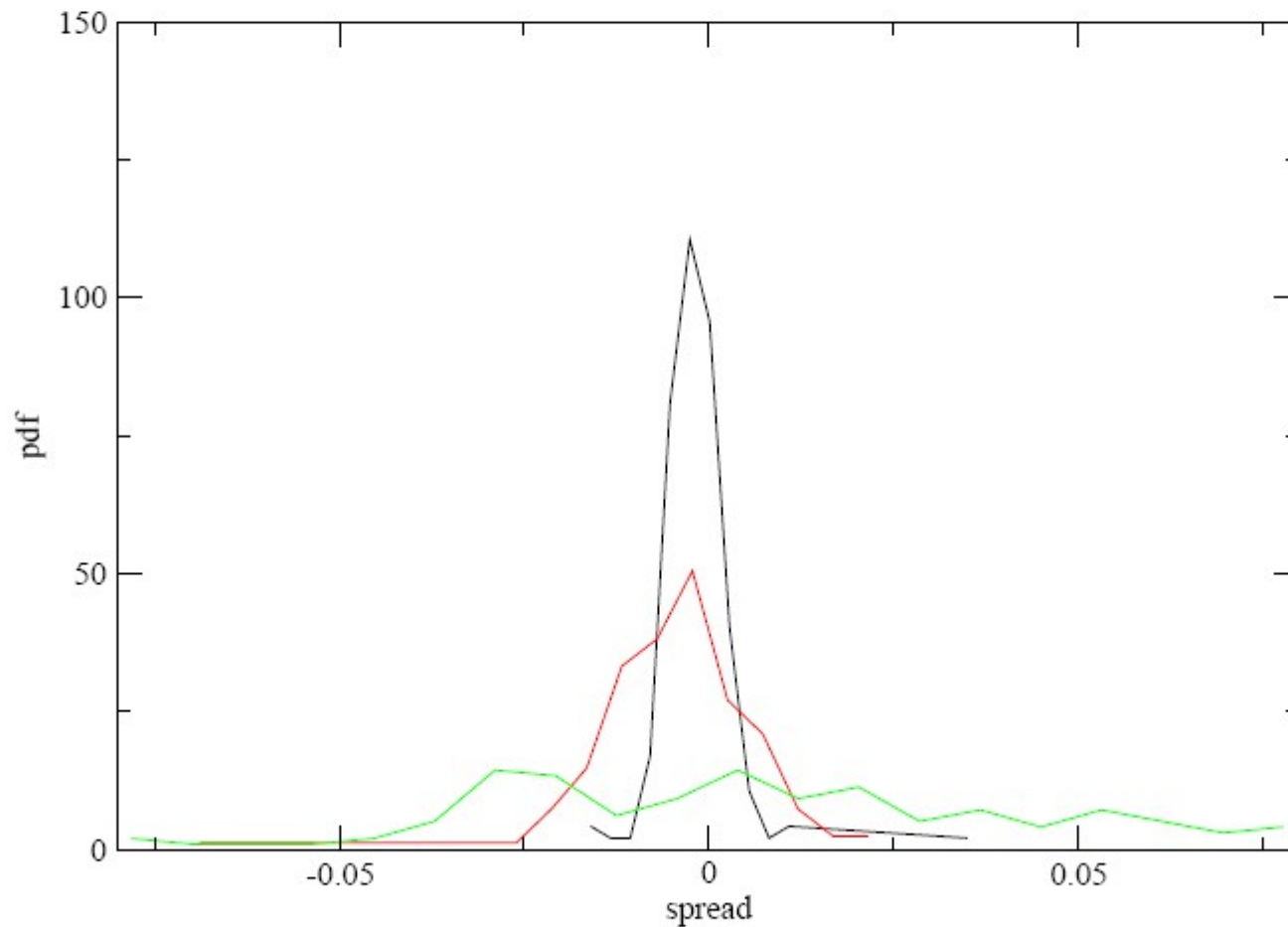
Daily buy spread for each bank (in order of bank) for the post crisis period



Pdf average sell spread per bank pre-crisis (black), mid-crisis (red), and post-crisis (green)



Pdf average buy spread per bank pre-crisis (black), mid-crisis (red), and post-crisis (green)



Findings question no. 2

- The number of buying banks is structurally higher than seller ones
- The pattern shows a break just before the Lehman collapse, especially for sellers
- Before Lehman buying banks appeared to follow a distribution by countries not affected by the sub prime crisis. After Lehman, German banks enter more significantly in the market, both with domestic operations and with international ones.
- The case of proposal banks shows a peculiar behaviour, due to the attraction for UK and Irish counterparts
- Volumes correlations between ordering and proposing banks is shocked by Lehman (from 0,256 to 0,428)
- The daily buy spread shows how the two crisis affected the market: while before sub prime events the range was high, volatility on balance appeared to be relatively small. In the mid period and the post volatility raises noticeably
- Finally, the probability density function (pdf) denotes, both for buyers and for sellers, a centrally concentrated path for the PRE period, more enlarged in the MID period, and absolutely randomly distributed after Lehman.

Research question no. 3

Are banks preferring domestic networks during financial turmoil?

Some figures of domestic transactions

domestic operations	O/N	T/N	S/N	1W	2W	3W	1M	2M	3M	6M	BD	Mean
Pre sub prime crisis	83,7%	90,8%	95,2%	89,8%	95,4%	96,9%	95,0%	95,6%	95,2%	96,1%	95,5%	84,7%
from sub prime to lehman	89,3%	89,5%	92,1%	95,8%	95,8%	96,3%	93,3%	96,3%	97,3%	90,0%	96,5%	89,7%
After Lehman	95,2%	98,0%	82,8%	79,4%	99,6%	100,0%	99,5%	100,0%	98,2%	100,0%	98,5%	95,1%
Delta Pre sub prime - Post sub prime	5,6%	-1,3%	-3,1%	6,0%	0,4%	-0,6%	-1,7%	0,7%	2,1%	-6,1%	1,0%	4,9%
Delta Post sub prime - Lehman	5,9%	8,4%	-9,3%	-16,4%	3,8%	3,7%	6,3%	3,7%	1,0%	10,0%	2,0%	5,4%
Delta Pre sub prime - Lehman	11,5%	7,2%	-12,4%	-10,4%	4,2%	3,1%	4,5%	4,4%	3,1%	3,9%	3,0%	10,3%
no. Operations	total	total	total	total	total	total	total	total	total	total	total	total
Pre sub prime crisis	162866	8254	1582	3055	1716	618	1681	457	889	228	3319	184665
from sub prime to lehman	100274	4636	403	1570	872	189	1073	326	920	130	2075	112468
After Lehman	21575	842	29	621	226	37	220	71	170	36	592	24419
no. Domestic operations	domestic	domestic	domestic	domestic	domestic	domestic	domestic	domestic	domestic	domestic	domestic	total domestic
Pre sub prime crisis	136245	7497	1506	2742	1637	599	1597	437	846	219	3170	156495
from sub prime to lehman	89498	4151	371	1504	835	182	1001	314	895	117	2002	100870
After Lehman	20538	825	24	493	225	37	219	71	167	36	583	23218

Some figures of domestic volumes

Period PRE

- Domestic volumes 4,7756E+11
- Total volumes 1,01114E+12
- Domestic/total volumes: 47,23%

Period MID

- Domestic volumes 2,64589E+11
- Total volumes 4,42863E+11
- Domestic/total volumes: 59,75%
- Delta MID/PRE = +26,50%

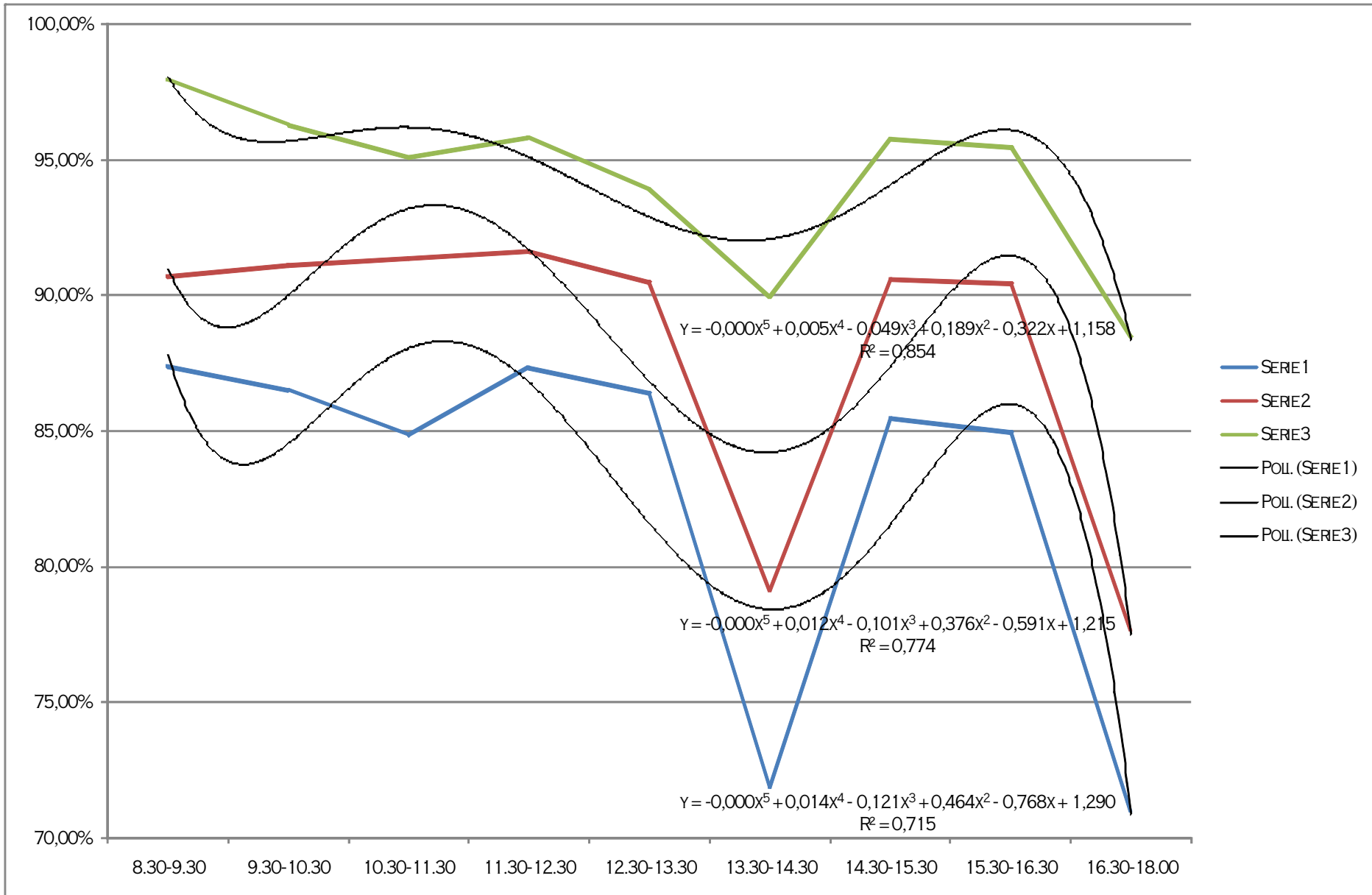
Period POST

- Domestic volumes 3.408.709.000
- Total volumes 4.283.659.000
- Domestic/total volumes: 79,57%
- Delta POST/MID = +33,19%
- Delta POST/PRE = +68,48%

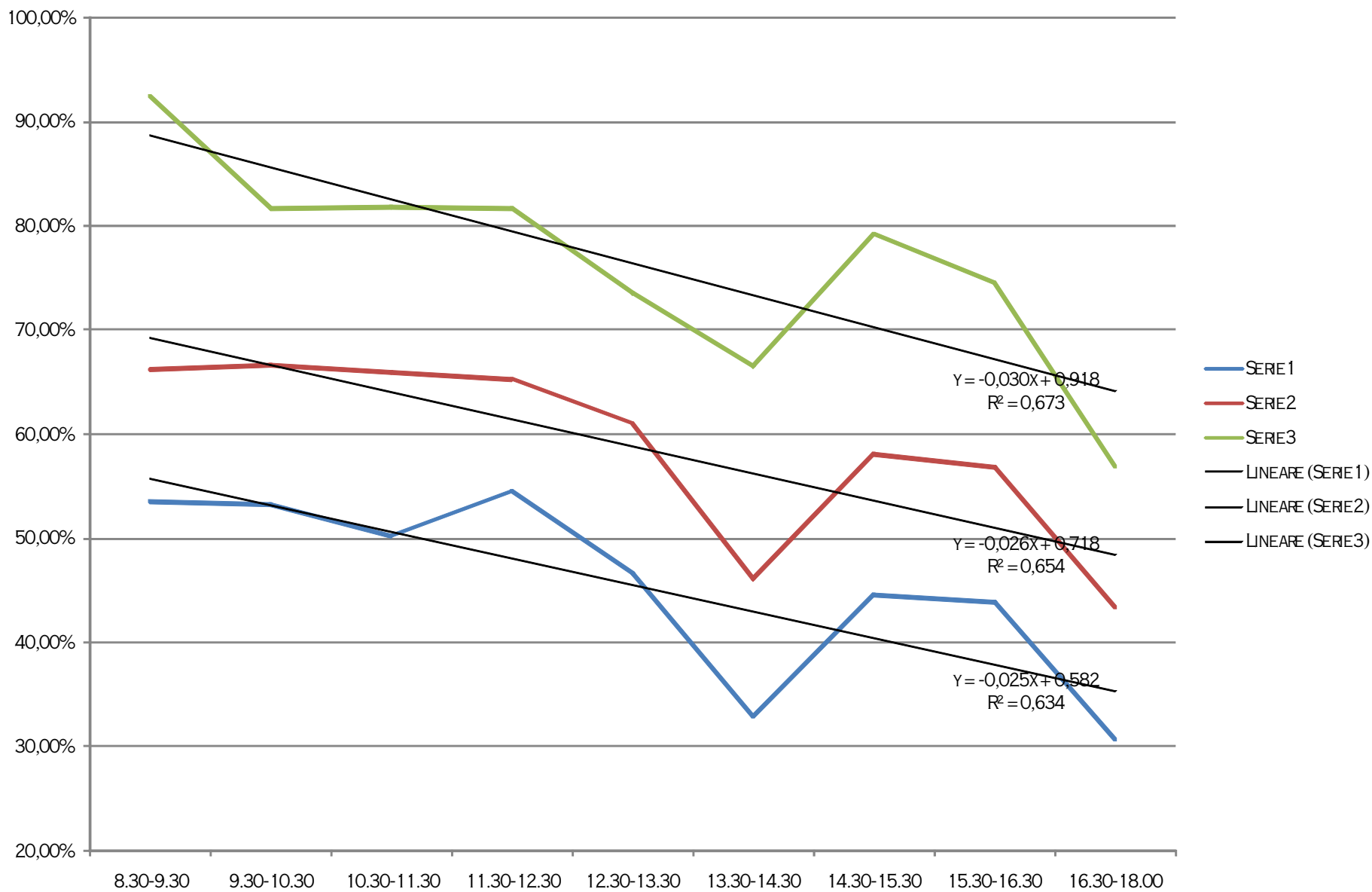
Domestic operations & volumes (hourly basis)

I PERIOD	8.30-9.30	9.30-10.30	10.30-11.30	11.30-12.30	12.30-13.30	13.30-14.30	14.30-15.30	15.30-16.30	16.30-18.00
DOM ESTIC/TOTALOPERATIONS	87,41%	86,51%	84,87%	87,34%	86,40%	71,84%	85,48%	84,95%	71,00%
TOT OPERATIONS	31661	36563	22253	18977	12408	5944	21599	23420	12426
DOM ESTIC OPERATIONS	27674	31632	18886	16574	10720	4270	18462	19896	8823
DOM ESTIC/TOTALVOLLUM ES	53,52%	53,28%	50,18%	54,48%	46,58%	32,81%	44,52%	43,82%	30,64%
TOT VOLLUM ES	1,82663E+11	1,87448E+11	1,15397E+11	86485446000	58795133000	48915595000	1,04677E+11	1,16642E+11	1,10114E+11
DOM ESTIC VOLLUM ES	97761448000	99880477000	57909162000	47120601000	27389502000	16050766000	46604942000	51109313000	33733734000
II PERIOD	8.30-9.30	9.30-10.30	10.30-11.30	11.30-12.30	12.30-13.30	13.30-14.30	14.30-15.30	15.30-16.30	16.30-18.00
DOM ESTIC/TOTALOPERATIONS	90,72%	91,10%	91,40%	91,62%	90,49%	79,13%	90,59%	90,44%	77,64%
TOT OPERATIONS	15556	22618	14121	12529	8598	3766	13438	14700	7370
DOM ESTIC OPERATIONS	14113	20606	12906	11479	7780	2980	12174	13294	5722
DOM ESTIC/TOTALVOLLUM ES	66,24%	66,68%	65,93%	65,20%	61,02%	46,14%	58,08%	56,91%	43,25%
TOT VOLLUM ES	59016013000	78286220000	48649921000	40809774000	30239771000	24566222000	50069892000	55936223000	55288811000
DOM ESTIC VOLLUM ES	39092313000	52201107000	32076311000	26606584000	18452441000	11333952000	29079482000	31832122000	23914456000
III PERIOD	8.30-9.30	9.30-10.30	10.30-11.30	11.30-12.30	12.30-13.30	13.30-14.30	14.30-15.30	15.30-16.30	16.30-18.00
DOM ESTIC/TOTALOPERATIONS	97,96%	96,27%	95,09%	95,81%	93,89%	89,93%	95,79%	95,45%	88,48%
TOT OPERATIONS	4408	5444	3398	2627	1832	5660,00%	2543	2398	1050
DOM ESTIC OPERATIONS	4318	5241	3231	2517	1720	5090,00%	2436	2289	929
DOM ESTIC/TOTALVOLLUM ES	92,44%	81,66%	81,88%	81,66%	73,53%	66,46%	79,14%	74,46%	56,86%
TOT VOLLUM ES	20194755000	14895075000	8403975000	5865185000	4642514000	2647558000	7088468000	8228594000	6790563000
DOM ESTIC VOLLUM ES	18668055000	12163375000	6881475000	4789635000	3413514000	1759488000	5610088000	6126674000	3860913000

Domestic trades



Domestic volumes



Interbank transaction matrix (PRE)

PRE CRISIS	TRADES % TOT PROPOSAL BANKS																
	AT	BE	CH	DE	DK	ES	FR	GB	GR	IE	IT	LU	NL	NO	PL	PT	TOT
AT	0,0%	8,8%	0,0%	35,2%	0,0%	0,0%	0,0%	0,0%	0,0%	7,7%	34,1%	7,7%	0,0%	6,6%	0,0%	0,0%	100,0%
BE	0,0%	10,6%	0,5%	24,5%	0,9%	3,3%	5,9%	2,3%	6,6%	6,5%	30,8%	2,0%	3,9%	1,2%	0,0%	1,1%	100,0%
CH	0,0%	6,2%	0,0%	35,5%	0,0%	6,4%	10,0%	1,6%	7,5%	5,2%	15,4%	1,3%	10,0%	1,0%	0,0%	0,0%	100,0%
DE	0,1%	6,8%	1,8%	25,2%	0,1%	1,1%	8,6%	9,4%	5,9%	3,7%	27,2%	2,0%	6,5%	1,4%	0,0%	0,2%	100,0%
DK	0,0%	1,8%	0,3%	14,8%	0,0%	0,0%	0,3%	0,0%	9,4%	10,0%	50,8%	0,0%	11,5%	1,2%	0,0%	0,0%	100,0%
ES	0,0%	8,2%	0,8%	14,0%	0,0%	5,1%	4,4%	2,5%	6,2%	5,3%	40,9%	2,4%	9,2%	0,4%	0,0%	0,6%	100,0%
FR	0,0%	9,3%	2,2%	27,0%	0,0%	3,4%	9,9%	4,0%	3,7%	7,3%	25,2%	2,0%	4,3%	1,5%	0,0%	0,3%	100,0%
GB	0,0%	6,2%	1,1%	25,7%	0,1%	4,6%	5,6%	1,6%	6,4%	5,7%	26,3%	1,1%	11,5%	3,8%	0,0%	0,4%	100,0%
GR	0,2%	4,2%	0,0%	3,5%	2,6%	0,2%	2,7%	1,5%	15,3%	7,7%	60,5%	0,2%	0,5%	0,3%	0,0%	0,6%	100,0%
IE	0,0%	8,0%	0,0%	16,9%	0,6%	3,4%	4,4%	0,9%	8,5%	6,4%	43,8%	3,9%	0,5%	1,1%	0,0%	1,7%	100,0%
IT	0,0%	0,4%	0,0%	1,2%	0,2%	0,4%	0,6%	0,5%	1,0%	0,7%	94,3%	0,1%	0,3%	0,2%	0,0%	0,1%	100,0%
LU	0,0%	7,5%	2,0%	39,4%	1,2%	2,0%	2,0%	0,9%	8,1%	12,8%	19,1%	1,7%	0,0%	3,2%	0,0%	0,0%	100,0%
NL	0,0%	11,1%	0,9%	22,2%	0,0%	6,5%	4,5%	3,0%	5,8%	5,8%	26,8%	2,5%	9,8%	0,7%	0,0%	0,4%	100,0%
NO	0,0%	3,4%	1,6%	19,6%	0,8%	0,0%	4,9%	15,2%	5,7%	7,3%	29,2%	1,6%	9,8%	0,0%	0,0%	0,8%	100,0%
PL	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
PT	0,0%	4,8%	0,0%	3,4%	0,0%	2,7%	4,8%	5,5%	5,5%	9,6%	63,0%	0,0%	0,0%	0,7%	0,0%	0,0%	100,0%

Interbank transaction matrix (MID)

MID CRISIS	TRADES % TOT PROPOSAL																
	AT	BE	CH	DE	DK	ES	FR	GB	GR	IE	IT	LU	NL	NO	PL	PT	TOT
AT	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	75,0%	0,0%	25,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
BE	0,0%	10,9%	1,4%	27,5%	0,7%	2,8%	6,5%	3,0%	6,2%	3,5%	22,5%	1,6%	9,1%	2,3%	0,0%	2,0%	100,0%
CH	0,0%	7,9%	0,0%	13,2%	0,0%	0,0%	10,5%	2,6%	2,6%	0,0%	44,7%	10,5%	7,9%	0,0%	0,0%	0,0%	100,0%
DE	0,0%	10,1%	2,7%	25,5%	0,1%	3,4%	8,2%	2,7%	8,7%	2,0%	16,0%	1,7%	12,0%	4,2%	0,0%	2,7%	100,0%
DK	0,3%	7,4%	0,0%	2,9%	0,0%	5,7%	0,0%	0,3%	5,4%	15,5%	34,4%	0,0%	26,1%	2,0%	0,0%	0,0%	100,0%
ES	0,0%	9,4%	1,1%	5,5%	0,6%	1,7%	6,1%	6,6%	1,7%	0,0%	55,8%	2,8%	7,2%	0,6%	0,0%	1,1%	100,0%
FR	0,0%	9,1%	2,5%	16,1%	0,0%	3,1%	11,2%	5,4%	5,3%	4,9%	28,2%	1,5%	8,8%	2,5%	0,0%	1,3%	100,0%
GB	0,0%	10,5%	1,6%	13,4%	0,0%	5,3%	5,8%	0,5%	2,1%	10,3%	24,2%	0,5%	7,1%	16,3%	0,0%	2,4%	100,0%
GR	0,0%	8,9%	0,2%	8,6%	0,0%	1,1%	6,8%	0,4%	22,8%	8,0%	36,3%	0,4%	6,1%	0,0%	0,0%	0,4%	100,0%
IE	0,0%	10,0%	0,0%	3,3%	0,0%	0,0%	6,7%	58,9%	4,4%	0,0%	13,3%	2,2%	0,0%	1,1%	0,0%	0,0%	100,0%
IT	0,0%	0,6%	0,1%	1,0%	0,1%	0,4%	0,5%	0,3%	0,6%	0,3%	95,6%	0,1%	0,3%	0,2%	0,0%	0,1%	100,0%
LU	0,0%	13,1%	1,5%	16,5%	2,9%	5,8%	4,4%	0,0%	19,9%	0,0%	27,2%	0,0%	0,5%	8,3%	0,0%	0,0%	100,0%
NL	0,0%	15,6%	3,6%	15,9%	0,0%	6,9%	4,3%	9,8%	5,8%	2,5%	21,4%	3,3%	8,7%	1,4%	0,0%	0,7%	100,0%
NO	0,0%	5,9%	5,9%	11,9%	0,0%	0,0%	3,0%	47,5%	1,0%	2,0%	17,8%	1,0%	3,0%	0,0%	0,0%	1,0%	100,0%
PL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT	0,0%	2,0%	0,0%	5,3%	0,0%	0,0%	7,3%	59,3%	0,7%	1,3%	24,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%

Interbank transaction matrix (POST)

POST LEHMAN	TRADES % TOT PROPOSAL																
	AT	BE	CH	DE	DK	ES	FR	GB	GR	IE	IT	LU	NL	NO	PL	PT	TOT
AT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE	0,0%	8,7%	0,0%	30,1%	0,0%	1,7%	11,6%	4,6%	6,4%	12,7%	4,0%	6,4%	11,0%	1,2%	0,0%	1,7%	100,0%
CH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DE	0,0%	9,9%	1,7%	36,0%	0,5%	2,7%	2,2%	12,4%	2,0%	2,7%	11,9%	3,2%	8,7%	5,7%	0,0%	0,2%	100,0%
DK	0,0%	15,4%	0,0%	23,1%	0,0%	0,0%	0,0%	0,0%	0,0%	30,8%	30,8%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
ES	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	12,1%	3,0%	84,8%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
FR	0,0%	5,7%	2,3%	15,9%	0,0%	0,0%	2,3%	12,5%	6,8%	8,0%	35,2%	1,1%	9,1%	1,1%	0,0%	0,0%	100,0%
GB	0,0%	3,6%	0,0%	60,7%	0,0%	0,0%	3,6%	1,8%	3,6%	5,4%	16,1%	0,0%	0,0%	5,4%	0,0%	0,0%	100,0%
GR	0,0%	4,5%	0,0%	0,9%	0,0%	2,7%	1,8%	8,2%	0,0%	26,4%	54,5%	0,0%	0,0%	0,9%	0,0%	0,0%	100,0%
IE	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	7,7%	53,8%	7,7%	0,0%	30,8%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
IT	0,0%	0,2%	0,0%	0,2%	0,0%	0,1%	0,1%	0,1%	0,4%	0,2%	98,6%	0,0%	0,1%	0,0%	0,0%	0,0%	100,0%
LU	0,0%	0,0%	0,0%	20,0%	20,0%	0,0%	20,0%	0,0%	0,0%	0,0%	40,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
NL	0,0%	16,7%	0,0%	8,3%	0,0%	0,0%	0,0%	41,7%	0,0%	8,3%	25,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
NO	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	12,5%	25,0%	12,5%	25,0%	25,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%
PL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%

Findings question no. 3

- Before the crisis, 84.7% of trades were domestic. In the MID period the frequency raised to 89.7% and after Lehman to 95.1%
- The volumes recorded a change as follows: 45.2% (PRE), 59.8% (MID) and 79.6% (POST)
- This change was experienced with a very similar distribution for all the hourly intervals (trades and volumes). The interpolation function shows coefficients (but the constant) very similar to each other
- The principal diagonal of the interbank trades matrix shows an increase, denoting that the impact was homogeneous for all the countries.
- The phenomenon could be explained as follows:
 - Information asymmetries
 - Uncertainty with regulators behaviour in case of systemic risk and difference of bail out solutions

Research question no. 4

Did the network analysis and interbank market data provided early warnings of the crisis?

Overlap measure

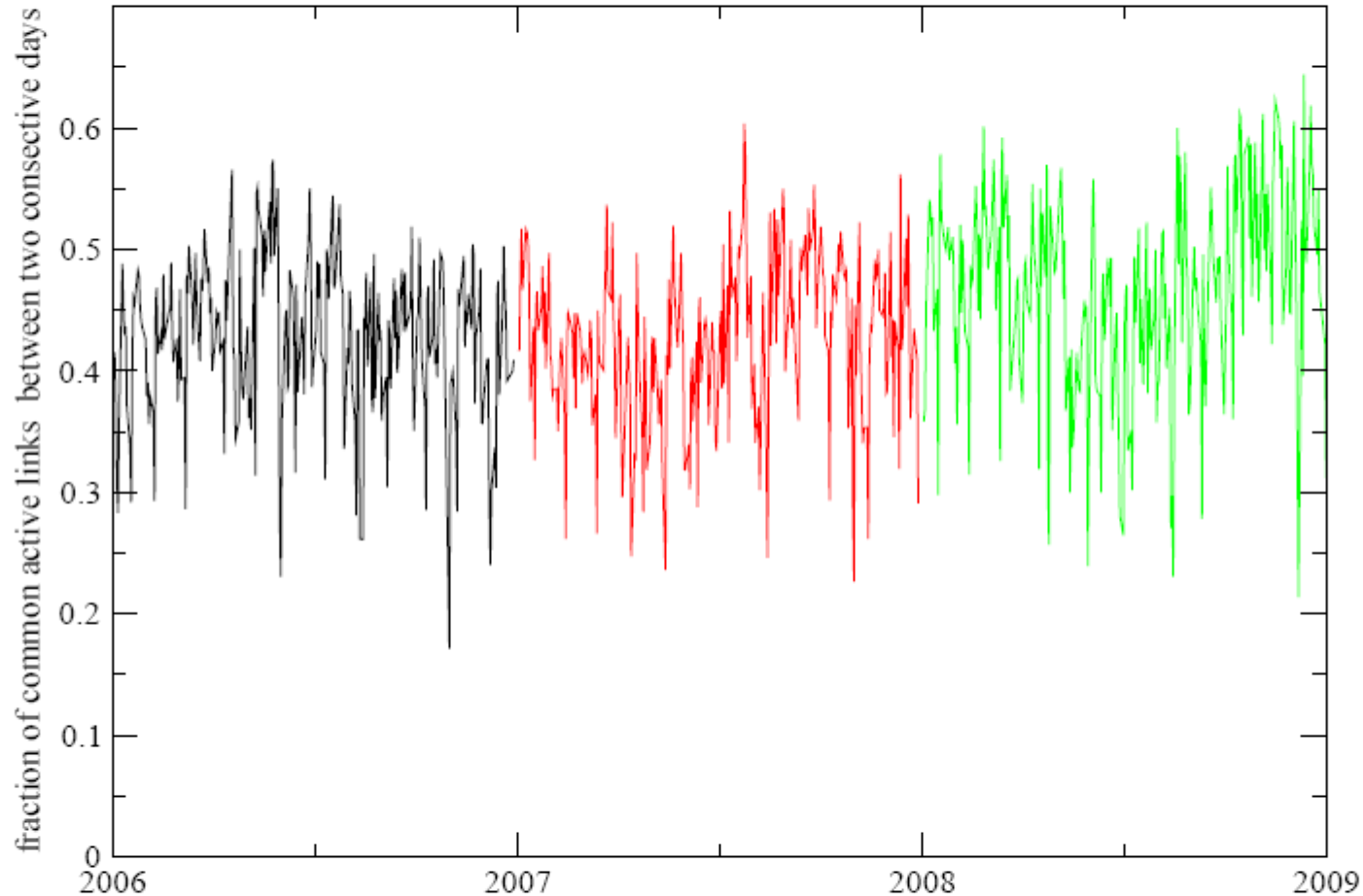
The topological overlap of two nodes reflects their similarity in terms of the commonality of the nodes they connect to.

In an unweighted network, the number of shared neighbors of nodes i and j is given by

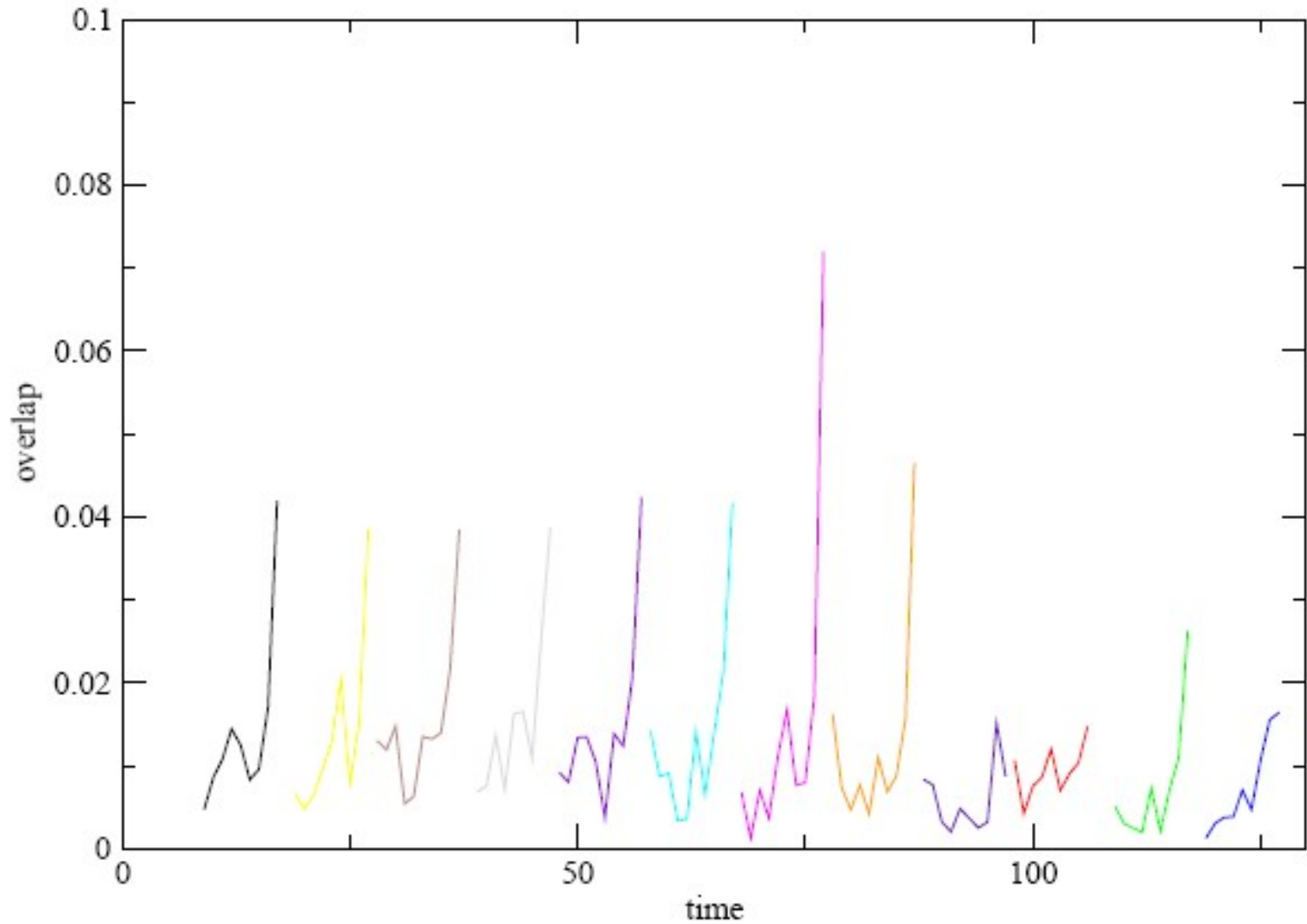
$$\sum_{u \neq i, j} a_{iu} a_{ju}$$

The topological overlap $T = [t_{ij}]$ is a normalized version of this quantity

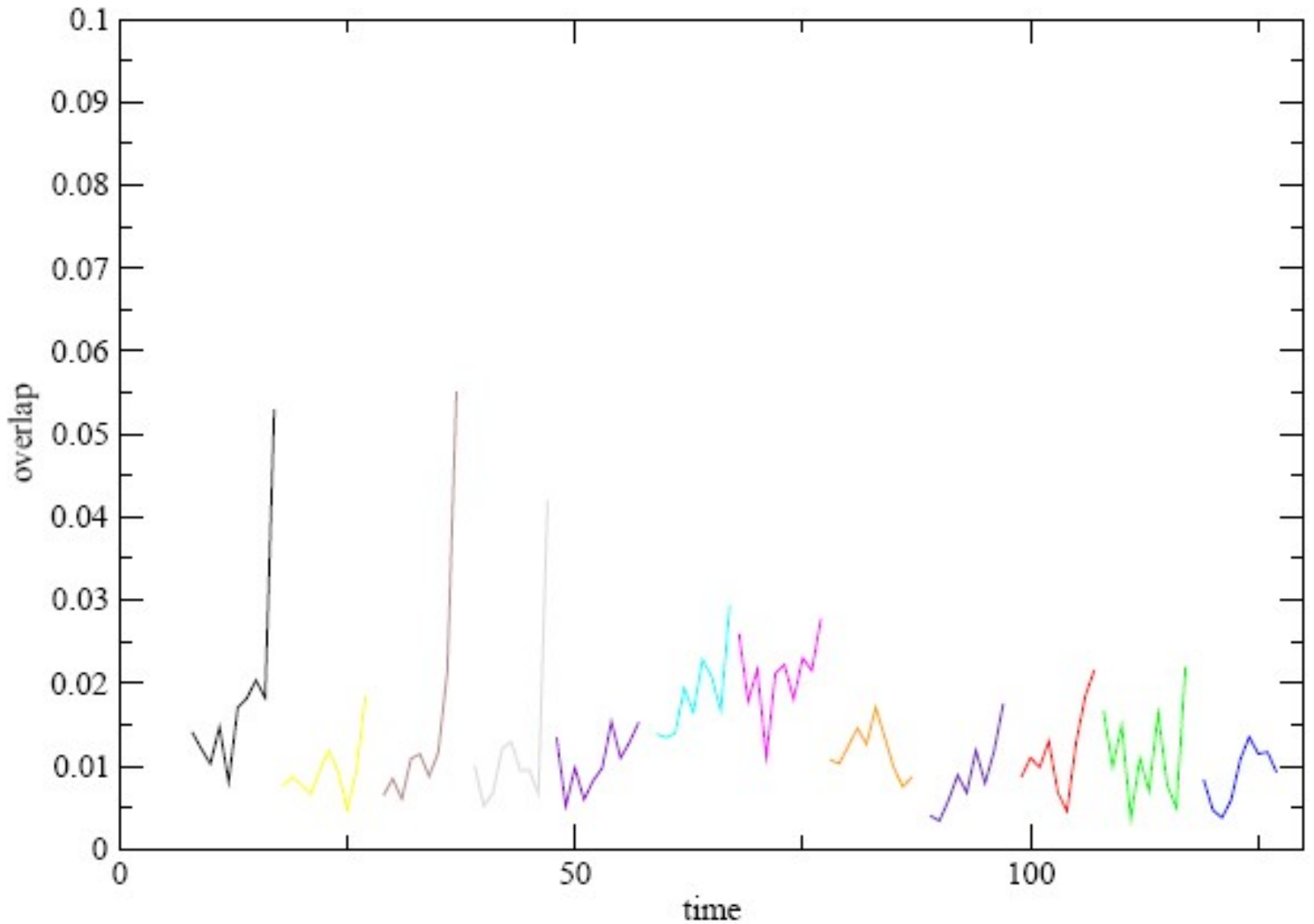
Overlap of transaction network from one day to the next



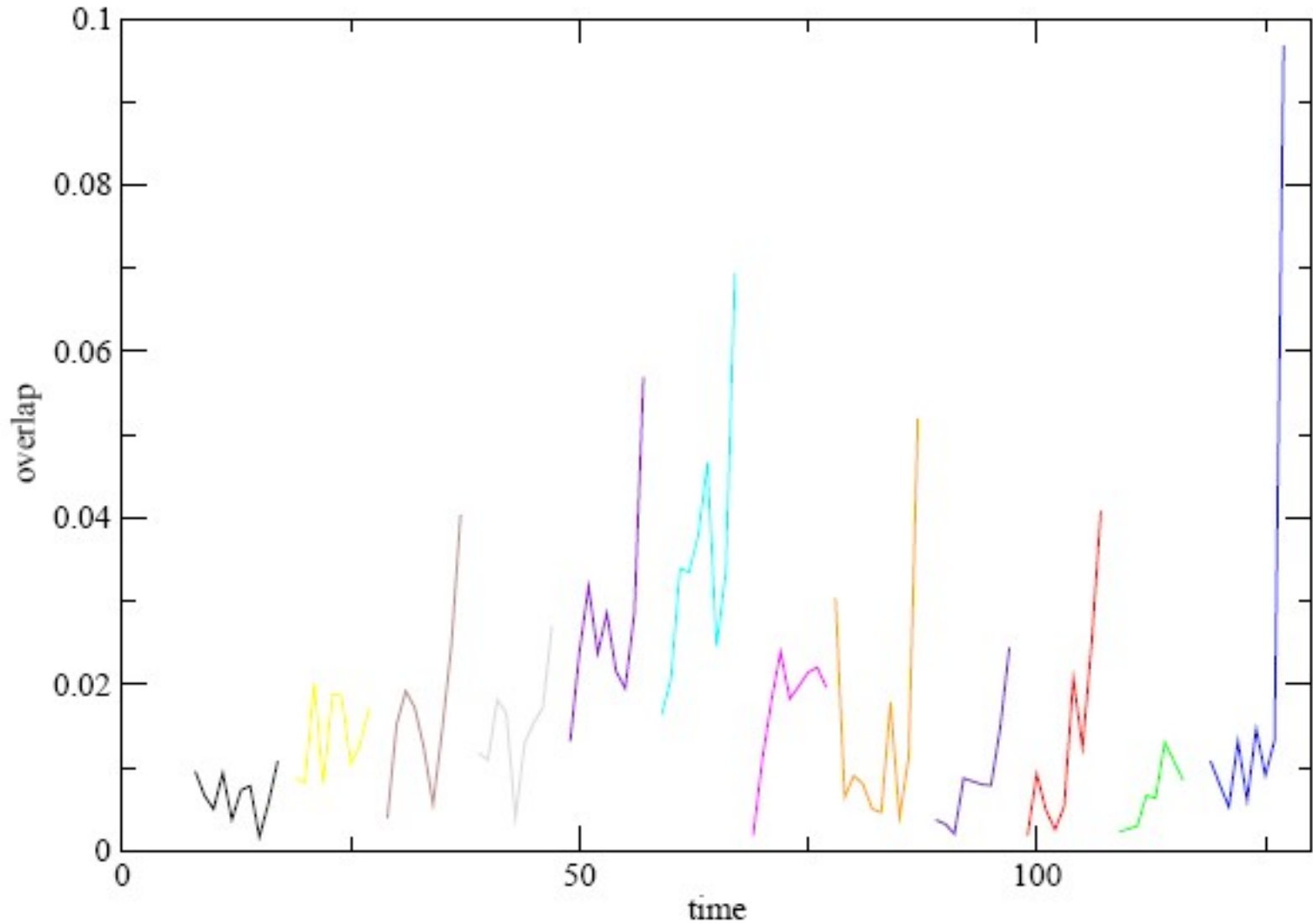
Intra-day Overlap 2006



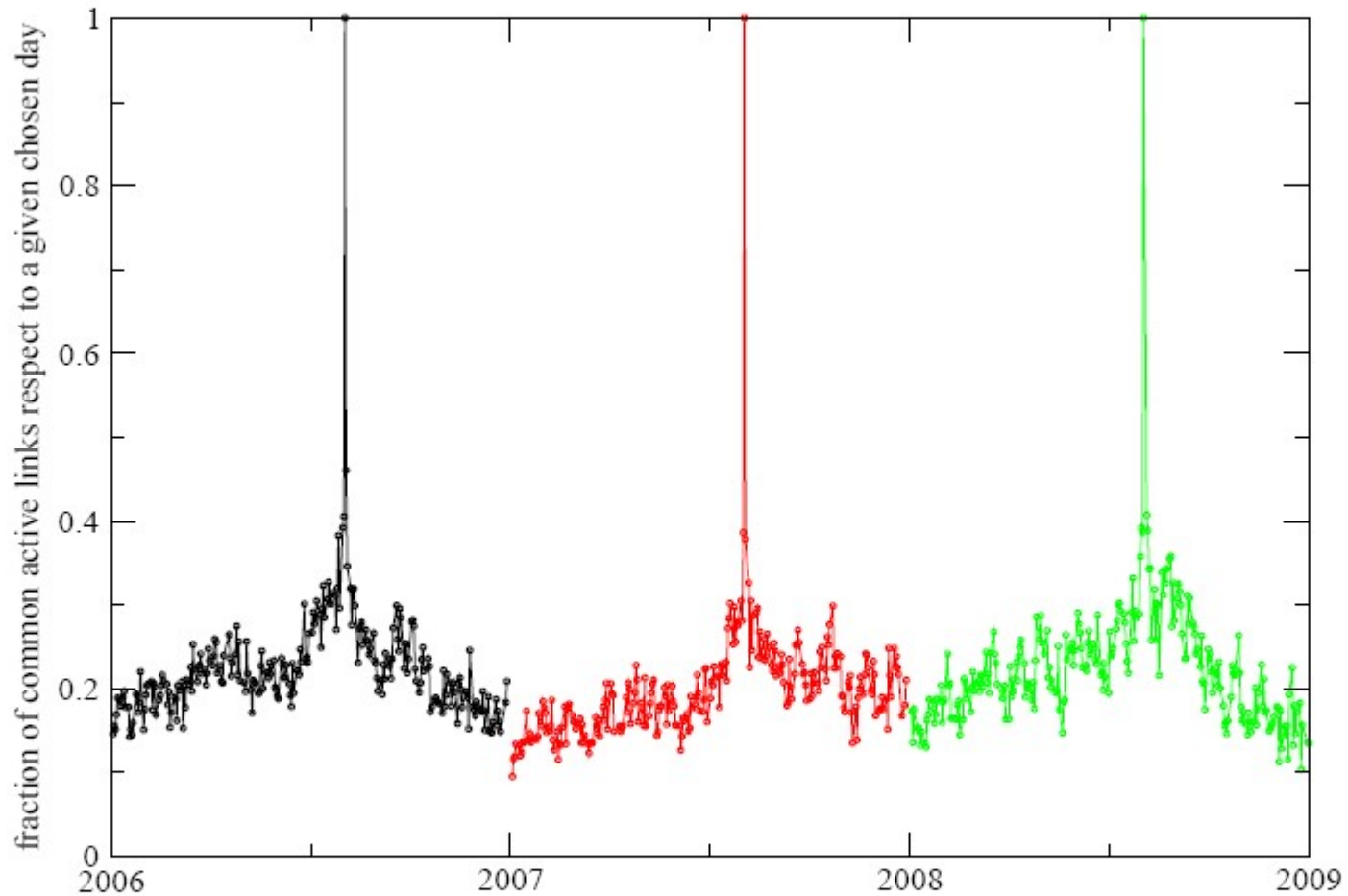
Intra-day Overlap 2007



Intra-day Overlap 2008



Overlap of transaction network respect to a reference one



Clustering

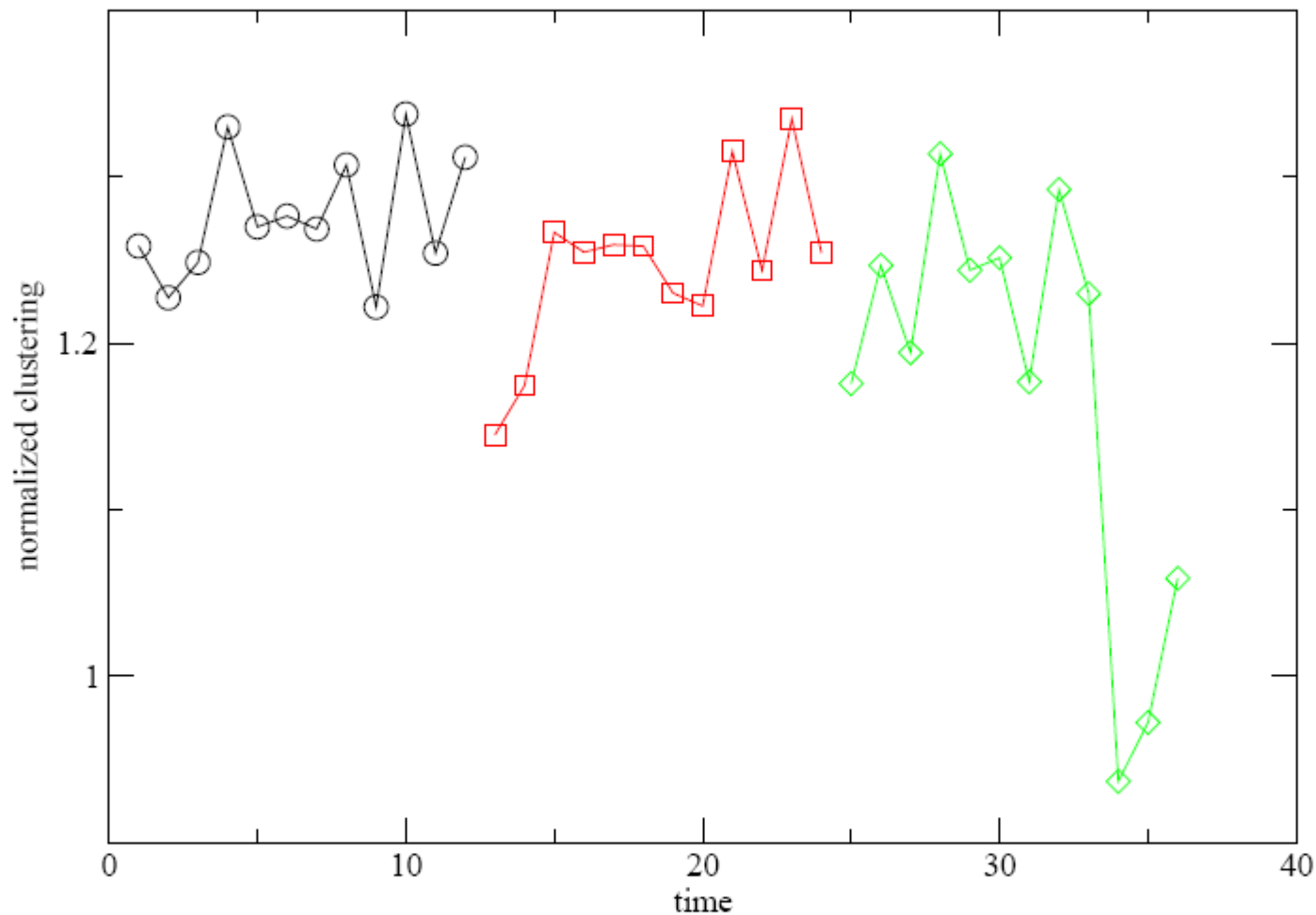
- The clustering coefficient c_i is a measure of connection density around vertex i and is defined as

$$\tilde{c}_i = \frac{2}{k_i(k_i - 1)} \sum_{j,h} a_{ij}a_{ih}a_{jh}$$

- The clustering coefficient represents the proportion of nearest neighbours of a node that are linked to each other. In our case, it indicates whether there is a link between two banks which have a common trading partner. The clustering coefficient measures the number of triangles in a system. In order to have a triangle in the payments system at least one bank must lend to one counterparty and borrow from another. The clustering coefficient provides us with a way to assess the extent of this kind of intermediary trading.
- The average clustering coefficient is an overall statistical measure of the density of interconnected vertex triplets in the network. It is defined as follows

$$C = \frac{1}{N} \sum_i \tilde{c}_i$$

Clustering coefficient relative to random network clustering coefficient, for transactions aggregated over a month period in 2006 (black), 2007 (red) and 2008 (green)



Participation ratio

- For a given node i , with connectivity k_i and strength s_i , the weights of the edges can either be of the same order of magnitude, $s_i = k_i$, or they can be heterogeneously distributed, with some edges dominating others. The participation ratio is defined as

$$Y_2^W(i) = \sum_{j \in \mathcal{V}(i)} \left[\frac{w_{i,j}}{s_i^W} \right]^2$$

- or equivalently

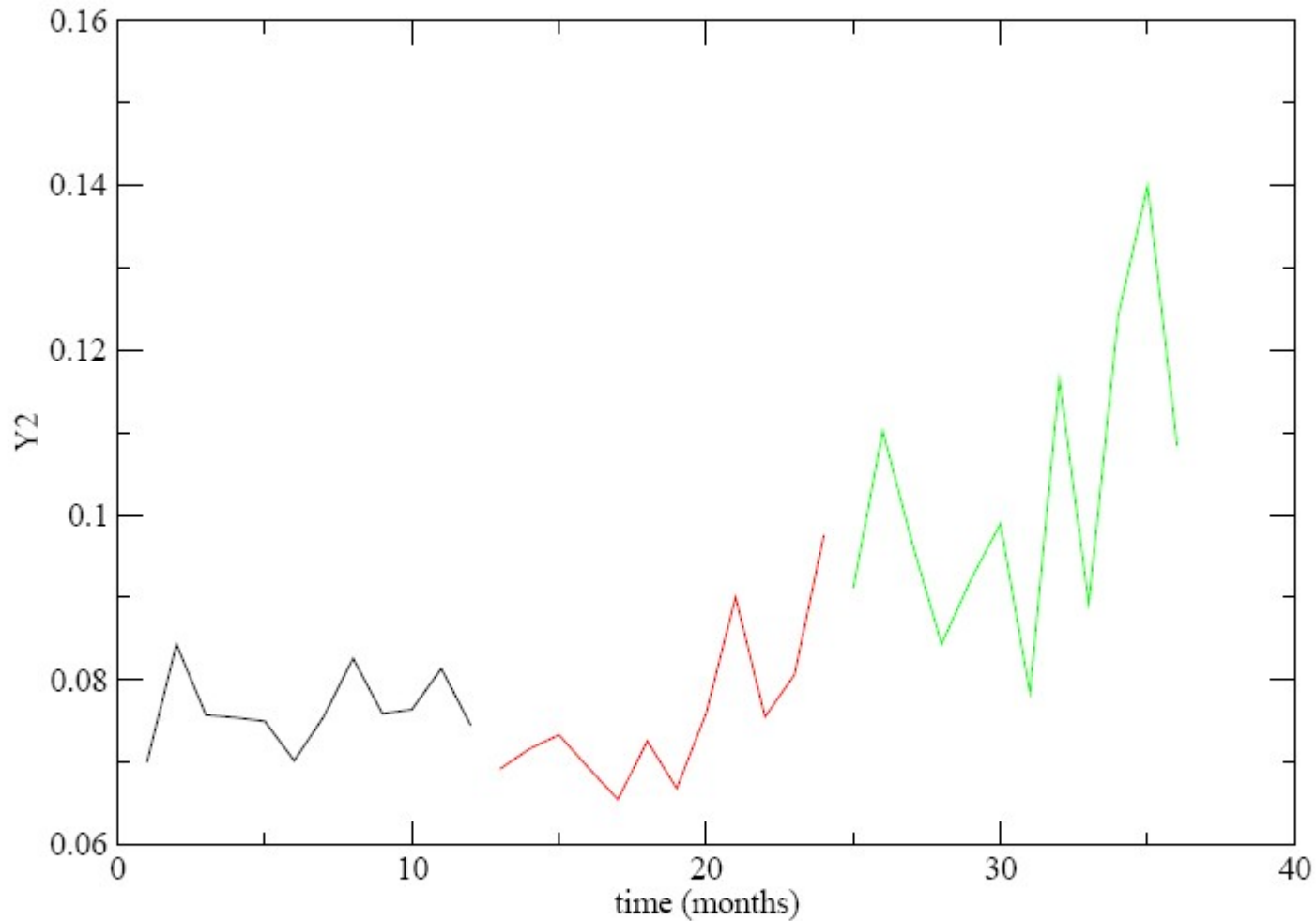
$$Y_2^C(i) = \sum_{j \in \mathcal{V}(i)} \left[\frac{c_{i,j}}{s_i^C} \right]^2$$

Participation ratio (Y2)

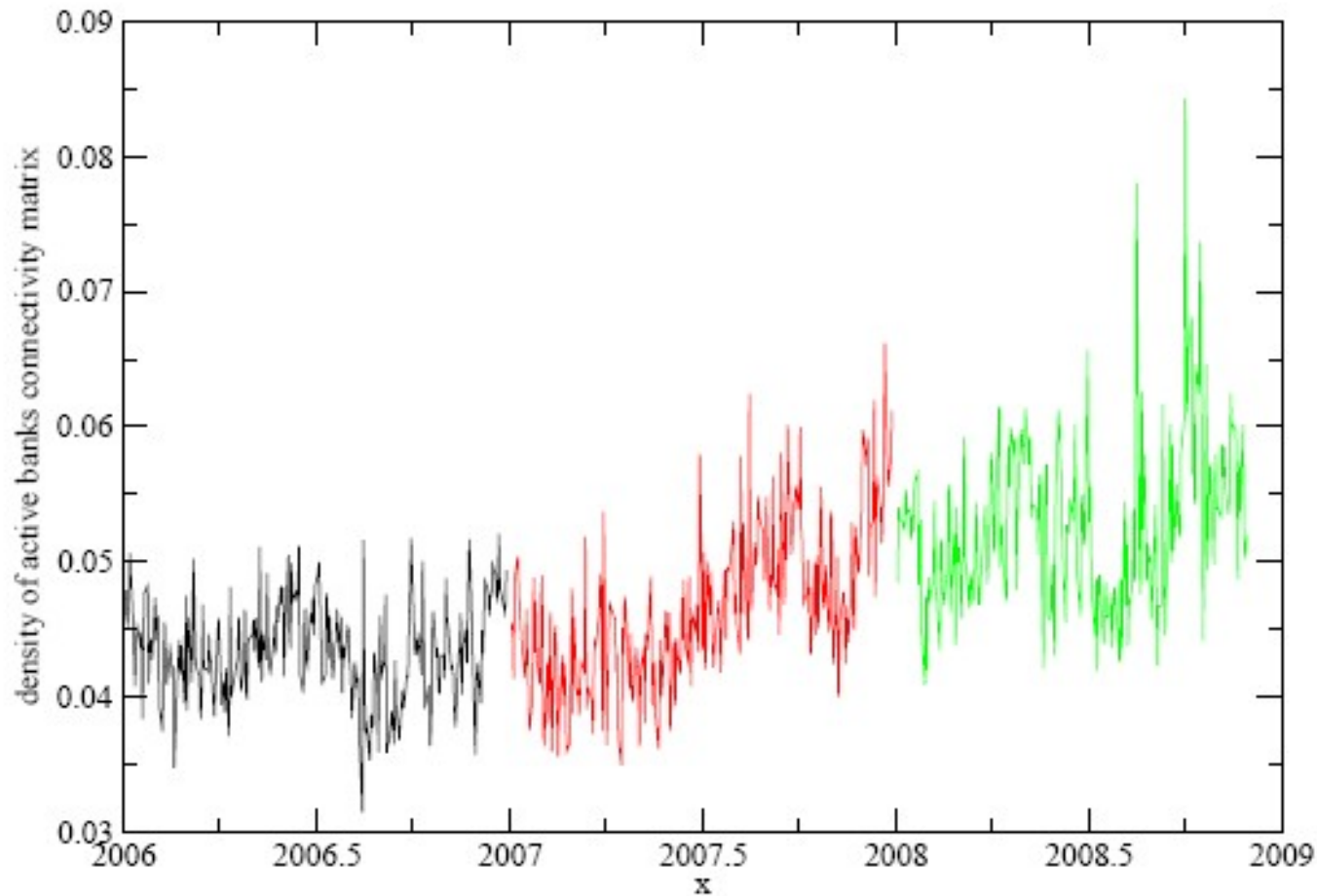
If all the weights are of the same order of magnitude then $Y_2 \sim 1/k_i$ but if a small number of weights are dominant then Y_2 is close to 1. A participation ratio close to unity indicates preferential relationships between banks.⁵ Similarly we can define the participation rates $Y_2^{w,b}(i)$ and $Y_2^{w,l}(i)$ separating incoming and outgoing links. The average participation ratio is then computed as

$$Y_2^w = \frac{1}{N} \sum_i Y_2^w(i), \quad Y_2^c = \frac{1}{N} \sum_i Y_2^c(i).$$

Y2 coefficient for transactions aggregated over a month period in 2006 (black), 2007 (red) and 2008 (green)



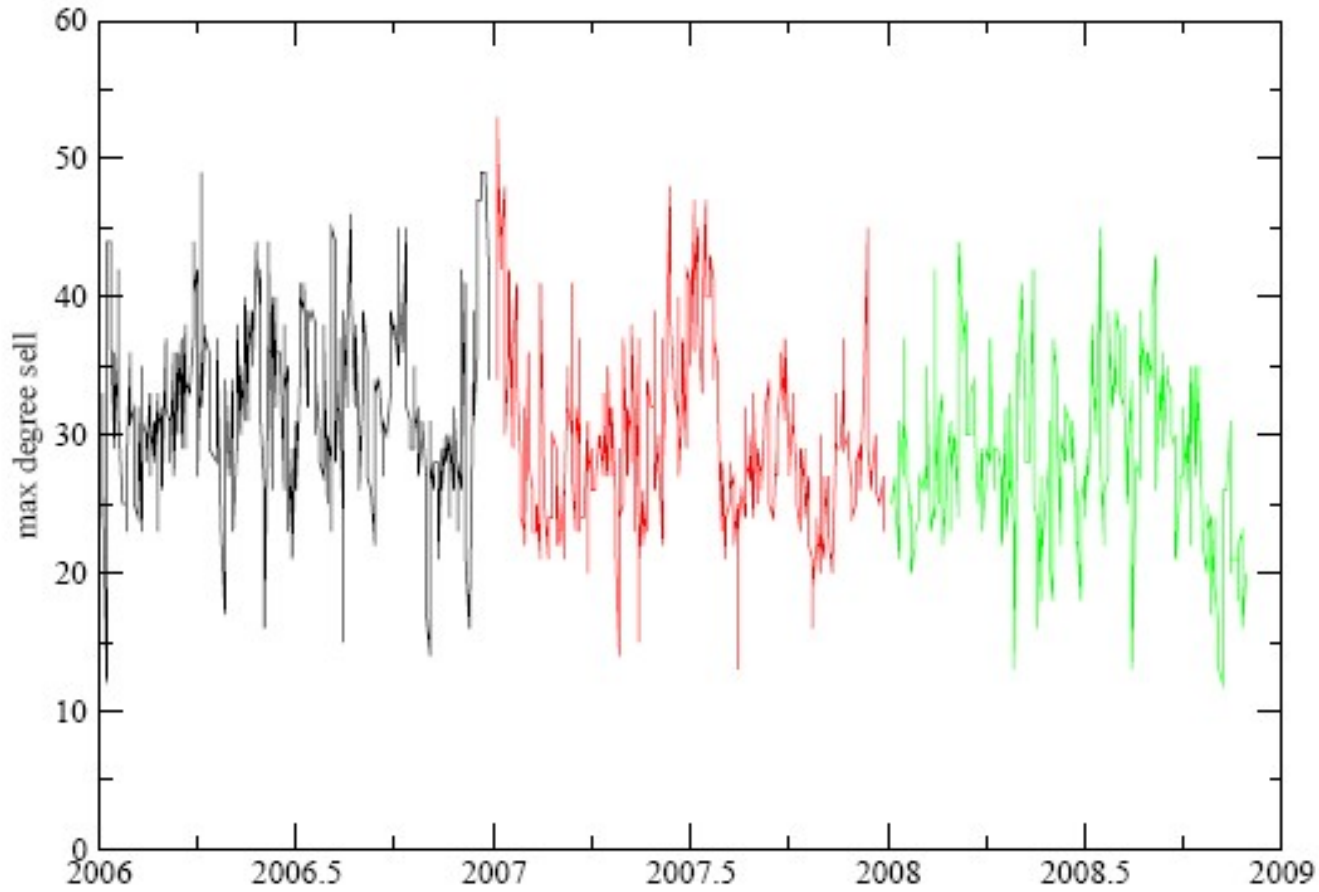
Fraction of active links in transaction matrix of active banks



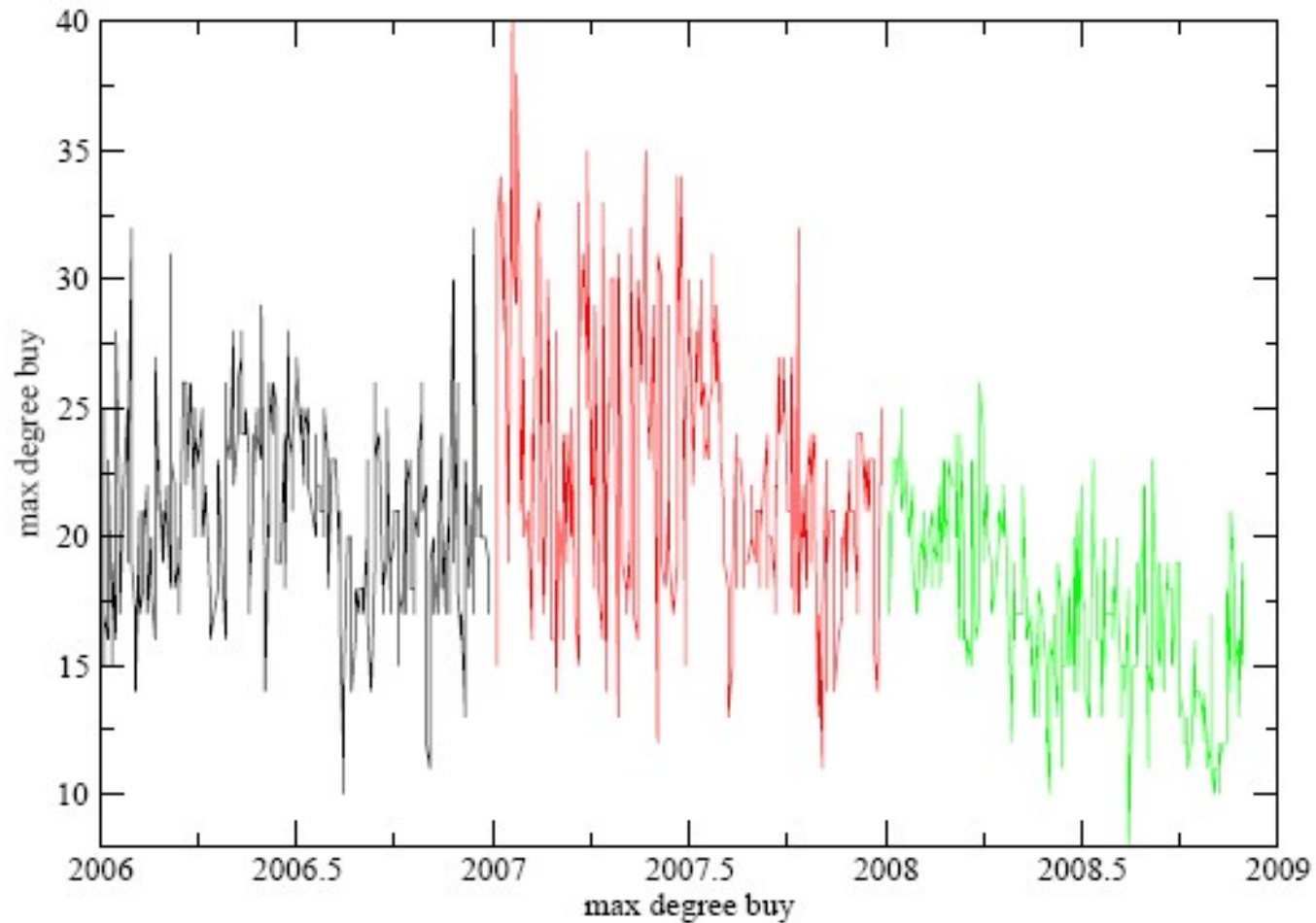
Degree

- The degree provides a measure of the number of counterparties a bank trades with (or lends and borrows in the case of directed networks).
- Random networks (i.e. networks where N nodes are connected at random with a given probability) are characterized by a Poisson distribution of degrees

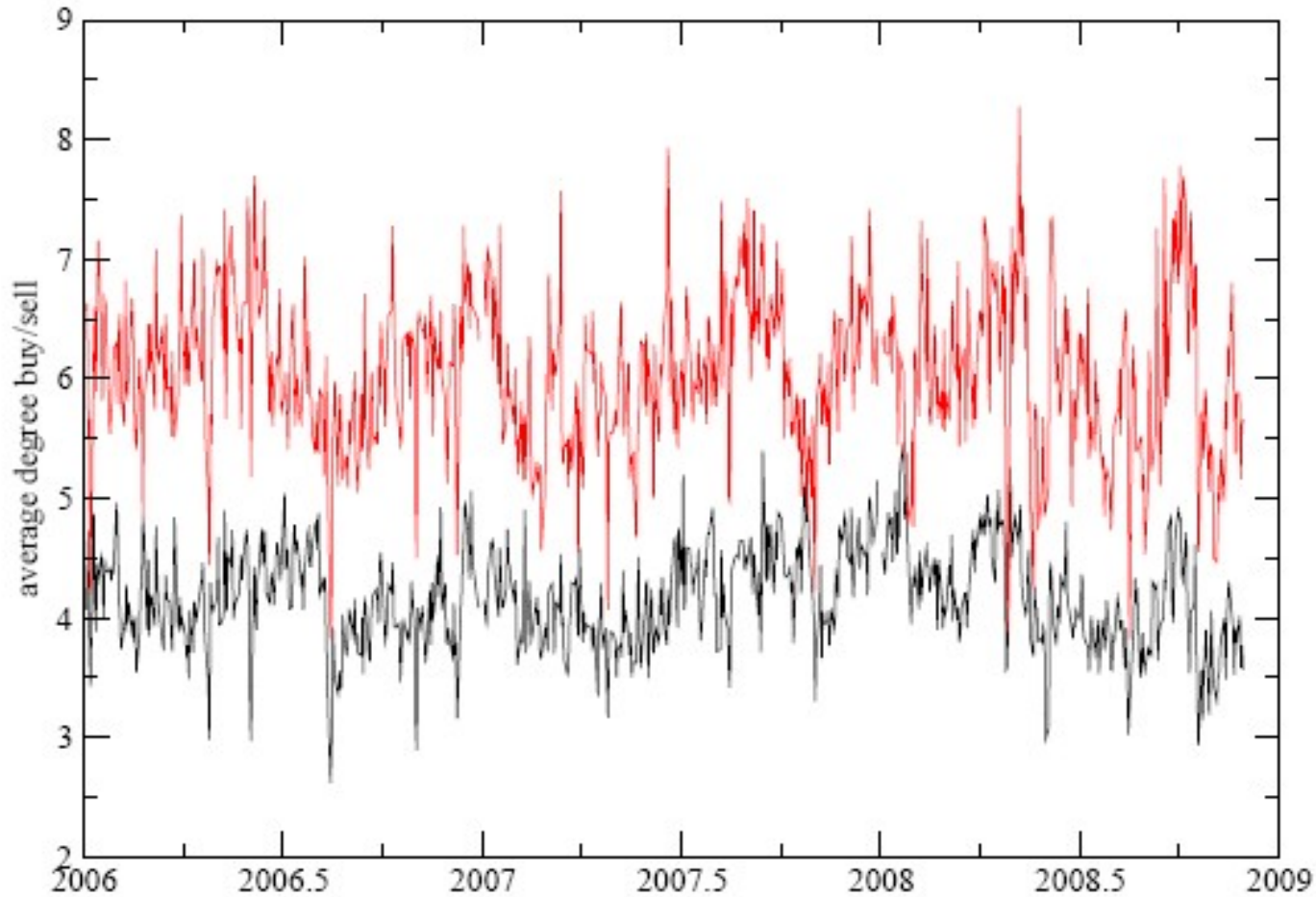
Maximum degree of selling banks



Maximum degree of buying banks



Average degree of buy banks (black) and sell banks (red)

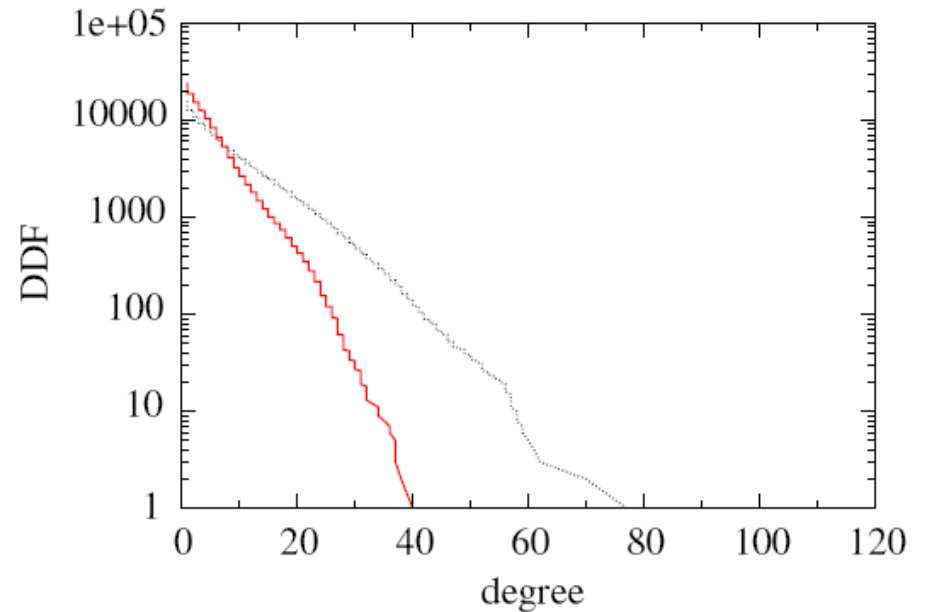
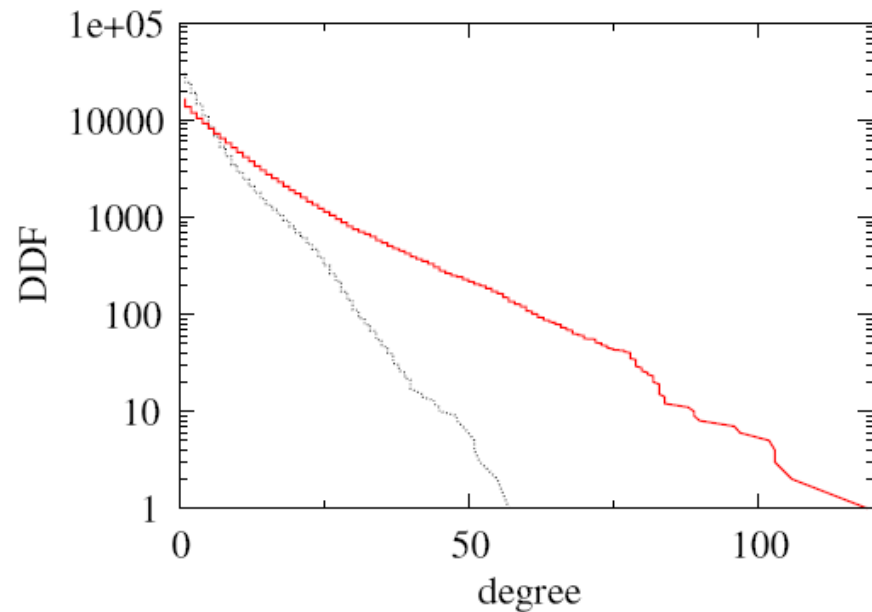


Decumulative density function (DDF)

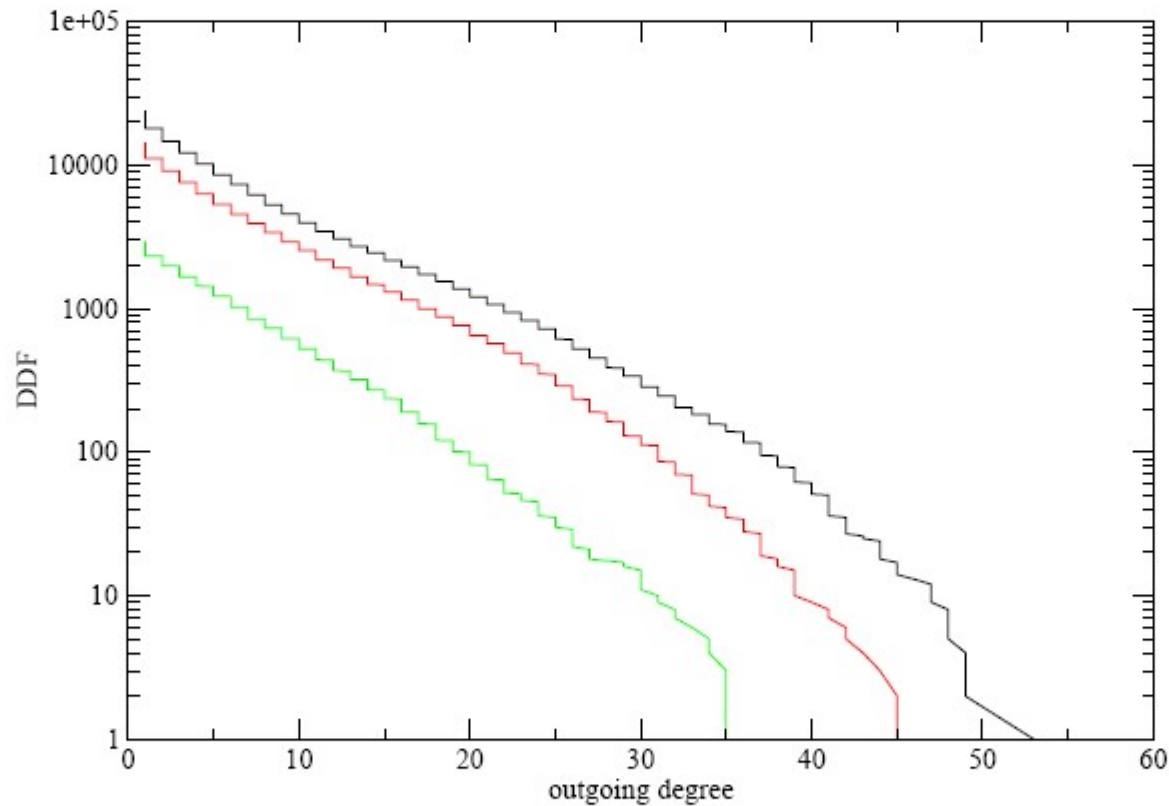
- In the 2008 study we compared the decumulative density function (DDF) of vertices' degrees and strength for the entire banking system.
- The maximum degree was lower in 2002 for both incoming and outgoing links as a consequence of a number of mergers between banks which has reduced the number of e-MID members from 215 in 1999 to 177 in 2002.
- The figure provides clear evidence that the market has undergone a transition over time, moving from a situation in 1999 when large lenders dominated large borrowers, and outgoing links were more numerous than incoming links, to the opposite situation in 2002.

Decumulative density function (DDF)

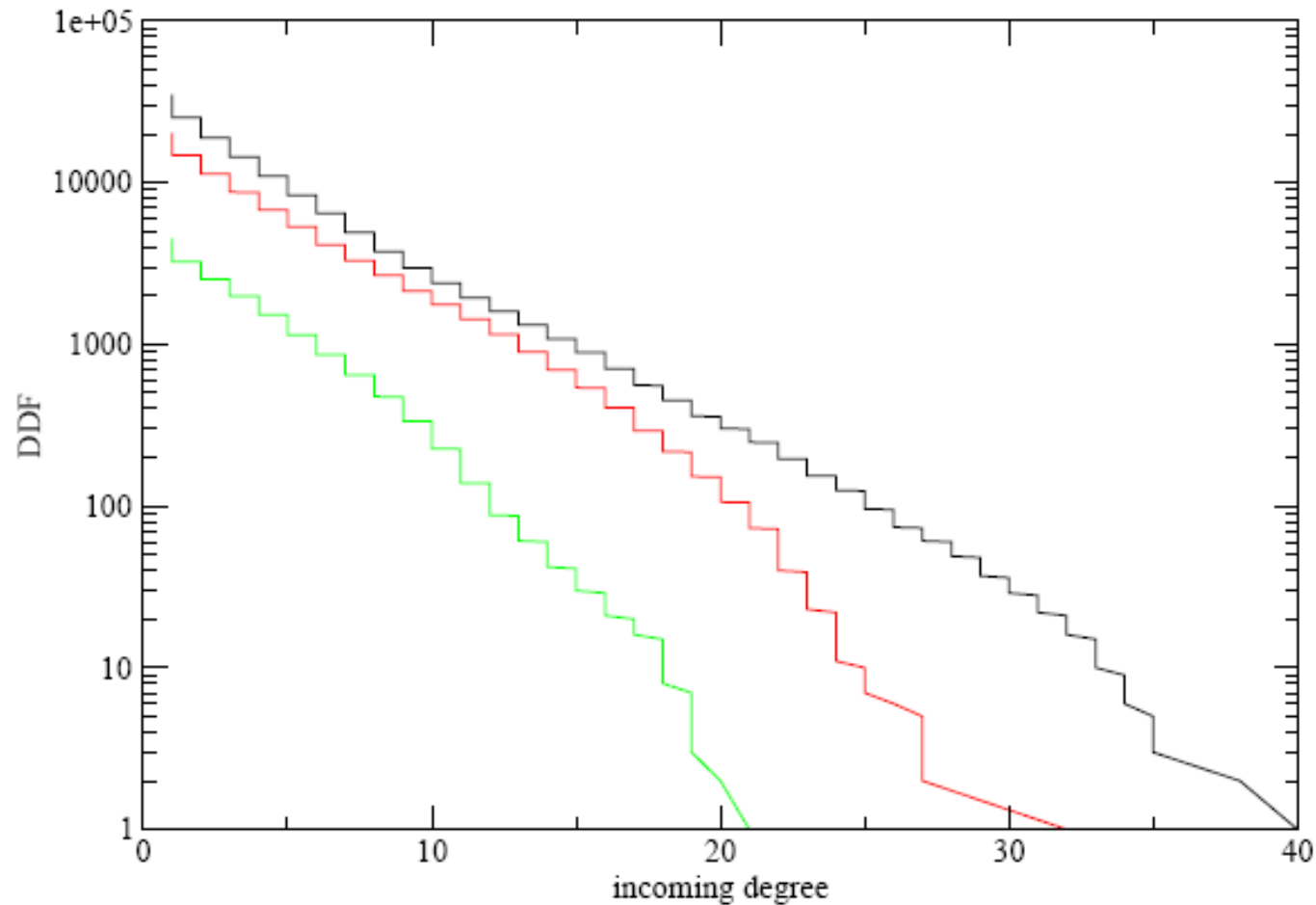
1999-2002: previous findings



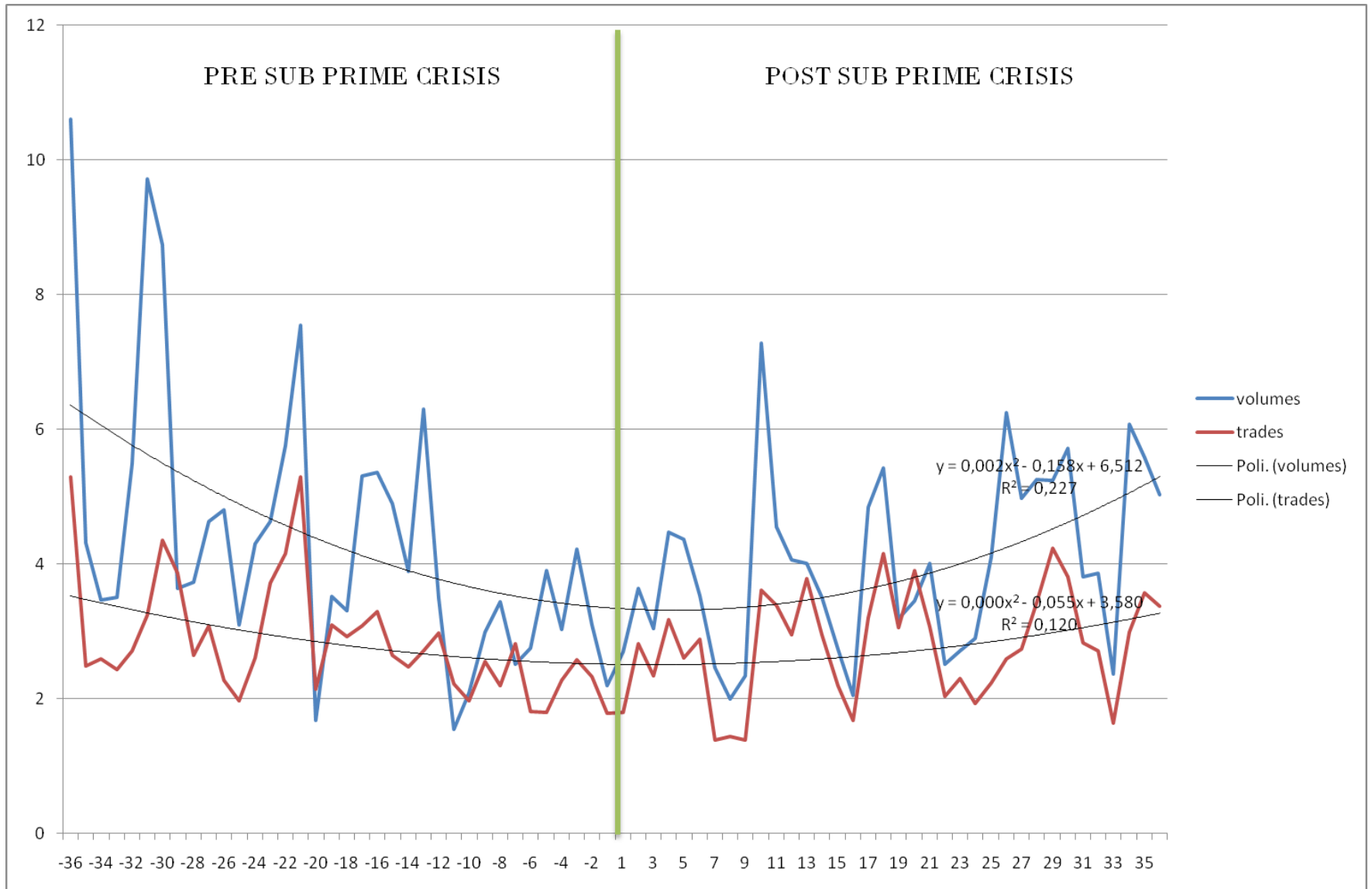
DDF of degree of sell banks pre (black), mid (red), post (green) crisis (OUTGOING)



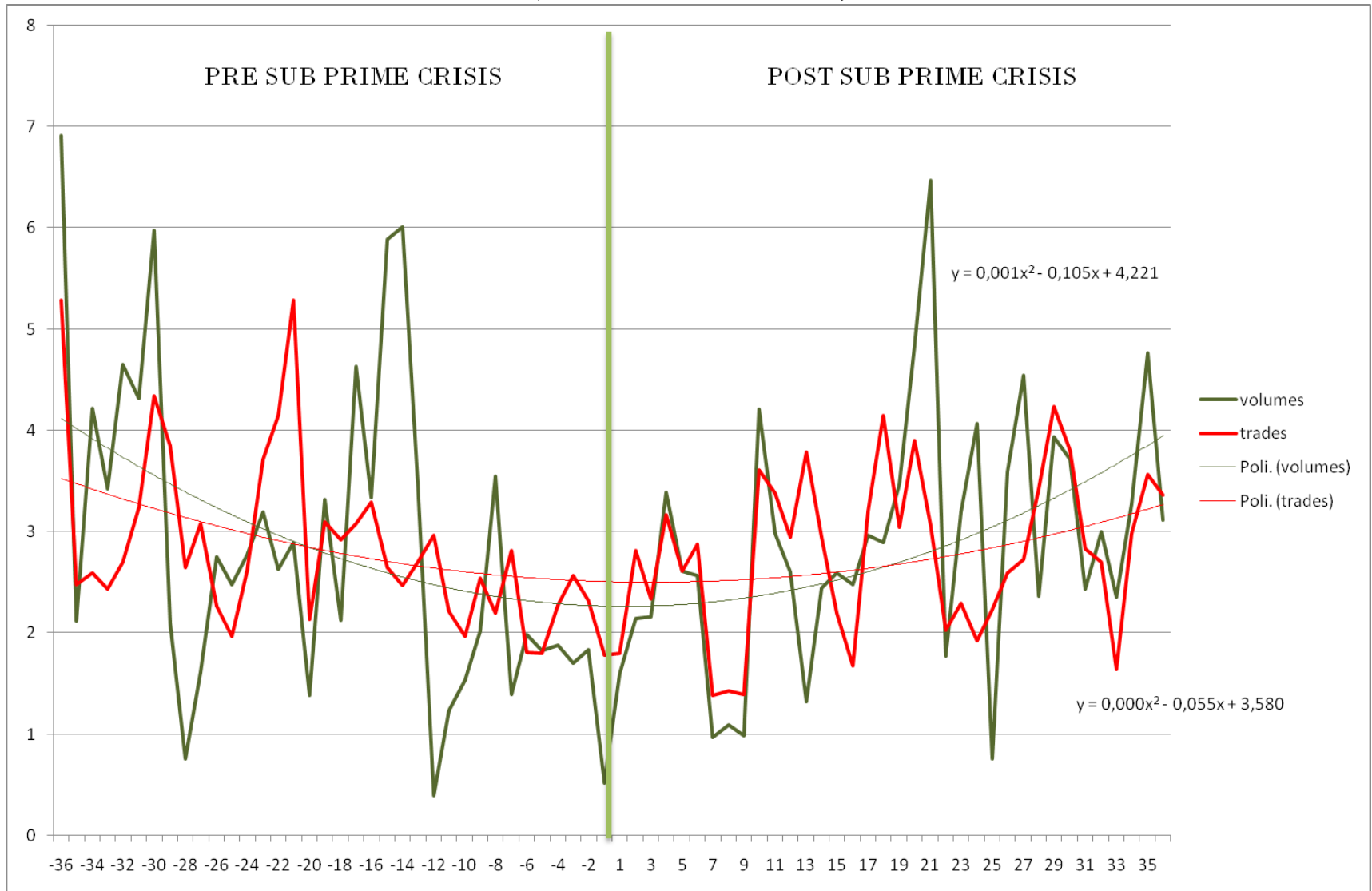
DDF of degree of buy banks pre (black), mid (red), post (green) crisis (INCOMING)



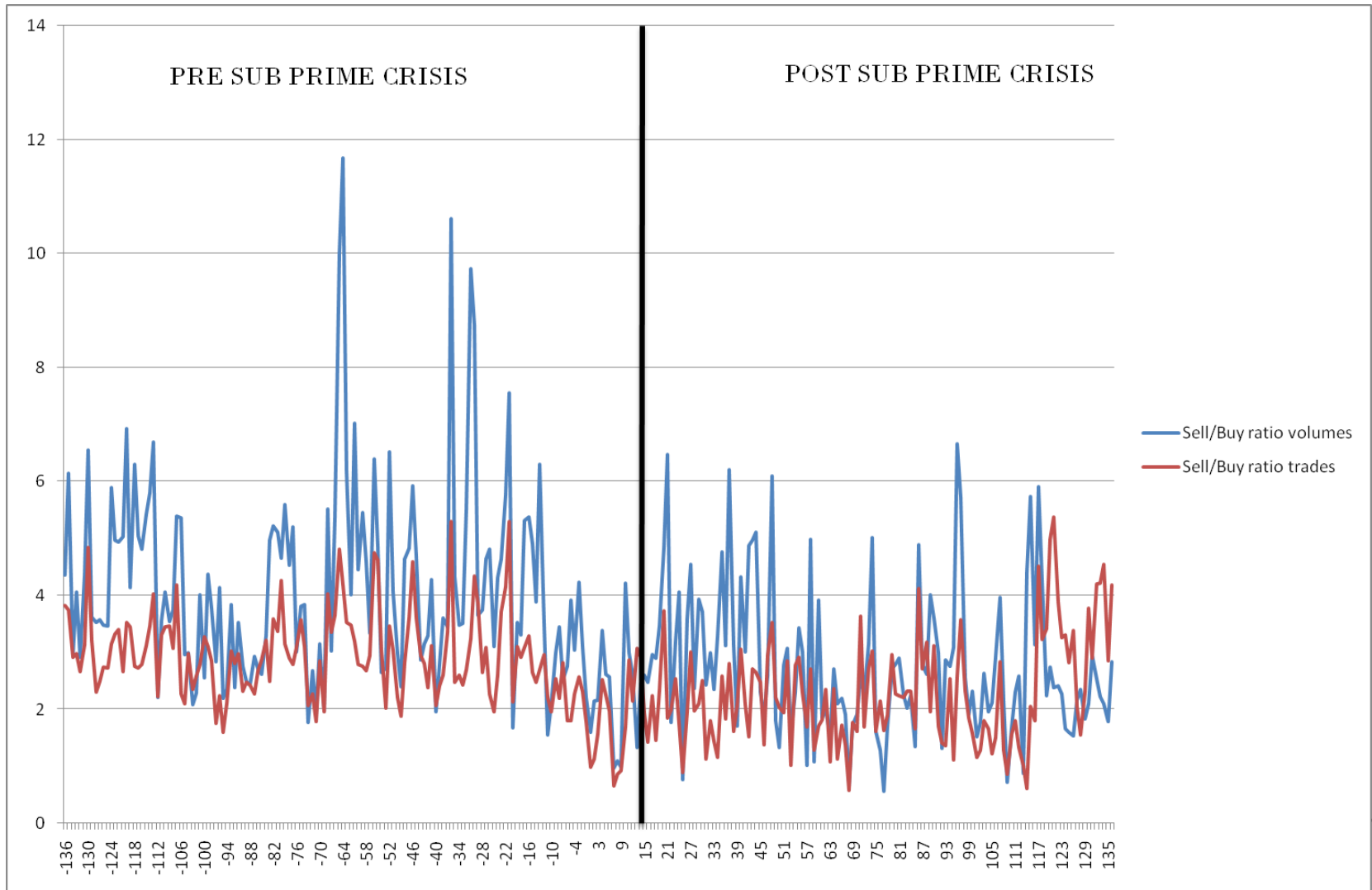
Sell/buy ratio (short run)



Sell/buy ratio weighted by time horizon (short run)



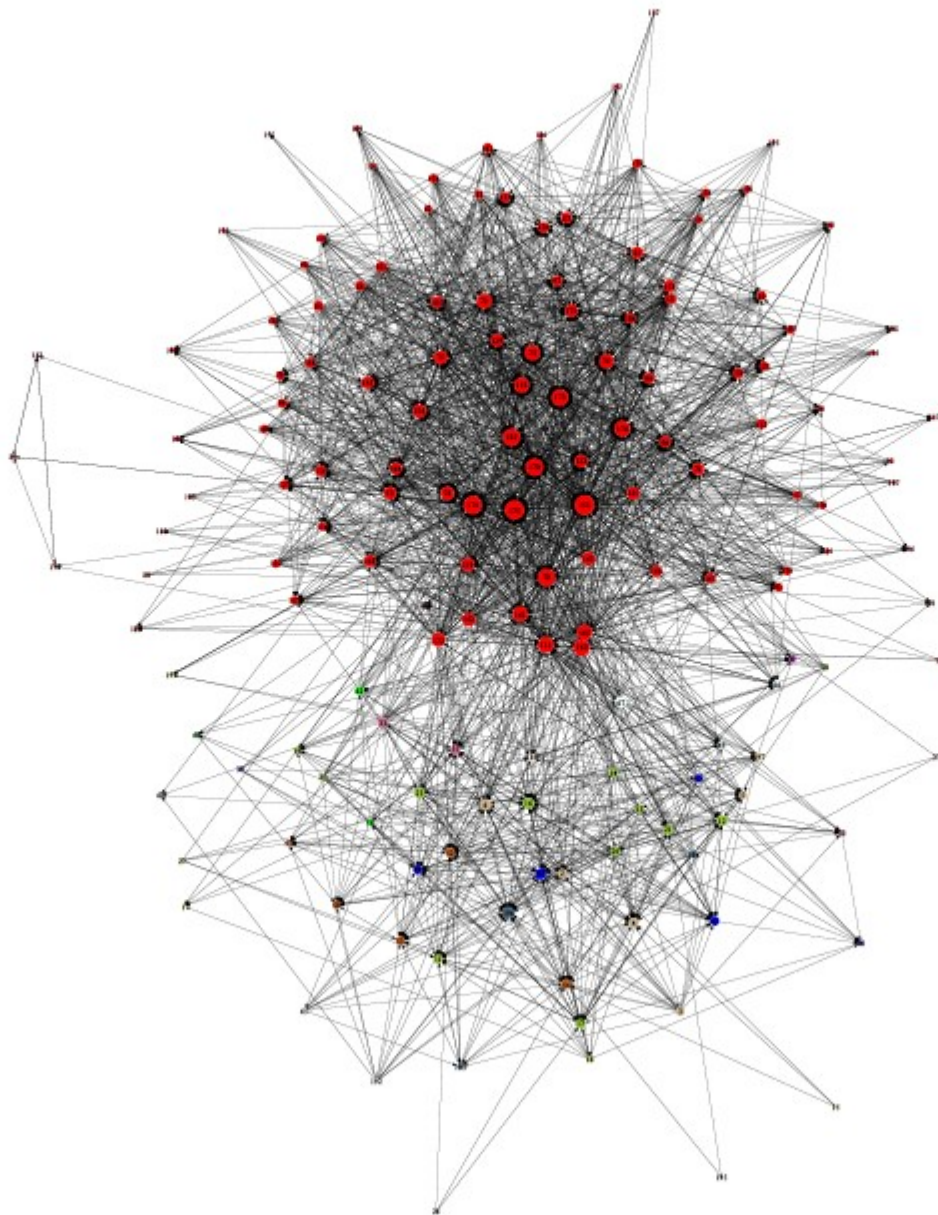
Sell/buy ratio (long run)



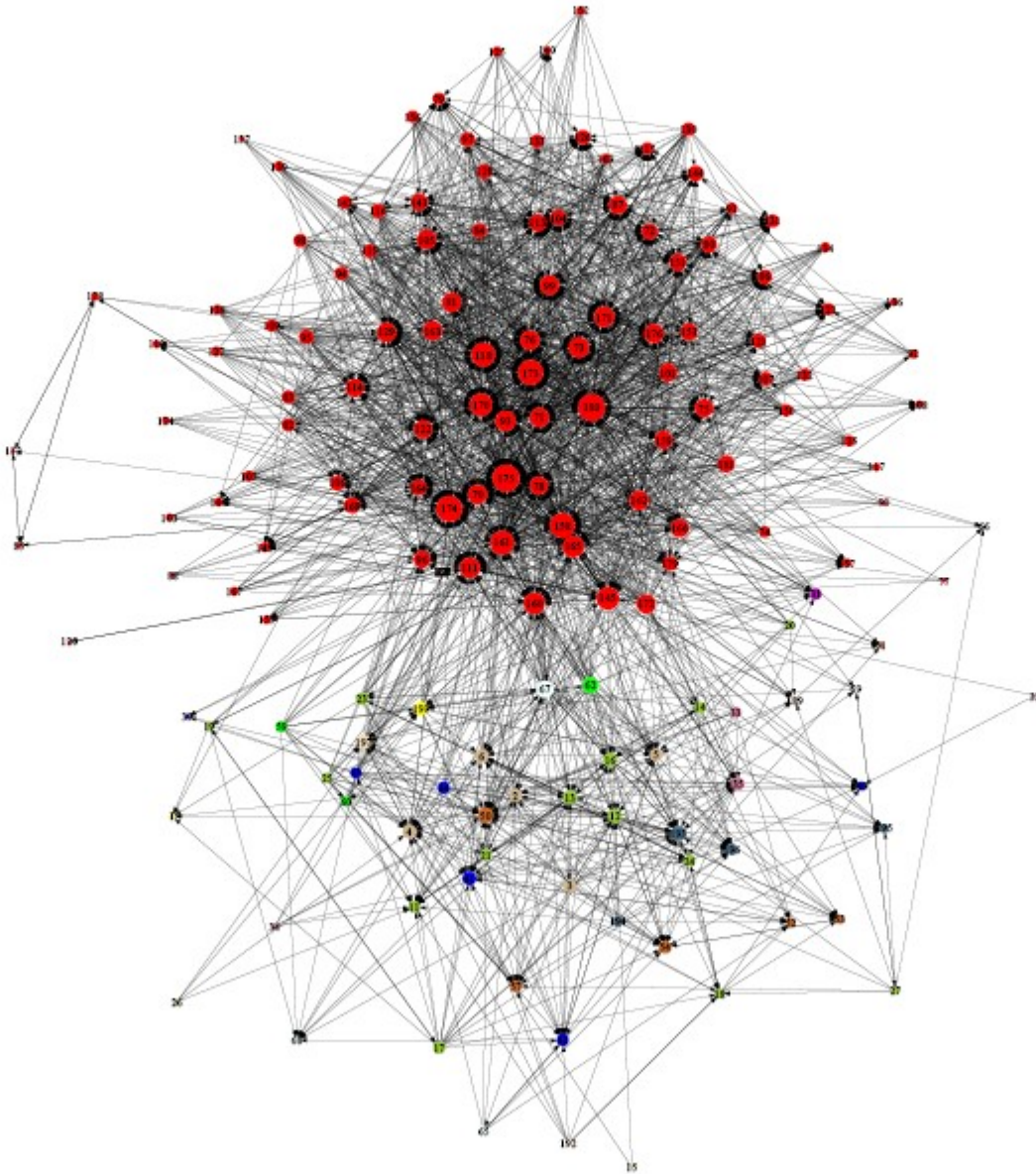
Topology of interbank networks

- Red dots are Italian banks, colorful dots are foreign banks.
- The size of the dots is proportional to the volume traded by each bank.
- Country color code
 - AT yellow
 - BE tan
 - CH brown
 - DE yellow green
 - DK magenta
 - ES pale violet
 - FR blue
 - GB chocolate
 - GR green
 - IE azure
 - IT red
 - LU antique white
 - NL sky blue
 - NO wheat
 - PL linen
 - PT grey

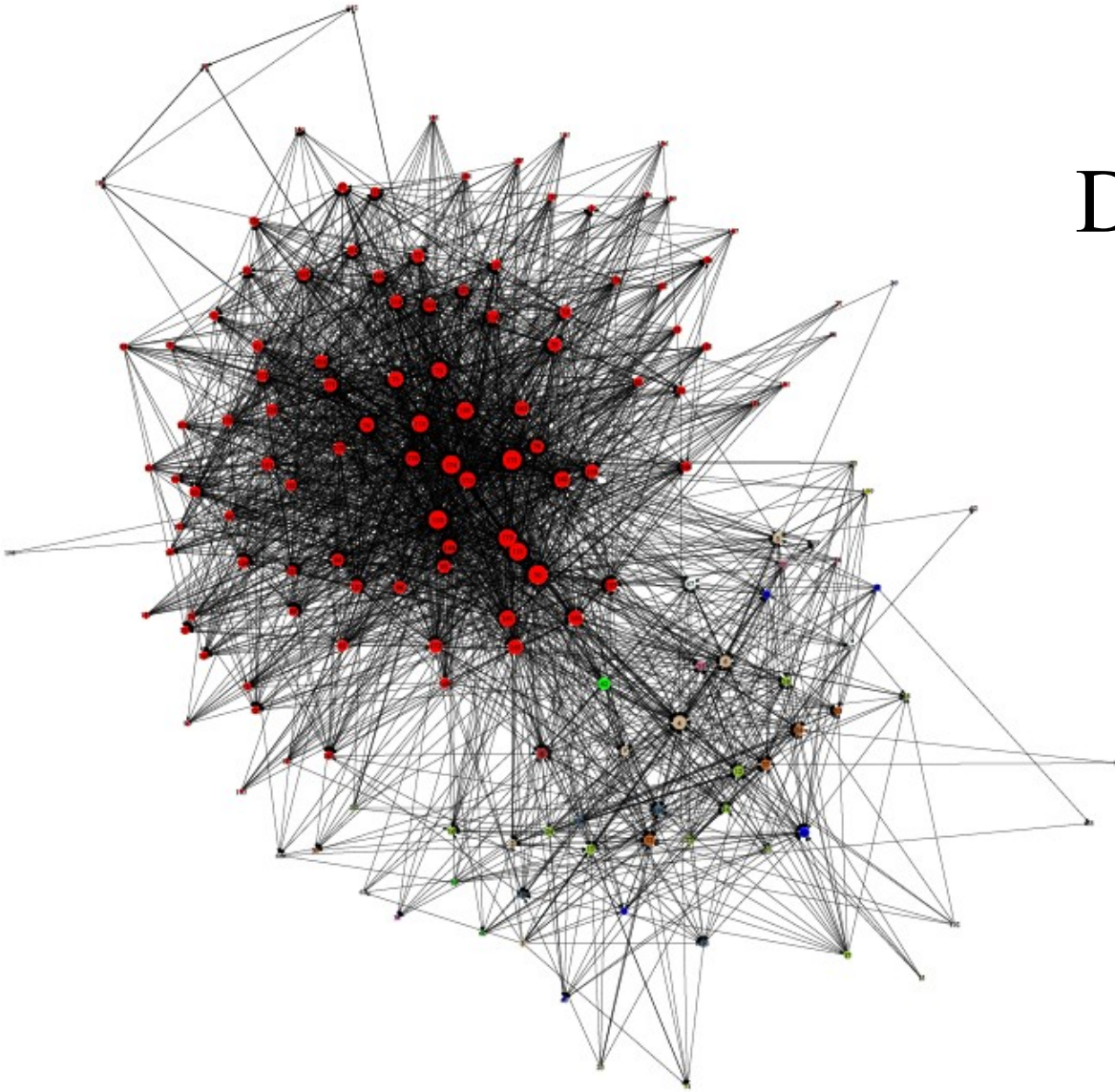
July 2006



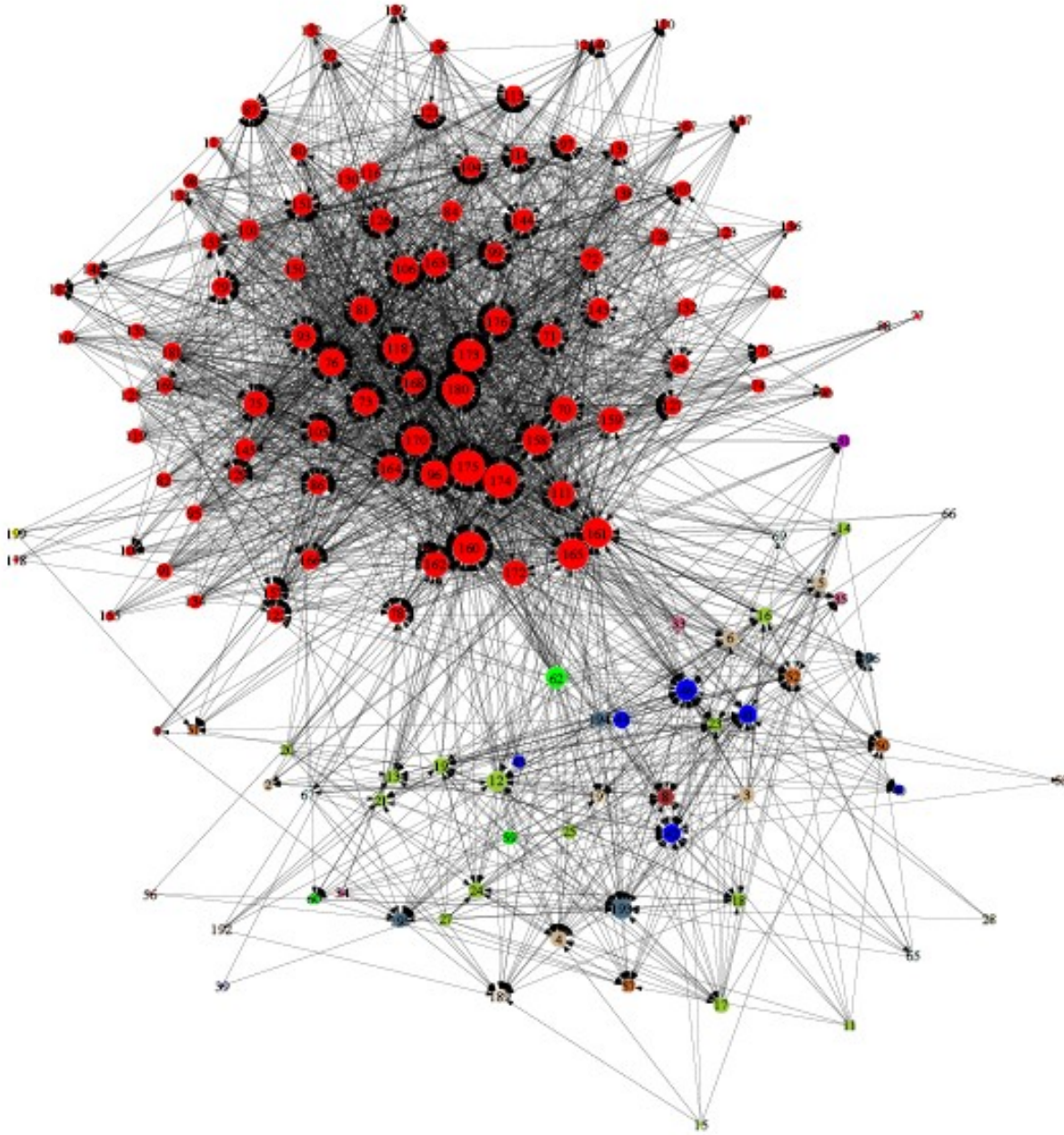
September 2006



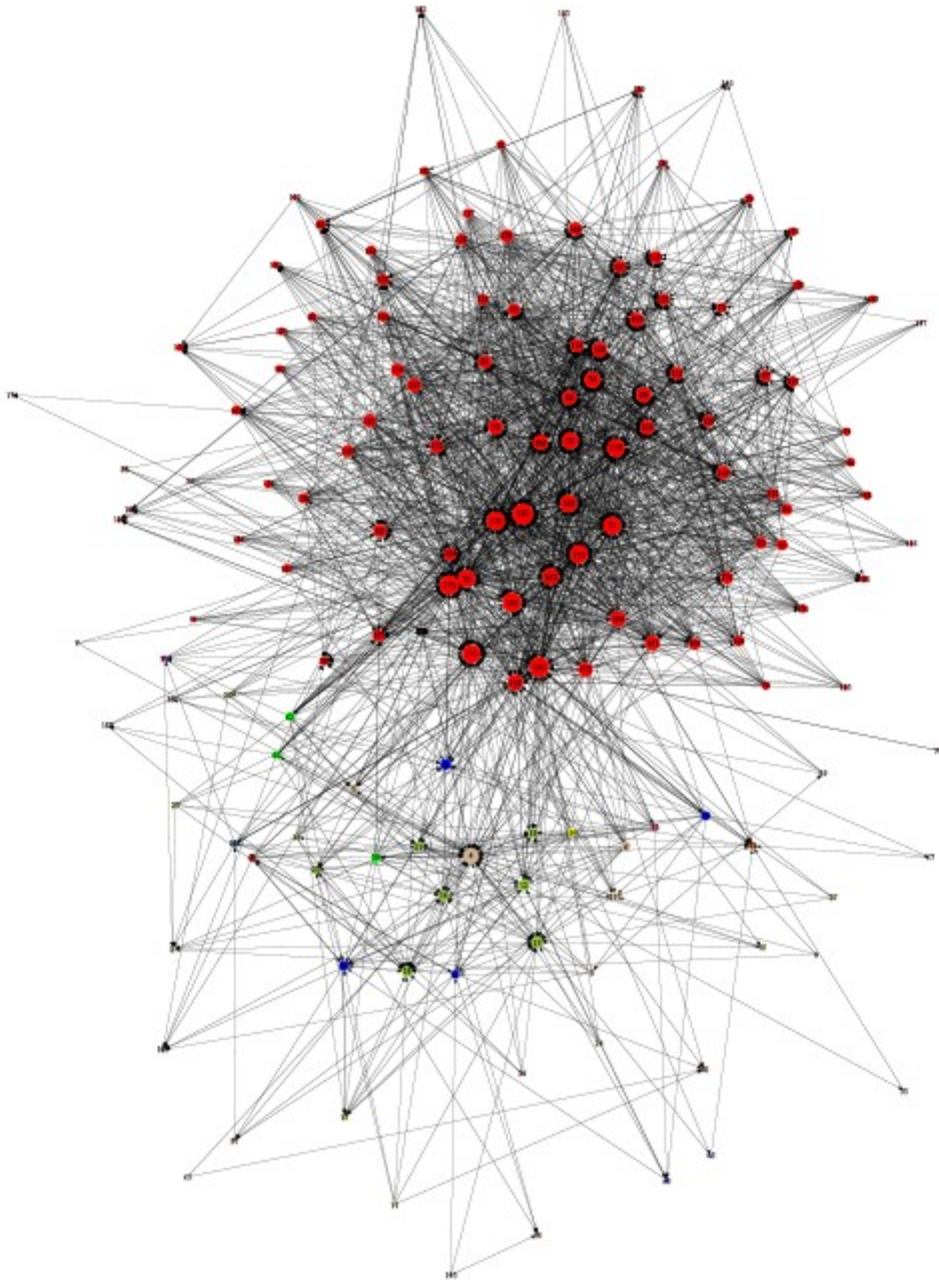
December 2006



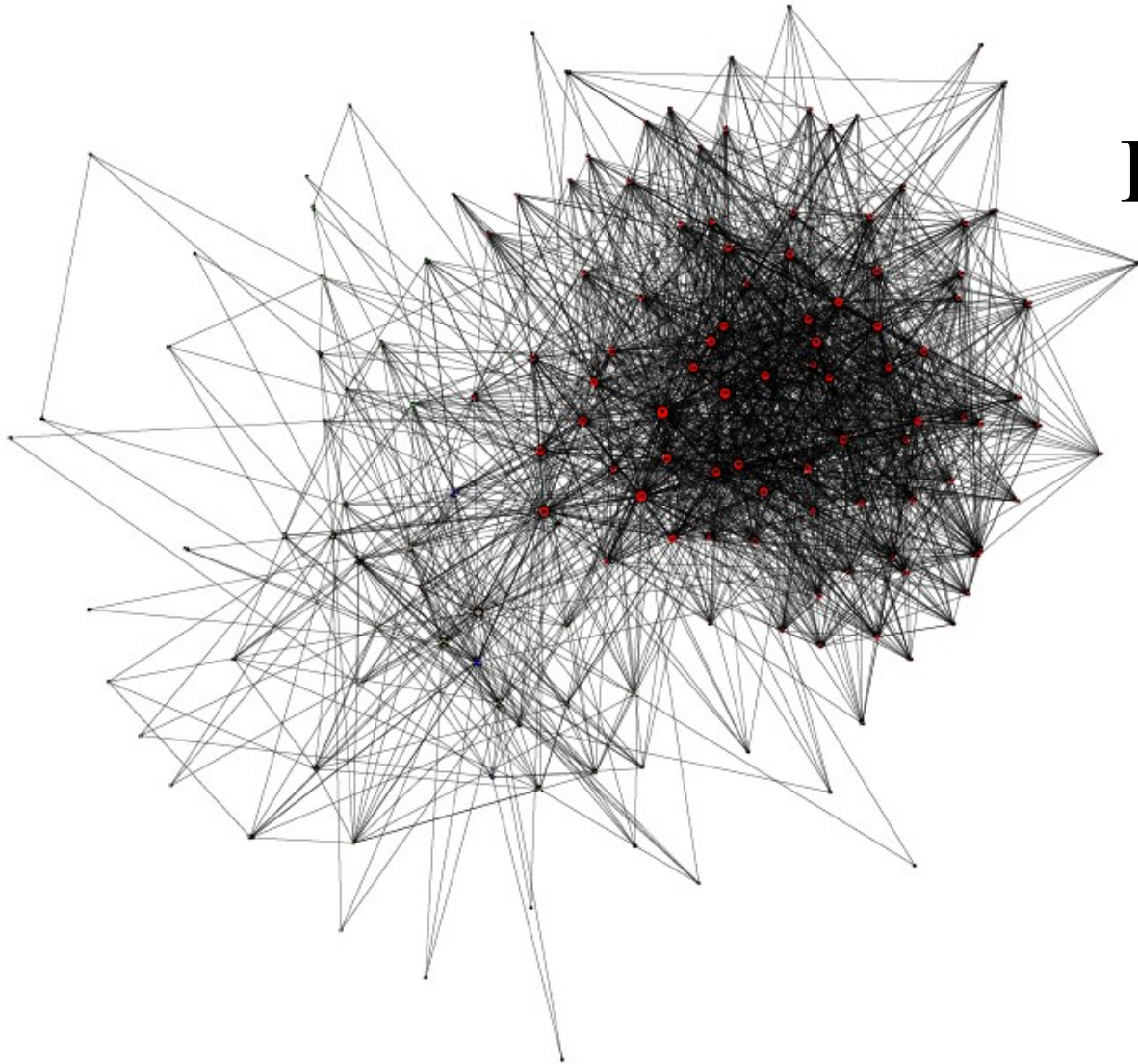
July 2007

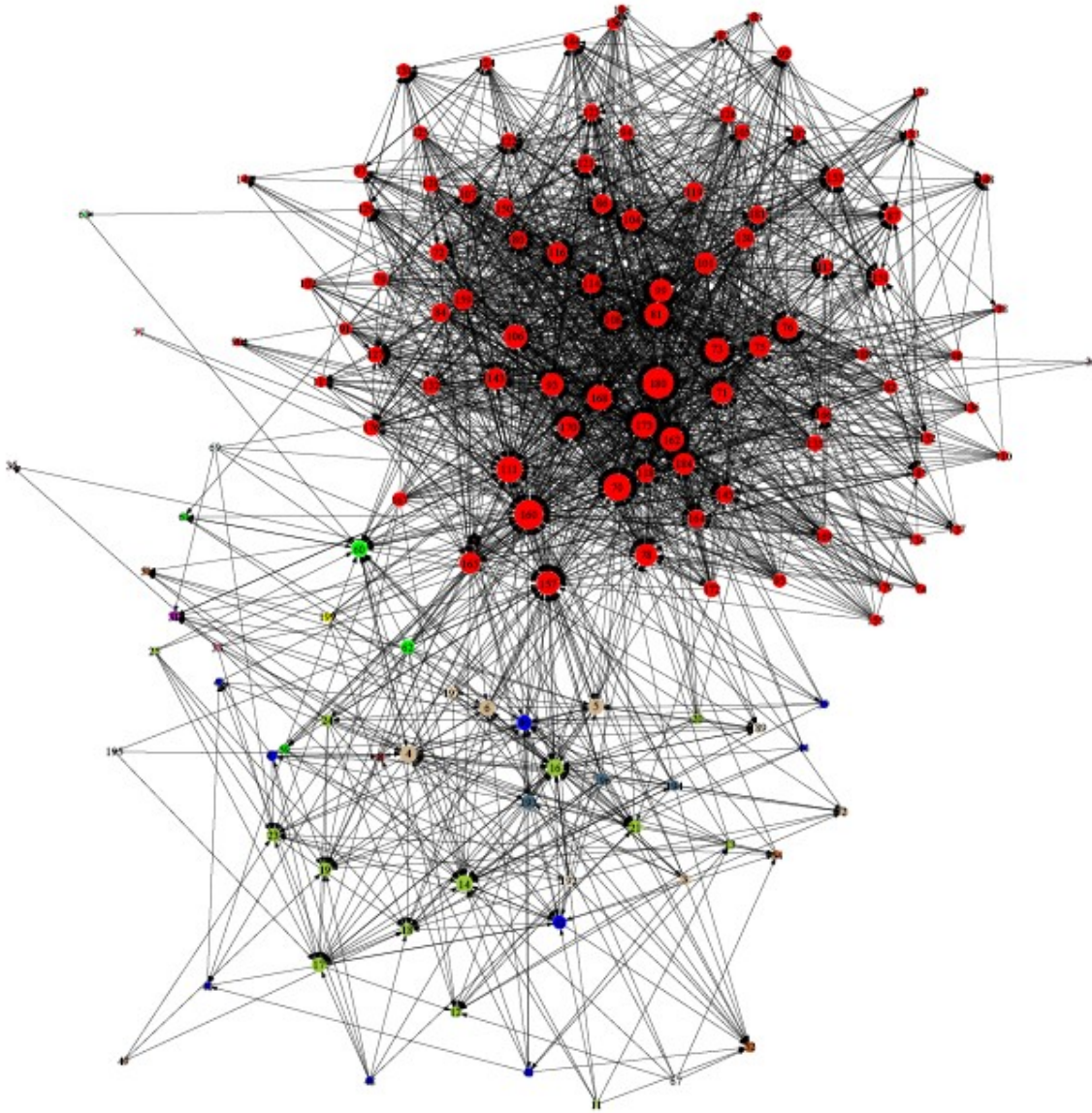


September 2007



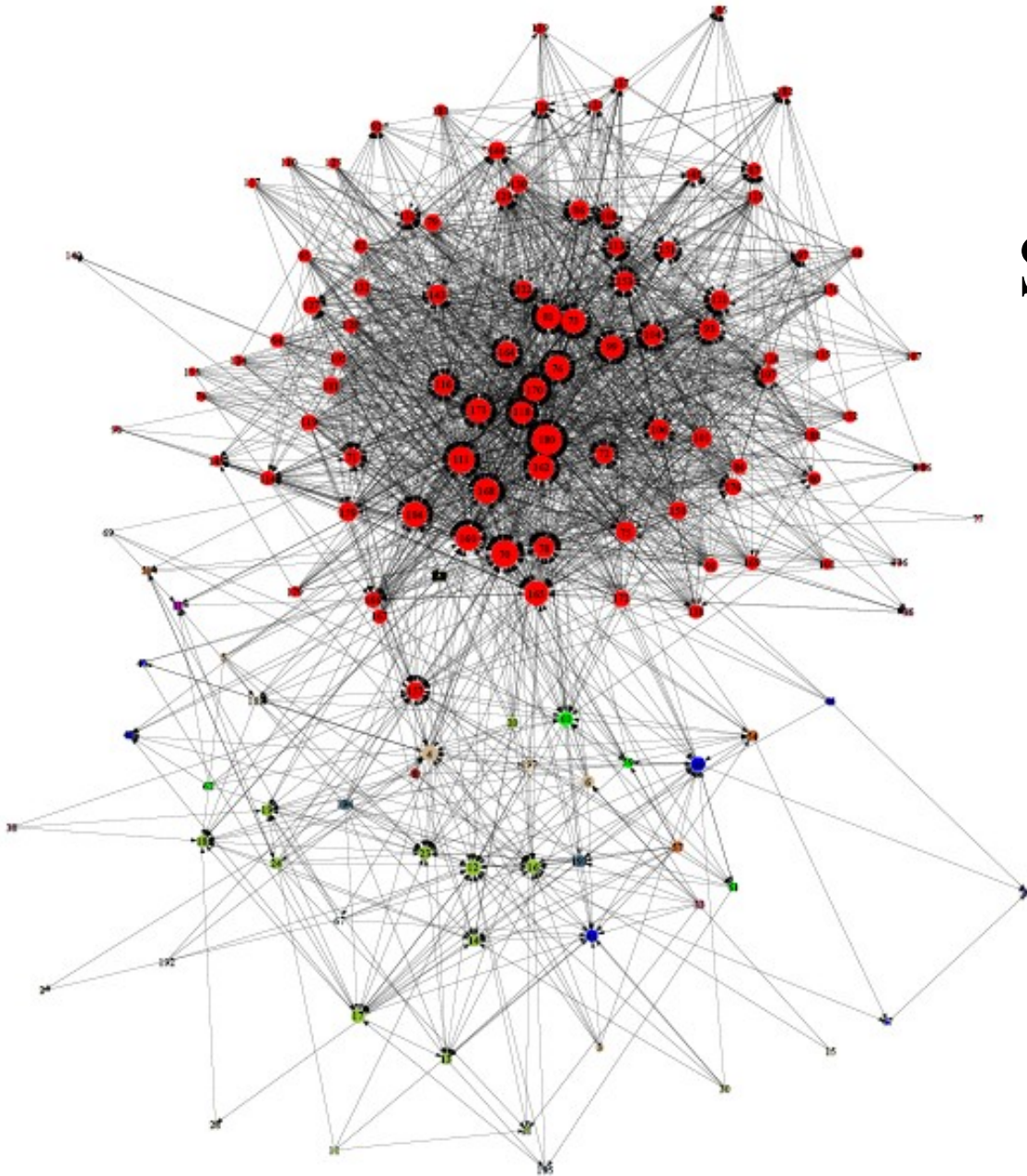
December 2007

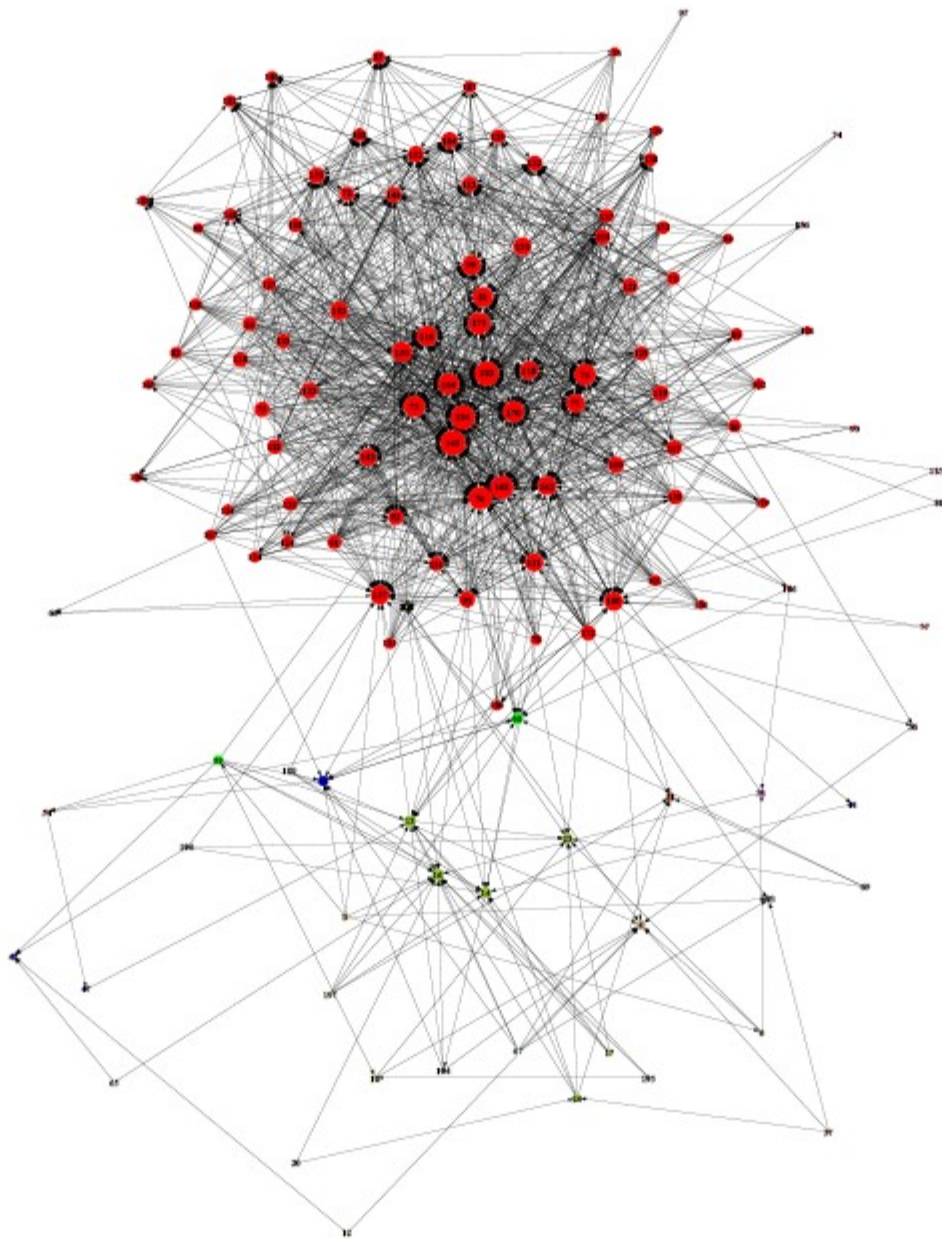




July 2008

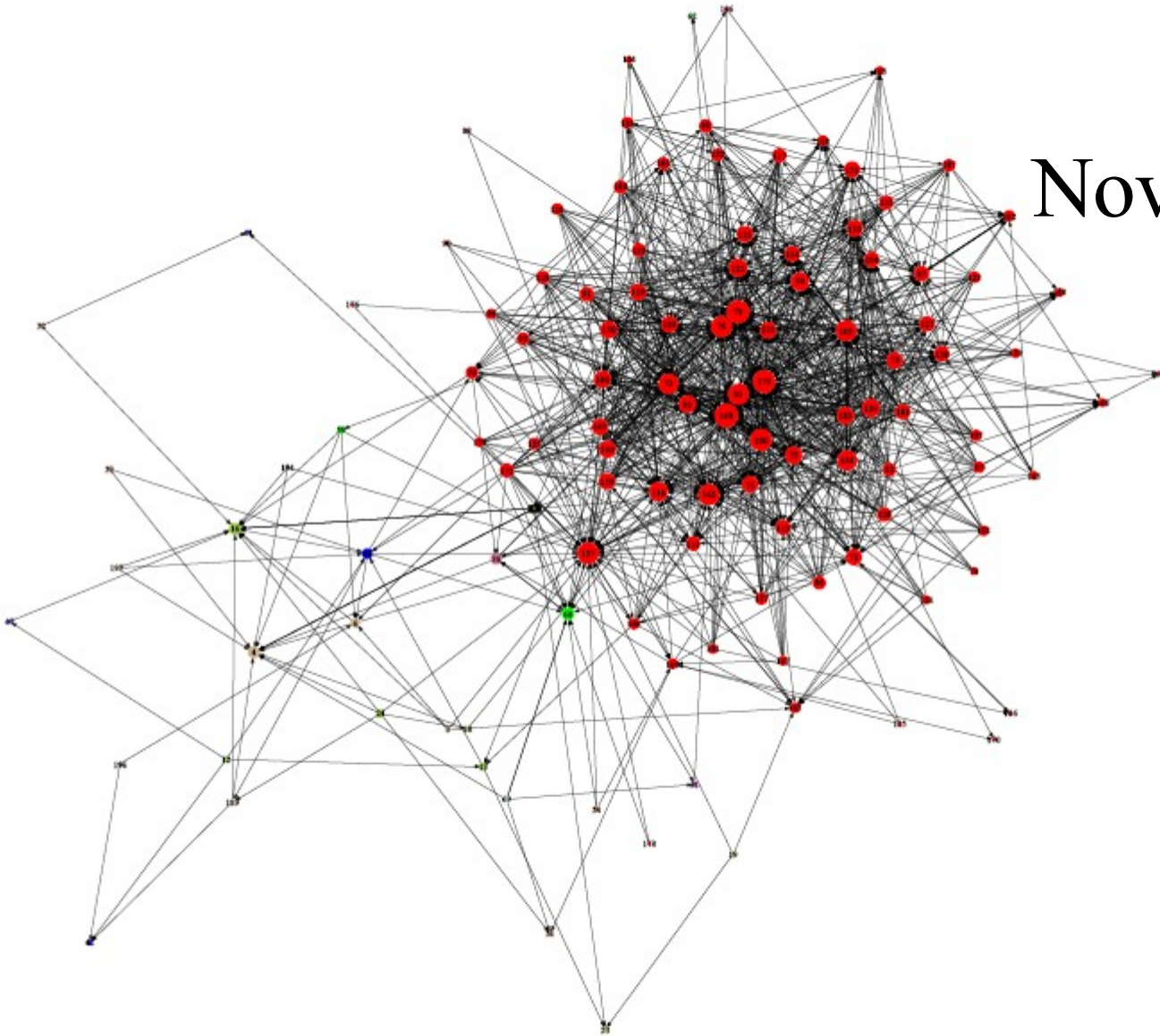
September 2008



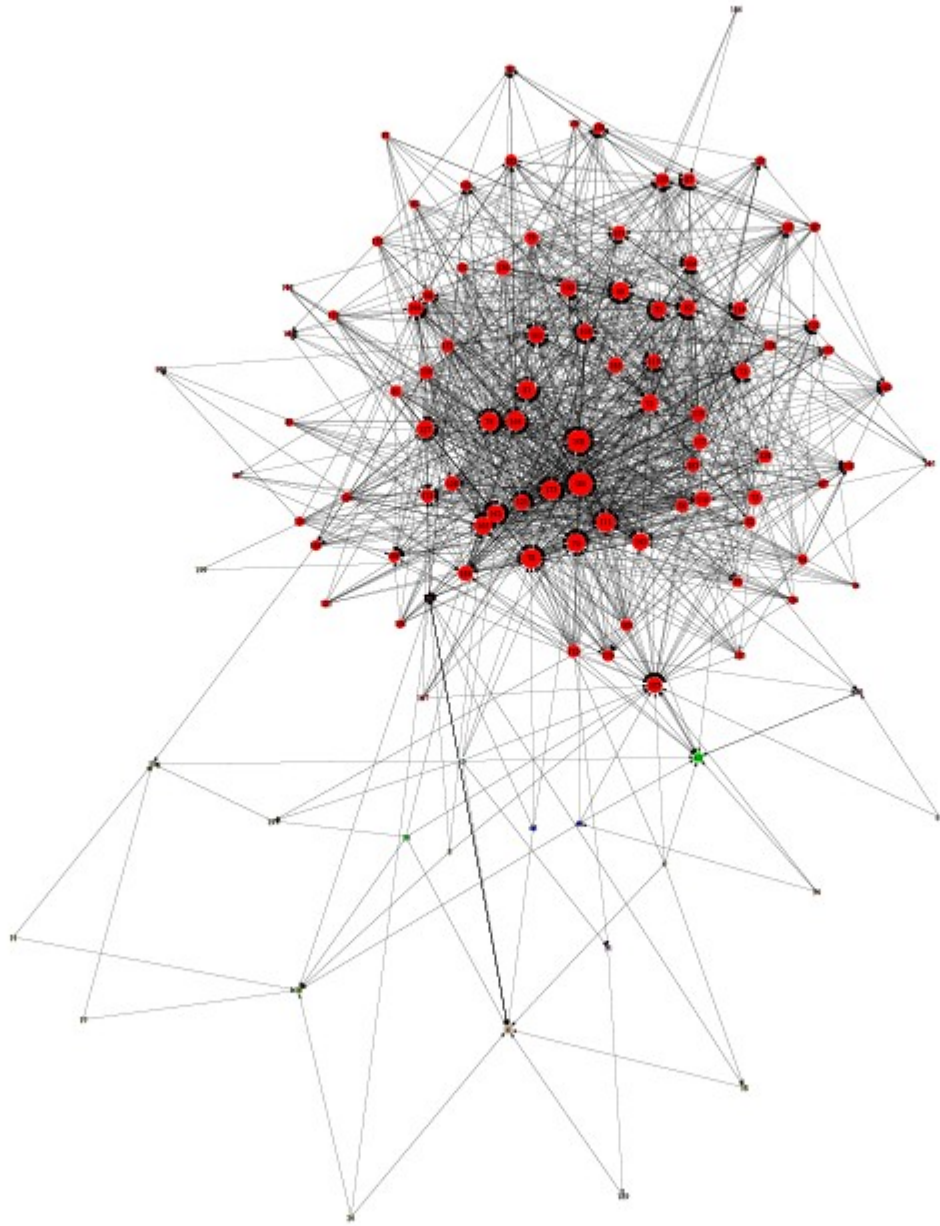


October 2008

November 2008



December 2008



Findings question no. 4

- The daily overlap shows that the network stability is significant until spring 2007. The number of common links among networks drops in May 2007, to stay low until March 2008. The highest value for the overlaps was shown in December 2008.
- The clustering normalized coefficient shows no early warning before the sub prime crisis, and even after that the values are homogeneous with the previous ones. The shock is recorded in October 2008, after Lehman
- The participation ratio shows an increase (far from 1) in 2008 and after Lehman above all. Before the sub prime crisis the value was at the minimum value of our series.
- The degree of the networks raises in the early months of 2007. The lowest values are recorded in 2008.
- The DDF shows that the degree drops during the crisis both for incoming and outgoing banks
- The sell/buy ratio is evidence for a change in the pattern exactly in July/August 2007
- Until July 2007 the structure of the networks was characterized by relatively significant hubs and a two polarized architecture. After the crisis, the networks displays the reduction of the hub's size and number and a network architecture which seems to start generating different poles, based on country based banks.

Conclusions

- The interbank structure changed dramatically after the crisis, in terms of trades, volumes and volatility
- While this first outcome was already demonstrated by empirical evidences, our study shows some new findings:
 - Daily volumes per trade decreased especially in the short maturities. Banks showed a preference for long deposits, from spring 2007. The same with interest rate volatility.
 - Buyers and sellers become more sensitive to the counterparty risk. This can be seen looking at buy spread change and the probability density function as well
 - After the crisis, banks seem to go back to a domestic preference, generating new network links, essentially due to information asymmetries and the uncertainty with regulators behaviour in case of systemic risk and difference of bail out solutions
 - Finally, the network analysis shows some changes in their architecture after the crisis, with a reduction of hubs dangerous in case of systemic crisis. This transformation was endogenously produced by the reduction of the risk appetite, after the sub prime crisis and the risk of bank collapses after Lehman.

Implications

- Improve the international collaboration among regulators as the markets become more open to international trades
- In case of crisis the effect is to implode towards national systems where regulation and bail out solutions are more clear
- Increase the study of network metrics changes in order to detect latent proxies for emerging risks, especially in a Basle 2 environment aimed at increasing tools aimed at facing domino effect within the financial system