Aalto University
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The World's Most Important Number Is Broken - Review of Reference Interest Rates

Economics

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ABSTRACT

This thesis studies the validity of unsecured interbank benchmark rates Euribor and Libor. In addition to the representativeness issues arising from the decline of unsecured interbank market activity, the reference rates have been subject to manipulation. I reviewed the manipulation scandal, and the academic studies related to it and contributed to the academic literature with my own empirical analysis. In the analysis, I studied the implied risk spread of individual banks' 12 month euro Libor submissions' co-integration relationship to maturity matched credit default swap rates (CDS) of the corresponding banks. I found evidence that during the years 2007-2009 the manipulation was more widespread than what was considered by the authorities. In addition, some banks continued (2009-) submitting rates that are not in line with their CDS rates. These findings speak for the necessity of ongoing reference rate reform. In addition, the methods presented in this thesis could be employed in the Libor quality monitoring.

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1 INTRODUCTION

Although Libor (London Interbank offered rate) is often called “the world’s most important number” (Abrantes-Metz & Evans, 2012) it is not a number, but actually a set of figures. To be precise, Libor is 37 figures that indicate interest rates of unsecured interbank transactions in 5 different currencies, and those figures are referred by contracts with notional value of thousands of billions. As a result of recent developments in the money market and the manipulation scandal in the rate setting, one could easily argue that those rates have been broken, if not anymore, at least for some time.

The history of the reference rates dates to 1980’s. At that time demand for standardized reference rate system grew together with the growth of popularity of financial derivative contracts (BBA libor, 2014). Since then reference rates such as Libor have been important institutions in the financial world (Brousseau, Chailloux, & Durré, 2013). Currently financial derivative contracts with nominal value of hundreds of thousands of billions have their cash flows determined by Libor and Euribor fixings (ECB, 2013a). Besides of derivative contracts, Libor and Euribor rates are used as reference rates in bank loans. For example, in Finland 93 % of mortgage stock is linked to Euribor rates (ECB, 2013a). In addition, reference rates provide useful information about ‘over the counter’ (OTC) interbank markets, which otherwise would be much more opaque. The reference rates are an important financial institution and their validity should be of great concern to the financial world. Invalid rates can cause substantial financial stability issues (Bank for International Settlements, 2013).

The validity issues comes in many forms: those related to the lack of representativeness of the rates, and the one with greater emphasis in this thesis, the direct manipulation of the rates. The representativeness is related to the fact that the unsecured money market is not as important source of bank funding as it used to be. Since the crisis the interbank market activity has been contracting and especially in the longer term secured lending has replaced unsecured. The weakening link between bank funding conditions and reference rates causes a mismatch between the properties and the end use of reference rates.

To understand how the manipulation is possible, it is important to know how the rates are formed. Libor and Euribor rates are generated daily by panel that consists of the largest banks in their respective markets. Libor panel is located in London whereas Euribor panel banks are mainly from euro countries. Neither of the reference rates are direct transaction-based rates, but instead, are formed based on expert judgment about prevailing market rates. Libor and Euribor formation process was considered somewhat a trivial fact before the manipulation scandal. From 2005 till 2011 traders of panel banks were trying to push the rates to a direction that would benefit their own or bank's good. Besides of portfolio manipulation, Barclays was found guilty of submitting lower Libor than actual unsecured funding rate. Barclays did this to avoid negative media attention.

The representativeness issues and the manipulation scandal are interrelated. During the crisis, rate submission must have been challenging due to the lack of market data. Low volume and low transparency in the underlying market made it difficult to separate manipulation from other sources of variation in the rates. Hence, it is not surprising that it took quite long before authorities started the investigations. Given the vital role of the reference rates in financial world and their high economic value, it is obvious that the manipulation scandal has sparked a lot of public discussion about the quality of the rates.

1.1 Structure and Objectives

In this thesis, I study the reference rates validity mostly from the manipulation point of view. I start the thesis by describing in detail the two most important reference rates Libor and Euribor: what they are, how they are calculated and why such reference rates exist. In addition, I discuss of their representativeness in the current money market context in the euro area. In chapter 2, I will go through the manipulation scandal, in which the British FSA/FCA[1], the U.S. CFTC[2] and the European Commission have been the main regulative authorities carrying out the investigations.

[1] Financial Services authority/Financial conduct authority
[2] Commodity Futures Trading Commission

In chapter 3, I will present the scarce academic literature about the manipulations. I have divided the literature in to two groups based on their study methods: behavioural and market indicator studies. Behavioural studies include, for instance, the game theoretic approach done by Chen (2014), and Snider & Youle (2012) and Benford's law application by Abrantes-Metz et al. (2011). The market indicator studies include, for example, studies by Abrantes-Metz et al. (2012) and Monticini & Thornton (2013). Most of the studies flagged the possibility of manipulation even before the manipulation scandal started.

Inspired by the market indicator studies, in the fourth chapter, which is my empirical part, I study the relationship of Libor and credit default swaps derivative contracts. According to theory, these two measures should be closely linked, as they both incorporate the credit risk component of the counterparty. Thus, there is an arbitrage condition between these two measures. If it does not hold, manipulation can be suspected. I study the long run relationship with co-integration method, something that has not been done before in interbank context. I am interested in the type of manipulation motivated by reputational issues, because the long term analysis does not capture the short term deviations of portfolio driven manipulation.

The above-mentioned arbitrage condition in the interbank market is illustrated by Eisenschmid & Tapking (2008). However, due to the lack of directly relevant literature, I will employ the CDS and bond market research. With respect to my thesis, an important concept is the CDS-bond basis, and relevant studies of the field are, for example, De Wit (2006) and Zhu (2006). I will complement the CDS-bond basis studies with the literature that studies composition of money market spreads. For example, articles by Taylor & Williams (2008a,b) and Ji (2012) offer possible drivers for the Libor-OIS development.

My empirical results imply that Barclays was not the only nor the most blatant reputation driven manipulator during the suspected period of manipulation in 2007-2008. The analysis supplements current academic literature of reference rates by extending the time period of analysis and employing methods that are not used in other manipulation nor money market studies.

1 Reference Interest Rates as a Window to Interbank Markets

In this chapter I describe the purpose and formulation of important reference rates and go through the developments in the European interbank market. I will start by describing the most important features of the money markets, and the interbank markets, which is part of it. This is useful helping in understanding of the conceptual location of reference rates in financial theory. In the latter part of this chapter I will describe in detail how Libor and Euribor interbank unsecured benchmark rates are calculated, and what they are used for. I will also go over the general development of euro money markets since the introduction of euro. This description of money markets has been done from euro perspective, as my empirical part is studying euro related rates, but it is to large degree applicable to dollar and some other currencies as well (Hartmann & Vall, 2008, p. 455).

1.1 Interbank Markets are Part of the Money Markets

Hartmann, Heider, Papaioannou, & Lo Duca (2008, p. 121) illustrate that the role of financial system is to allocate resources from those with surplus to those with deficit. In other words, Hartman et al. (2008, p. 121) see financial system as a set of institutions through which households, commercial sector and public sector obtain funding or save funds. Money market can be considered to be one part of the financial system. (2008, p. 454).

The particular economic function of money markets is to solve cash flow mismatches. Economic agents have, in practice, always mismatch between income and cost, in a given short period of time. Via money markets agents with a surplus, even for a short period, can deposit the surplus to those who are lacking funds. Hence, the money markets are channelling the funds from positive net savers to negative net savers, but at the same time, they are used to fine tune longer term fund inflows and outflows to match in a daily basis. This liquidity allocation process causes the money markets to have important role in financial stability, risk sharing and in maintaining price stability. (Hartmann & Vall, 2008, pp. 453-455)

Hartmann & Vall (2008, pp. 454-455) state that the supply side of money market offers place to hold cash with interest rate and thereby offers a way to lower the cost of holding cash. On the demand side participants have, in case of liquidity shock, possibility to get cash and thus, better ability to absorb liquidity shocks. Hence, money markets allow participants easily to invest funds for short term and also help in sharing the liquidity risks. All in all, instruments used in money markets, are such that allow for lowering the opportunity cost of cash, but still have relatively short duration and hence bear smaller risks. (2008, pp. 454-455)

Money market is in practice a collection of different markets i.e. different traded instruments and market places (Hartmann & Vall, 2008). Hartman and Vall (2008) divide money markets in to three components: 1) financial instruments and 2) market segments or market participants and 3) trading mechanisms and systems. I will go through these three.

A good picture of European money market instruments can be obtained from ECB's money market surveys (ECB, 2013b), which covers unsecured market, secured market, short-term securities and derivatives market. According to (Hartmann & Vall, 2008) interbank lending is often considered the core. It consists of unsecured and secured lending. The unsecured market is most active in short maturities, whereas secured (and derivative) markets are also used in the longer end of the maturities. Collaterals used in repos are mostly government bonds. Banks who are subject to reserve requirement use interbank markets in managing of the reserve requirement fulfilment and flows of their customers funds. (ECB, 2013b)

Derivatives are used to hedge against interest rate risks, but can also be used to speculate on the future interest rate movements. Interest rate swaps, interest rate forwards, and futures are examples of interest rate derivatives. A general and stylized view is that financial instruments with maturity below one year belong to money market and instruments with maturity over one year, are considered to belong to the capital markets. (Hartmann & Vall, 2008)

By market segments Hartman and Vall (2008) refer to different parties involved in the market. Banks and firms are the fundamental agents of the market. Especially in Europe, a number of big banks have also an important role as market makers. They are committed to quote price for given instrument when asked. Other important agents are market funds and large non-financials. However, the one with most influence is central bank. Central banks steer short term interest rates and often have short term rates as operational targets. Central banks rate decisions are highly anticipated events on the markets. Other important players are governments, who are mainly net borrowers. (Hartmann & Vall, 2008)

Trading mechanism and system are the third money market component presented by Hartman and Vall (2008). It is very important to understand, that of the instruments described, most of trade is done on over the counter basis (OTC). Exception of the rule are interest rate futures, which are traded on a dedicated marketplace like Euronext.liffe (London International Financial and futures and Option Exchange). In practice OTC deals are done via electronic trading platforms, direct dealing in phone or voice brokering. It is also noteworthy that the despite the European financial integration, conventions still vary across countries. For example, Italy is the only country so far, where interbank deposits can be done via electronic trading system (e-MID) (Hartmann & Vall, 2008). Unfortunately, the OTC trading activity and turnover is not as easily observed as in exchanges (ECB, 2013a). The OTC nature of interbank markets offer one important explanation to the question why reference rates are not formed directly from market transactions.

1.2 Definitions of Libor and Euribor

In this subsection I provide definitions of Libor, Euribor, and Eonia. The Euribor and especially Libor are discussed thoroughly in this thesis, whereas Eonia and one particular derivative (Overnight indexed swap) linked to it are important in the empirical part of this thesis. Starting from 2013 the definitions of Libor and Euribor have been subject to changes, which were seen necessary after the manipulation scandal revealed some weaknesses. During the review period of my empirical part (2003-2013), these changes

were not implemented yet. To large extent these changes do not change the information what reference rates are believed to offer, but instead, they are made to ensure that the information represents what is believed.

1.3 LIBOR

Libor (London Interbank Offered Rate) is a benchmark of unsecured lending in London interbank markets. It is submitted every business day in five different currencies, Swiss franc, euro, British pound, Japanese yen and U.S dollar. Excluding euro, for each of the currencies multiple maturities are published. In 2013 publication of some tenors were abolished, but the remaining are following: overnight/spot-next, 1 week , 1 month, 2 month, 3 month, 6 month, and 12 month. After reforms Euro has only two tenors: 1 week and 1 month. All together its 37 maturity currency pairs that are published every business day (BBALibor, 2012). The rates are quoted as annualized rates and maturity dates are standardized according to ISDA norms, to ensure that each submitter in each currency/maturity pair refers to same dates. (BBAlibor, 2014b)

Libor is an interbank unsecured lending rate, but it is not directly linked to market transactions. Instead of market transaction in a particular market place, Libor is formed based on panel banks submissions. On every day when Libor is published, each member of each currency's panel bank is asked the following question: *"At what rate could you borrow funds, were you to do so by asking for and then accepting inter-bank offers in a reasonable market size just prior to 11 am?"* (BBAlibor, 2014b). Of the answers (rate submissions) a trimmed arithmetic mean is calculated. In case of Libor trimming means that 25 % of highest and lowest values are dropped out and the mean is then calculated from the remaining values. Purpose of trimming process is to exclude the outliers. (BBAlibor, 2014b)

In practice Libor is a snapshot of banks' subjective view of their unsecured funding conditions at 11 a.m. London time. It is not assumed that banks would trade every day on each tenor they submit rates. Hence, they are encouraged to submit their best estimate on what the rate would be. If the rates were based on only actual rates, there would be a risk that for some days the Libor could not be constructed. As stated by BBALibor

(2014), “it would not be feasible to create a full suite of LIBOR rates if this (real transaction) was a requirement”. The above presented question Libor rates are based on has been in this form since 1998. (BBAlibor, 2014b)

The question which defines Libor is supplemented by some other technical definitions. For example, the term “fund” is defined as “interbank cash or cash raised via primary issuance of interbank Certificates of Deposit.” In addition some quality requirements for the submission process exists. One example is that the staff member submitting the Libor has to be primarily working in banks cash management (BBAlibor, 2014b).

As stated above, Libor rates are published for different maturities and currencies. Each currencies have separate panel of banks. In this thesis the empirical part is focused on euro panel of Libor, but most of the academic literature is about US dollar, which is the most used reference rate. The Libor euro bank panel consisted of 15 members (BBALibor, 2012) during the period of my data. The Libor has been governed by British Banking Association (BBA), but the governance is moving to Nyse Euronext during the year 2014. Banks join the panel on voluntary basis, but governance organization approves them and manages the panel size. In addition to governance organization and panel banks other stakeholders in the rate setting process are the rate calculator and publisher. Currently these both roles are taken care by Thomson Reuters.

According to BBA (2014b) the first time Libor was published was in 1980’s. Banks’ had asked their association to build a system that could be used as an “impartial basis” for interest on syndicated loans. Before standardized Libor rate was established in daily publication, often ad-hoc based panels were created to get impaired view of interest rate levels. Case for the standardization was obvious and Libor was created. Gradually financial derivative contracts started to use Libor as the underlying market interest rate i.e. reference rate. (BBAlibor, 2014c)

1.4 EURIBOR

In similar manner as Libor, Euribor (European interbank offered rate) is benchmark interest rate for interbank unsecured lending. However, Euribor is currently published

only for euro denominated loans and the banks are, excluding few, geographically located in the Eurozone. Like in Libor, also the Euribor rates are published every banking day. Euribor interest rates are quoted for 1 and 2 weeks and 1,2,3,4,6,9,12 months. (Euribor-EBF, 2013, p. 2)

Besides the geographical location, there is one fundamental conceptual difference in Euribor and Libor, which is very relevant in credit risk terms of the rates. Where Libor banks are asked to quote their own lending, would that happen during that day, Euribor panel are asked what is the rate when hypothetical "prime bank" lends money (Euribor-EBF, 2013). In fact, before 1998 Libor rate was formed in alike way, but as a result of consultation conference between BBA and market participants, the question was reformed to the current one (BBAlibor, 2014c). According to BBALibor (2014b), definition was changed because the prime bank term was not universally definable and it was seen as a good thing that the rates were explicitly linked to individual banks' funding.

The Euribor is defined in the code of conduct (Euribor-EBF) as follows: "Euribor® is the rate at which euro interbank term deposits are being offered within the EMU zone by one prime bank to another at 11.00 a.m. Brussels time. It is quoted for spot value (two Target days) and on actual / 360 day basis."

This is supplemented by the definition of the prime bank: "A 'prime bank' should be understood as a credit institution of high creditworthiness for short-term liabilities, which lends at competitive market related interest rates and is recognised as active in euro-denominated money market instruments while having access to the Eurosystem's (open) market operations." (Euribor-EBF, 2013, p. 2).

Before October 2013, when new code of conduct came into effect, term prime bank was undefined. Improving the definitions of key terms was not the only thing done in the process. New Euribor code of conduct is, in terms of pages, together with appendices over 40 pages, whereas the older was solely 9 pages (Euribor-EBF, 2011). From this naive comparison of the number of pages, one can get a good picture the scale of reforms Euribor has been subject to. The reforms are further discussed in the section 2.2 of this thesis.

The technical calculation process of Euribor is similar to Libor. The panel consists of 26 banks (4/21/2014)[3]. The final Euribor rate is trimmed average, where the 15 % of highest and lowest values are excluded. The Euribor is published in accuracy of three decimals. Publication and calculation processes are managed by a private company Thomson Reuters. EBF manages the panel, but banks join it on voluntary basis. (Euribor-EBF, 2013)

1.4.1 Differences of Euribor and Libor

It is important to highlight the differences between Euribor and Libor from the credit risk perspective. At first glance, the two interbank benchmark rates seem somewhat same. However, because Euribor is quoted for prime bank, the credit risk component of Euribor is not linked to any bank particular, but instead, represents a trimmed average of panel banks' subjective thoughts of some prime bank's credit risk. If the perception of prime bank (and its credit risk profile) stays fixed, the credit risk component of Euribor rate should stay relatively fixed as well. In other words, the credit risk component of Euribor moves only, if the perceived risk of European prime banks moves. Yet, the perception of prime bank is far from unanimous among participants based on study by Taboga (2013).

The credit risk component of Libor can, in theory, be much more easily tracked: each panel bank can be accounted for a certain credit risk component based on their rate submissions (see section 4.2 of this thesis). Libor submission may also have signalling value of submitting banks' credit conditions unlike Euribor.

Because Euribor is loosely anchored to some particular credit risk, without making very specific assumptions of the credit profile of a prime bank, it is hard to justify the use of no-arbitrage condition to explain individual banks Euribor submissions. Hence, I can only study Libor rates with the method I use in the empirical part.

[3] There used to be over 40 panel banks, but since the manipulation scandal the number has been declining

1.5 EONIA

Eonia (euro area overnight indexed average) is overnight lending interbank benchmark rate, which contrary to Euribor and Libor, is directly calculated from market transactions. More precisely, Eonia is weighted average of the rate, at which Eonia panel banks lend money overnight to other credit institutions. Eonia is unsecured and only includes euro denominated loans. Unlike Libor and Euribor, Eonia is not a snapshot of money market conditions, because the overnight lending deals can be agreed on during the whole day before Target system close, and hence, the window of rate determination is longer than in Euribor or Libor. I will not go further into details of Eonia, as Eonia as a reference rate is not under examination in this thesis. Instead, Eonia is an important part of the risk free rate indicator used: overnight indexed swap (OIS). OIS's are further discussed in the empiric part of this thesis. (Euribor-EBF, 2014b)

1.6 ECONOMIC FUNCTIONS OF REFERENCE INTEREST RATES

Reference rates in general are a public good. Standardized rates increase the efficiency of contracts such as financial derivatives, which reallocate the risk in financial system (Bank for International Settlements, 2013). Trough derivatives and hedging reference rates are also directly linked to the money market (ECB, 2013a). Besides acting as reference for contracts, the rates play the role of a pricing benchmark. Hence, Libor and Euribor function as benchmarks and pricing references. In this subsection I will clarify these roles.

The economic efficiency value of reference rates lies in the standardization gains (Hou & Skeie, 2013; Bank for International Settlements, 2013). Before introduction of Libor in the 1980's in each derivative contract the referable rate had to be separately decided. In addition of being costly, this was also considered to hinder the growth of market (Bank for International Settlements, 2013, p. 4).

From the financial market point of view, the most important role of Euribor and Libor is being the reference rate of derivative contracts. According to ECB (2013a) the notional value of contracts linked to Euribor and Libor is approximately 490 trillion dollars. A typical Libor or Euribor linked instrument is interest rate future, which variable leg cash flow

is determined by the settlement dates rate fixings. Interest rate derivatives, like futures, forwards and interest rate swaps are highly standardized and liquid. They help pricing other less liquid interest rate and credit products. Thus reference rates affect indirectly in pricing of some less known instruments (ECB, 2013a).

The importance of derivatives is a subject of its own, and I will not go deeply into that. In the big picture, well-functioning and efficient derivative markets reduce the cost of risk allocation in the financial system (Bank for International Settlements, 2013). Furthermore, the interest rate derivatives are particularly important for banks as their business is, to be simple, to borrow short and lend long. As Hou & Skeie (2013) put it: with help of Libor and its derivatives, banks are able to fix their returns and costs with a margin.

The important role of reference rates does not end in derivatives. In Europe, 60 % of total loans to non-financial corporations and 40 % of total to households are linked to floating rates (ECB, 2013a). A typical loan rate is often banks margin plus Euribor. Given the direct link in households' and corporations' loans cost and important role in formation of interest rate expectations, reference rate are vital transmission channel of central banks' monetary policy. In addition, Eonia for example, is also a reference rate, and ECB's operational target. According to BIS (Bank for International Settlements, 2013, pp. 10-12) references rate have important implications in monetary policy transmission and financial stability. For extensive discussion of reference rates and central banks see BIS report on the matter (Bank for International Settlements, 2013).

As was described in chapter 1, in OTC markets the transactions are not necessarily standardized, public or practically visible for the public. Hence, reference rates can be a good (stylized) proxy of the markets they represent (ECB, 2013a). Reference interest rates play important role in formation on expectations of future rates (ECB, 2013a). Via expectations, reference rates are indirectly linked to capital markets, which consist of bonds and other longer term instruments (Brousseau, Chailloux, & Durré, 2013). Another benefit of benchmark rates is the expert judgement involved in the rates: For example, in the case of Euribor, we have 12 month interest rate for every banking date,

despite we do not necessarily have any actual transaction on every date. All in all, benchmark rates provide the public with a snapshot of money market interest rate curve, which contains simplified information about the otherwise opaque market.

1.7 Developments of the European interbank market

As has been discussed above Euribor and Libor are representing interbank unsecured interest rates, and they have an important direct link to money markets through derivative contracts. Hence, it is important to know how money market, especially the unsecured segment, has developed over time. In this chapter I will shortly describe the conceptual changes happened in the money market since the establishment of reference rates, and second, describe the market activity during euro era in greater detail. One will find that the validity of reference interest rates as a bank funding measure has suffered as a result of decline in unsecured money market activity and fragmentation of unsecured markets. By fragmentation I mean the country and counterparty based risk variation across banks i.e. market participants.

1.7.1 Paradigm Shift in Money Markets

In IMF's working paper Brousseau, Chailloux and Durré (2013) present the idea of paradigm shift. They argue that during the 1980's, when Libor was established, money market and interbank market were practically a synonym. Back then the money markets were bank centric and bulk of banks refinancing was done via interbank operations. In this context, given limited credit risk variation, it is obvious that Libor rate fixings were accurate proxies for banks' funding costs. It was especially accurate for those banks, who did not have large deposit base. (Brousseau, Chailloux, & Durré, 2013, pp. 4-5)

The paradigm started gradually evolve together with growth of fund management industry and bond markets in Europe. Market participants of new kind appeared during the high pace deregulation period of the 90's. Traditional interbank markets were complemented by so called non-banks, funds, central banks of other currencies and together they were the new roster of players at the money markets. These developments increasingly pushed down the interbank market volume in absolute and relative terms of the total money market activity. (Brousseau, Chailloux, & Durré, 2013, pp. 5-6)

The new funding channels generated by the new players were seen more appealing in the context of relaxing regulatory environment. Deposits were moving to from banks to non-bank, like funds. Trend was that more and more banks were net borrowers of funds instead of net lenders. In addition, asymmetric treatment of unsecured borrowing (regulated) and lending (not regulated) by Basel capital regulation, caused banks to only borrow in the unsecured market and do lending in other forms like repos. Same time, reference rate linked derivatives' notional amount continued to grow. (Brousseau, Chailloux, & Durré, 2013)

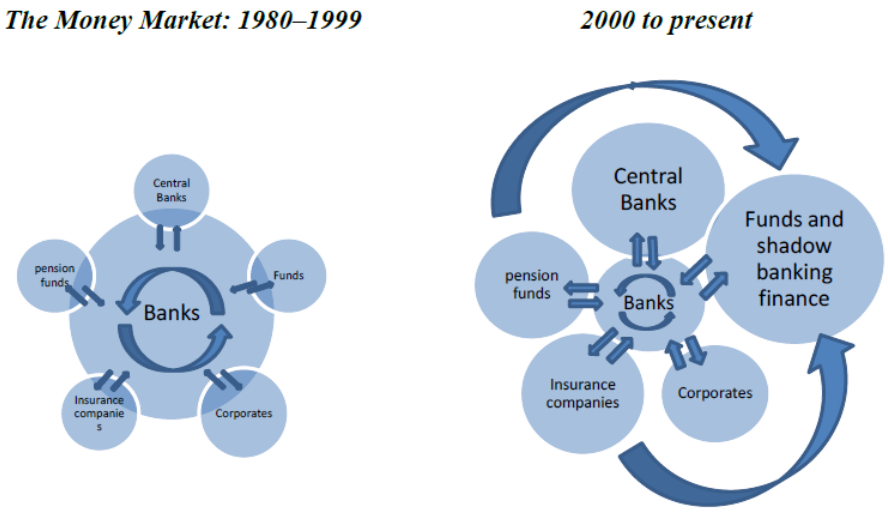

FIGURE 1.1 ILLUSTRATION OF MONEY MARKET CONCEPTUAL CHANGES, (SOURCE: BROUSSEAU, CHAILLOUX, & DURRÉ, 2013)

1.7.2 EURO ERA AND THE FINANCIAL CRISIS

Hartmann & Val (2008) describe the euro money market as liquid and efficient market. They claim that this was evident from the day one of euro introduction (2008, p. 456). However, their analysis is before the crisis years in 2007-2008. The period of market functioning is also visible in the figure 1.2, which shows how the turnover of unsecured money markets in 2003-2008 stayed relatively constant.

According to ECB's Financial Integration report (2013c, pp. 15-17) the collapse of Lehman Brothers changed the nature of money markets in a remarkable way: banks became suspicious of each other banks' ability to raise fund and pay back its debt. Before that the money markets were somewhat standardize markets (Hartmann & Vall, 2008, p. 456), but now each banks was concerned of counterparty's creditworthiness and default

risk. Interest rate did not work to compensate for higher credit risk, but instead, banks stopped lending to each other's. Cross-border trade declined the most. (ECB, 2013c, pp. 15-17).

Figure 1.2 shows how the unsecured interbank market activity in 2013 was just a fraction of what it was in 2008. In figure 1.3 is shown how market participants consider unsecured market significantly less efficient than before the crisis. The declining pace in volumes and quality was fastest during the financial crisis 2008.

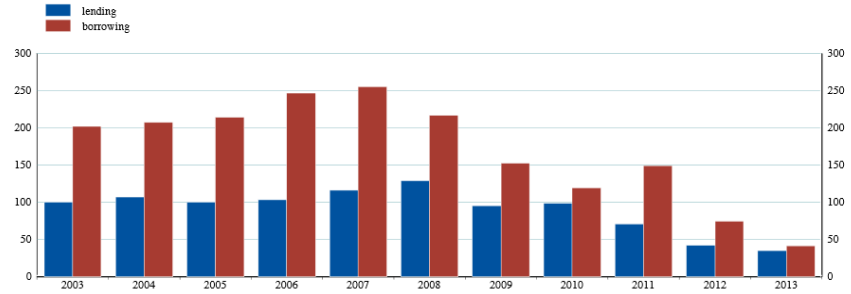

FIGURE 1.2 TURNOVER OF UNSECURED INTERBANK MARKET (SOURCE: ECB, 2013B, P. 13)

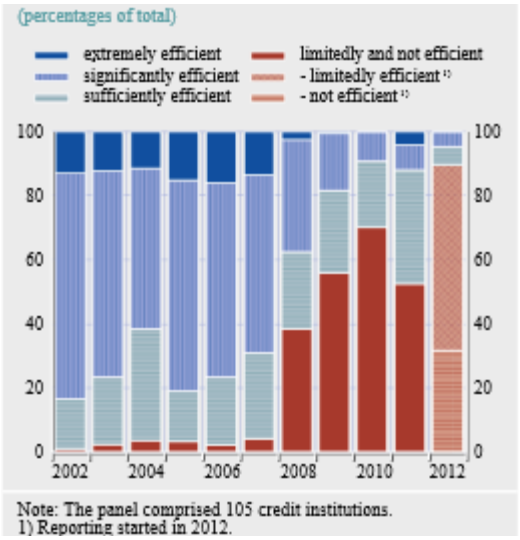

FIGURE 1.3 THE SUBJECTIVE ASSESSMENT OF UNSECURED MONEY MARKET EFFICIENCY. HOW EFFICIENT MARKET PARTICIPANTS CONSIDER THE MONEY MARKET UNSECURED SEGMENT (SOURCE: ECB, 2013B, P. 13)

Other segments of money market were also under pressure, but not to the same extent. The growth trend in secured market stabilized. See figure 1.4. Also the collateral credit quality used in repos started to play bigger role in the pricing. The effect was even

stronger when both the collateral and borrower where from same country. Derivatives were also less traded, especially OIS, futures and others without currency dimension. This can be observed from the figure 1.5. Volume in FX-swaps did actually increase even over the years of most market stress. (ECB, 2012, pp. 23-26, 31-48)

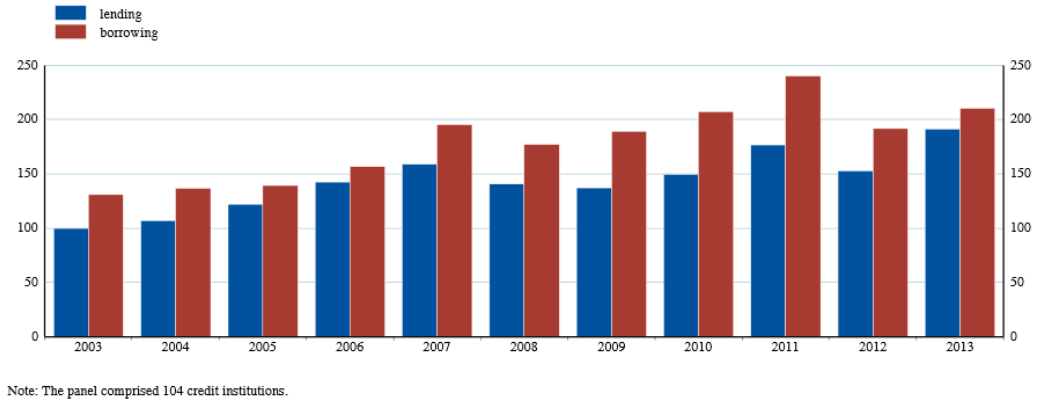

FIGURE 1.4 SECURED MARKET TURNOVER (SOURCE: ECB, 2013B, P. 33)

ECB has also conducted a special data collection exercise, in which all the participating banks reported their daily interbank activity over the first two months of 2012 and the second half of 2012 (ECB, 2013a, p. 78). The exercise revealed devastating results from the perspective of reference rate representativeness. Volumes of even rather short term unsecured interbank markets were found low and often concentrated to only few participants. Some of the results are described in table 1.2. (ECB, 2013a, p. 78). The declining trend in the unsecured money market is also discussed in report by BIS (2013, p.8).

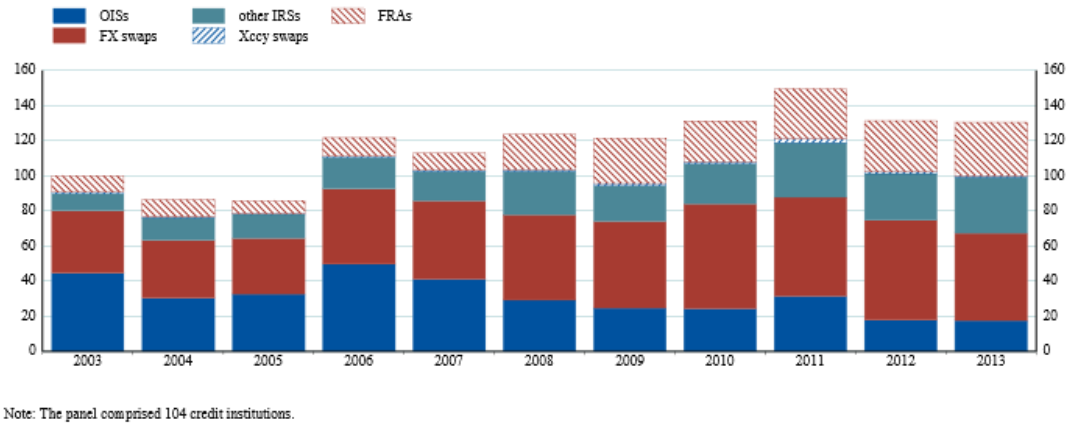

FIGURE 1.5 TURNOVER OF VARIOUS OTC DERIVATIVES MARKETS (SOURCE: ECB, 2013B, P. 18)

TABLE 1.1 FINDINGS OF ECB DATA EXERCISE (SOURCE: ECB, 2013A, P. 80)

	Dimensions	Tenors	January 2012 to February 2013	July 2012 to February 2013
Robustness/resiliency (All borrowings)	Volume suffiency (daily average)	one-week	€ 3.5 billion	€ 2.9 billion
		one-month and three-month	€ 09-1.1 billion	€ 0.6-0.8 billion
	Volume distribution (% of days in which daily volume < a threshold)	one-week	1% of days daily volume < € 1 billion 1% of days daily volume < € 0.25 billion	1% of days daily volume < € 1 billion 1% of days daily volume < € 0.25 billion
		one-month and three-month	~25%-30% of days daily volume < 0.50 billion 10% of days daily volume < € 0.25 billion	~40%-50% of days daily volume < 0.5 billion ~10%-15% of days daily volume < € 0.25 billion
	Volume concentration (% of days in which one or two contributors account for 80% or more of the daily volume)	one-week	<1%	1%
		one-month and three-month	~15%-20%	~20%-30%
	Contributor sufficiency (daily average)	one-week	27	24
		one-month and three-month	16-17	14
	Contributor distribution (% of days in which number of contributors < a threshold)	one-week	Number of contributors equal or above 15 every day	Number of contributors equal or above 15 every day
		one-month and three-month	3%-5% of days <10 contributors ~15%-20% of days <15 contributors	5%-8% of days <10 contributors ~30%-35% of days <15 contributors

In future the money markets are also subject to increased regulation. Coming regulations directives like LCR (Liquidity Coverage Ratio) and CRD IV (Capital Requirements Directive) treat unsecured lending more strictly than secured, which, in turn, will make secured lending more appealing for banks (ECB, 2013a, p. 75).

1.7.3 REFERENCE RATES IN THE CURRENT MONEY MARKET CONTEXT

As stated above, the activity in unsecured money markets has been decreasing over time. Hence, the markets Libor and Euribor represent are not as important as they used to be back in the 1990's or even in the beginning of the 2000's. Back then, the unsecured rate was a very good proxy for overall wholesale funding cost of a bank. As was discussed in previous subsection, in 2010's the share of secured lending is in remarkably bigger. As Broussea et al. (2013) puts it: it is recognized that the average whole sale funding cost of a bank is a complex combination of unsecured borrowing, secured borrowing (in

which collateral quality must be taken into account), central bank access, access to different currencies' market places and multiple more variables (Brousseau, Chailloux, & Durré, 2013). The fundamentally changed funding profile of banks has raised the doubts of the representativeness of Libor and Euribor (BIS, 2013, p.8; ECB 2013a). In addition to representativeness issues, it makes the formation process of reference rates also questionable, as there are no real transactions were the rates could be anchored to.

How big a problem the lack of representativeness is depends on what is expected from the behaviour of references rates. The downside of standardization is what is lost when derivative contracts are not tailored exactly to match the needs (BIS, 2013, p.7). Together with the grown variation of credit risk among end users, grows possibly the mismatch between reference rates' properties and end use (BIS, 2013, p.7). In case of hedging, it is very important that the link between risk variable, like funding cost, and hedging instrument is predictable. If this link breaks down the hedging instruments may cause additional risks.

Brousseau, Chailloux, & Durré (2013) point out that interest rate derivatives are often used hedging against variables that move in tandem with reference rates. Because derivatives linked to Libor and Euribor rates have huge markets and liquidity, it is often cheaper to use proxy-hedging, than direct hedging. As a result, proxy hedging can be regarded as a significant phenomenon related to reference rates. (Brousseau, Chailloux, & Durré, 2013)

Given the large direct and indirect hedging activities related to Libor, the financial stability risk related to unpredictable or even invalid reference interest is potentially very dangerous. In addition, if the invalid reference rates lead to falsely priced risk components in the market, it can also lead to inefficiently priced risk in the market.

From the central bank point of view the mechanism between policy rate and reference rate can be of great importance, as the reference rates are important part of interest rate channel. If this relationship behaves in an unpredicted way, than the policy decision based on reference rates may have unanticipated consequences. (BIS, 2013, p.11)

Now one should shift his mind into a banks money market desk. That is a typical desk which is responsible of banks daily Libor and/or Euribor submissions. During the crisis many banks lost their access to unsecured money markets but did not lose their place in reference rate bank panel. What resulted was that banks with little to none unsecured deals were using expert judgment to produce representative money market rates. Rates that for some days did not exists! For example, corresponding markets of 3 month Euribor, which is referred by contracts worth of billions of dollars, had no trades on 13 % of dates according to a data exercise conducted by the ECB (ECB, 2013a, p. 79).

The missing evident market transactions caused the reference rate to have no valid rate to compare with. This gave experts in charge of submissions a huge levy of determination as the accountability of submissions was nearly non-existent. Point of this example is to show, that the validity of both Libor and Euribor rates could have been easily questioned since the onset of financial crisis.

In the next chapter I will break down the manipulation scandal, which is one symptom of the broken reference rates, in detail: who did what wrongdoing, what were their incentives and how did this all happen. However, even thought it might be generally accepted idea that crisis was catalyst for manipulation, it is not the cause of it: manipulation did happen already in 2005. As one can see from the figure 1.2, unsecured markets were still relatively active during that year.

2 Interest Reference Rate Manipulation Scandal

In this chapter I will present the stylized timeline of the manipulation scandal: the wrongdoing, doubts, investigations, prosecutions. In the end of this chapter, I will shortly present some of that discussion done about the reforms of reference rates. The interest reference rate scandal is often referred in media as "Libor scandal", because that is where the doubts of manipulation initially originated. Nonetheless, as this chapter will show, Libor and Euribor scandals are very integrated together. One should reckon with the fact that banks participating in Libor referring markets are to large extend the same ones doing business in euro area, which is the corresponding market of Euribor.

Manipulation were of two kind: portfolio driven, and reputation driven. The motive for portfolio driven manipulation is to increase mainly derivative portfolios return. Reputation manipulation happened, because high Libor submissions relative to others were feared to be regarded as a signal of funding problems.

2.1 Manipulations: an Elephant In the Room?

"In a development that has implications for borrowers everywhere, from Russian oil producers to homeowners in Detroit, bankers and traders are expressing concerns that the London inter-bank offered rate, known as Libor, is becoming unreliable." Wall Street Journal April 16 2008 (Mollenkamp, LIBOR fog: bankers cast doubt on key rate amid crisis, 2008)

British FSA's (Financial Service Authority) final notice to Barclays, is to my knowledge, the first official allegation of reference rate scandal. Barclays was found guilty of submitting rates in a way that was violating the rules set by Libor code of conduct (FSA, 2012a). The allegations were for two type of misconduct[4]. The first type misconduct

[4] As a results of manipulation, banks were convicted of failures in internal process, incompliances with respective code of conducts. However, the ultimate reason for the lawsuit has been the manipulation or manipulation-attempt and other allegations are just by-product of it. The scope of the thesis is in the manipulated rates, not in the internal processes, and hence, I will not go further into details of what have banks technically been accused of.

was the case of submitting rates in which banks traders' derivative positions were taken into account. The other case was intentional submitting of lower than actual borrowing rates in fear of negative media content. Both of types of misconduct were violating code of conduct, which requires banks to submit the rates based on their best estimate of what the actual borrowing rate would be – other circumstances must not be considered in submissions.

Type two manipulation, the avoiding of negative media attention, is only related to Libor, in which, by definition, banks are submitting their own funding costs. Manipulation occurred under circumstances where banks did not trust each other and were afraid of possible bankruptcies or defaults. Barclays' higher than others banks' Libor submissions was actually noted in financial media, see for example Bloomberg's article by Gilbert (2007), which in turn resulted in a bank's management guidance to lower the submissions.

Evidence (email and phone conversations) presented in FSA's final notice to Barclays (FSA, 2012a), show how mid-level management explicitly told money market desk employee's to submit rates to levels " where others quote Libor". Unfortunately, it is not clear were the order originated from. It is not proven wrong that mid-level management might have just misinterpret the top-managements guidelines. Regardless of all, Barclays settled the allegation of this type among others allegations (FSA, 2012a). Barclays is, to my best knowledge, the only bank which has been convicted of lowering submissions to avoid negative publicity.

How did the manipulation happen in practice? In the investigation of Barclays It was found that several times, when media notices Barclays submissions were in the upper quartile of submissions, the mid-level management of Barclays told their subordinates to "put the Libor where the Libor is" or something alike (FSA, 2012a). The most blatant examples where the cases were actual transactions were done during that day, but mid-management overrode transactions offered by submitters and required the submission to be lower than the actual transactions (FSA, 2012a, p. 26). As stated above and in the

final notice report, this violates the code of conduct by not being, obviously, the best estimate of banks current interbank cost in given maturity.

Despite the fact that Barclays might be the only one who has been convicted of lowering rates to avoid negative media attention, the idea (or doubts at least) of other panel banks doing the same have been under speculation in media and public. One of the first times officially the question of low rates was raised was in in Bank of England sterling money market liaison meeting in November 2007. Meeting's minutes state that "Several group members thought that Libor fixings had been lower than actual traded interbank rates through the period of stress" (Bank of England, 2007). Probably less known to the public is the ICAP's (broker/dealer company) weekly newsletter from 3rd of September 2007, which even before the meeting of Bank of England, raised similar questions.

In 2008 Wall Street Journal published series of articles are the most cited main stream financial articles (Mollenkamp, 2008; Mollenkamp & Whitehouse, 2008b) credited for bringing the issue of too low Libor submissions to the awareness of the general public. The main conclusion of WSJ article (Mollenkamp & Whitehouse, 2008b) is that several banks had been submitting lower than their actual borrowing cost. The claims were based on comparison of the banks' credit default swap and their respective Libor submissions, which, according to the article, were contradictory. The article can be considered to be an important milestone in reference rate scandal due its high media influence. Furthermore, a few academic studies have used alike but more sophisticated methods in trying to answer the same questions. In addition to the public discussion, it is now known that many noteworthy private discussions were taken between banks management and officials in U.K and U.S (Hou & Skeie, 2013). Above presented discussion in media suggests that the submitting of low rates was more widespread than what one might asses on basis of authorities' decisions so far: only Barclays was found guilty.

Most of the manipulation allegations that have been covered in media is about the portfolio driven manipulation. Banks submitted Libor rates in coordination with money market traders who in turn benefited of the crooked Libor through their net positions in derivatives. Inquiries were done inter and intra bank. Based on FSA/FCA different final

notices, the Rabobank is the one with longest period of manipulation, from 2005 to 2011 (FCA, 2013). However, FT article of a former bank insider claims that Libor has been manipulated since 1991 (Keenan, 2012).

A comprehensive description of how type derivative position based manipulations happened in practice can be found in FSA's/FCA's final notices to banks (for example see FCA, 2013). A typical case is where derivative dealer asks same or other banks submitter to submit extremely low or high Libor fixing, because the dealer has a big derivative position expiry on that day. Often the dates of rates manipulation were so called international money market days (IMM-days)[5] which are important settlement dates of interest rate derivatives. Like stated above, these inquiries were both internal and external. Given the trimming mechanism of Libor and Euribor, the more banks join in the rate collusion the more likely is the manipulation to succeed.

Beginning from Barclays in summer 2012, there has been numerous manipulation related lawsuits. For example, FSA has fined RBS, ICAP, UBS and latest one is RABO bank in December 2013. The same banks were fined by the U.S commodity and futures trading commission (CFTC) and it was done in cooperation with national authorities (CFTC, 2013). In December 2013 European Commission (2013) imposed a penalty on nine banks of cartel in Libor and/or Euribor submissions. In all above cases the banks agreed to settle with the authorities, which in turn, discounted their final penalty fee significantly. For example, UBS and Barclays were found guilty, yet they were released of paying penalties due to their whistle blowing (European Comission, 2013). Commission still has active investigations considering those banks who did not accept to settle in this case.

The legal acts are not limited to those presented above. However, acts are highly decentralized, which makes the tracking of them task of its own. Financial Times estimated in December 4th (Barker, Schäfer, & Binham, 2013) that the total sum of penalties to be

[5] IMM-dates are days when standardized futures expire. The idea behind the concept is to bundle futures to certain dates to get appropriate market volume for each future.

$5,8 billion. In addition, Barker, Schäfer and Binham (2013) estimated that alone in U.S there were over 50 lawsuits in progress.

First wave of lawsuits were against corporations but now courtrooms are also judging individuals (Fleming, 2014). In addition, the banks have cancelled bonuses from those dealers who have been found guilty of manipulation (Fleming, 2014). In general, top management of banks have underlined the fact that they have not been aware, let alone ordered for illegal actions. So far all legal actions against individuals have been targeted to midlevel management and below (Fleming, 2014). Nonetheless, it is not only one or two banks whose CEOs have resigned as result of the crisis.

Another interesting question is: why Barclays is so far the only bank convicted of media attention driven manipulation? As stated above, it seems like, that besides media, even market participants (ICAP, BoE liaison meeting) were worried of the rates. If Barclays had been the only bank to submit lower than actual rates, the wide spread worries would have been exaggerated. In the empirical part of my thesis I try to tackle this issue, and see, if Barclays stand outs of the others somehow.

2.2 Aftermath of The Scandal

Because of the scandal, the reference rate reform has been discussed broadly in the public. In economic sense the reference rates have been relatively loosely anchored on the banks' real funding costs. Since the representativeness of the rates has been worsening it has been a good point to rethink reference rates validity. The validity issue was there even without the manipulation. Crisis and manipulations revealed plenty of vulnerabilities in the current reference rate regimes. Both, the conceptual properties and the rate setting process of reference rate has been subject to public discussion.

What it comes to media publicity, FSA's Wheatley report is probably the one with most of it. Report named after the CEO of FSA Martin Wheatley analysed the failures in the Libor of that time and proposed, based on discussion initiative launched in summer 2012, a number of reform ideas (FSA, 2012b). The report did not recommend a totally new reference rate regime, but instead argued that Libor should be reformed. After

Wheatley's report, the European banking Association (EBA) and European Securities and Market Authority (ESMA) have given their joint suggestion of Euribor reform (ESMA-EBA, 2013). International Organization of Securities Commissions published guidelines for financial benchmarks, which did cover, not only rates, but benchmarks in general (IOSCO, 2013). The reforms done to Libor were based on recommendations in Wheatley Report (BBA, 2013) and reforms done to Euribor were based on EBA-ESMA recommendations (Euribor-EBF, 2014). However, the recommendations are to large extent similar.

In Wheatley report (FSA, 2012b, pp. 79-80) the main weaknesses of Libor regime that time were as follows. First, it was acknowledged that particularly during periods of market stress, panel banks may have incentive to lower submissions to signal better creditworthiness. Second, panel banks are both, makers and end users of reference rate. Since the end users often have values of assets and/or liabilities very sensitive to changes in Libor, the combined maker and end-user status has obvious conflicts of interest: banks have incentives to submit rates that favour their positions in their balance sheet. Wheatley report argues that the three failings of Libor system are in 1) mechanism 2) governance and regulation framework and 3) regulatory powers and sanctions. Also it was pointed out, that the submissions should be based on transactions whenever it is possible. The report resulted a reform proposal of ten points (FSA, 2012b, pp. 8-9). These same failures and proposal are also to large extend recognized in ESMA/EBA joint recommendations (ESMA-EBA, 2013).

The following reforms are done according to the recommendations and aim to fix the presented sources of weaknesses. Most visible changes done to both Libor and Euribor were the suspension of certain rates. In Euribor, maturities with insufficiently considered underlying market volume where suspended. Whereas in Libor, some currencies were totally dropped out and the other currencies lost least active maturities. By active, it was referred to rates that had neither active underlying interbank market nor derivative market referring to them. Another visible change was done to fix the Libor underreporting incentive issue: the publishing of individual submissions are lagged by three months. Thus the panel banks do not have immediate reasons to be scared of the media attention submissions possibly get. (FSA, 2012b; Euribor-EBF, 2014)

From economist point of view, reforms with least interest are those related to internal and external reporting. Under the new code of conducts, panel banks are required to have improved their internal processes. For example, banks must have predetermined systemic plan for data submission, which is reviewed regularly (Euribor-EBF, 2013; BBA Libor, 2013b). Banks are obliged to report all employees who are in charge of bidding and part of the determination process. Any person, who is involved in the process, is not allowed to be money market derivative dealer or any of a kind. In addition to improvements in the actual rate setting process, governing organisation and calculation agent are doing back testing, in order to verify the validity of rates. (Euribor-EBF, 2013; BBA Libor, 2013b).The governance of Libor has moved from BBA to NYSE Euronext over the year 2014.

Many banks have decided to exit the Euribor panel as a results of the scandal. Official reasons banks have reported are often related to the challenging environment of rate determination i.e. lack of market activity. However, I dare to argue that banks have done their cost benefit analysis and arrived to the conclusion that costs exceed benefits. Costs have indeed risen in form of the regulation. Cynical observer could say that benefits have declined as well, because manipulation is not possible anymore.

Not all have been fully satisfied with the reference rate reforms. For example, Abrantes-Metz & Evans (2012) propose that Libor should have both, offer and bid prices, and the submitting banks should be committed to do transactions with given prices. According to my knowledge, the Helibor system if Finland had this feature. One branch of reference rate reform discussion is the idea of forming a totally new reference rate. As is pointed out in the BIS report (2013) the reference rate properties should be closely related to its use. As is pointed out in subsection 1.7, the modern bank funding is complex combination of different funding forms. Therefore, it might be that in the future multiple reference are used. BIS (2013) calls this concept as a “menu of different reference rates”. The subject is interesting, but I will not go further into the details of possible new rates and reforms, as the subject could be a thesis of its own.

3 LITERATURE REVIEW OF MANIPULATION STUDIES

Major of the academic literature regarding manipulations is published in last two years and most of the literature is still in form of working paper. The first papers are written in 2008 (example Abrantes-Metz, Kraten, Metz, & Seow, 2011), which is shortly after Libor became subject to manipulation speculation in media. The legal investigations mentioned in the previous chapter have their focus on the direct acts related on manipulation. Sometimes the style is referred as "smoking gun" approach (Snider & Youle, 2012, p. 4). The Smoke (i.e. the evidence) was in forms of emails and recorded phone calls. These explicitly proved the wrongful acts.

In financial academic literature the approach is different. Instead of explicit private evidence, literature mostly relies on public data and is also interested to view the matter in broader perspective. I divide the academic studies in two groups based on the approach selected. First group are studies, which compare Libor submissions to market measures. The remaining group is something I call behaviour model approach, in which, game theory, forensic theory, antitrust methods, or combination is often used. The common feature of these studies is that they often build their model on a hypothesis of what either dishonest or honest submission behaviour looks like. Hence, putting all together, I have divided manipulation research in three different groups based on the approach used: smoking gun (previous chapter), market indicators, and behaviour model.

3.1 BEHAVIOURAL MODELS OF MANIPULATIVE PANEL BANKS

Chen (2013) approaches the Libor submission process from game theoretic perspective. He builds a model on assumption that all banks are strategic bidders i.e. each Libor submission are input of a payoff function per panel banks' rate. Thus, each banks has a bidding strategy which maximizes the expected pay out. He assumes that portfolio gains of Libor fixings are maximized with low Libor fixings. Chen then argues that banks' manipulation gains are the bigger the bigger is the maturity mismatch[6] of respective bank bal-

[6] Maturity mismatch between assets and liabilities

ance sheet. Thus, bigger maturity mismatch would imply higher motivation for manipulation, ceteris paribus. In the model he assumes that each bank has same maturity mismatch parameter. The cost of manipulation he assumes to be linear function of the level of seriousness of manipulation, that is, the spread between actual loan cost and submission. The justification is that regulator is more likely to fine bank who submits rate far from the actual borrowing cost. He then builds two different scenarios: one with signalling effects and second without. In signalling, bank is assumed to have costs' in form of expected bank run, which is higher the higher is banks relative submission. (Chen, 2013)

The conclusions of model with signalling is that banks report lower than actual costs. What more, Chen's (2013, pp. 20-21) model imply that maximum submitted amount is always lower than what is truly highest borrowing cost. The bigger is bank's credit risk, the bigger is the bias of Libor fixing. The gain from under reporting is higher even if only the perception of banks credit worthiness by audience goes down and the actual fundamentals remain same. Hence, the market turmoil causes the Libor bias to grow. Study suggests that individual submission should not be published and be only information of the regulator. (Chen, 2013)

Even if no signalling exists, Libor bias relative to the maturity mismatch in balance sheet, exists. However, Chen (2013) suggests a payment system linked to submission, which would make it optimal for panel banks to submit the real best estimates of borrowing costs. Another important conclusion of the study is that Libor bias grows if banks borrowing cost dispersion grows. The intuition behind is that banks have more space for bidding low. (Chen, 2013)

A bit similar to Chen's model, is the one offered by Snider & Youle (2012). They recognize that there is a cost for misreporting which is bigger the bigger is the difference between misreported rate and the actual borrowing rate. Given this cost and banks willingness for strategic bidding, banks pursue to submit rates which are just out of the trimmed mean. In USD Libor panel there are 16 panel banks quoting 16 rates, of which four lowest and highest values are trimmed off before the mean is calculated. Hence, given that the

costs of manipulation is relative to the spread between real and submitted rate, submitting either fourth highest (prefer high Libor) or 13th lowest (prefer low Libor rate), are in other words, the cheapest places to effect the actual Libor fixing. (Snider & Youle, 2012)

The model by Snider and Youle (2012) suggests, that if strategic bidding existed, there should be "bunching" near the expected boundary values. They test this assumption against evidence and find, significant results. From forensic perspective, the limitation of their model is that data is needed over time, and hence, "pinpointing" particular case of manipulation is impossible. They also point out that the data was consistent with the results of regulators' investigations, yet they find also signs of more widespread manipulation (Snider & Youle, 2012).

Gandhi et al. (Gandhi, Golez, Jackwerth, & Plazzi, 2013) study the relation of panel banks' balance sheet exposure to Libor linked derivatives and individual submissions. Their hypothesis is simply that banks whose gain from lower Libor, submit low rates. They find a significant relation between balance sheet exposure and Libor submissions (Gandhi, Golez, Jackwerth, & Plazzi, 2013).

Their (Gandhi, Golez, Jackwerth, & Plazzi, 2013) study methods in more detail are following. First of all, they have end of month Libor exposure for different currency-maturity pairs in Libor, which is measured via a multi factor model. The model is a function of changes in Libor, other control variables, and equity returns. They find that banks with particular exposure to Libor in one month, will submit accordingly in the following month. Other interesting findings they have are that the magnitude of that relation was biggest during years 2005-2009 and that banks which have already settled with regulators, had strongest relation. Thus, results are remarkably consistent with the information from legal investigations. The total estimated cumulative market value increase of banks due to manipulation is €22, 76 billion. (Gandhi, Golez, Jackwerth, & Plazzi, 2013)

Abrantes-Metz, Kraten, Metz, & Seow (2012) have, similar approach to test for manipulation. They do not test bunching around particular pivot levels, but instead, argue that "Libor quotes of 'manipulative' banks should group together in non-random patterns". In other words, banks who cooperate with submissions, should have their submissions

correlated more than others. They find that during the first period (1/2007-8/2007) out of three, individual quotes are very alike and clustered together: most of the days the eight submissions which are left after trimming are from 9 banks. Vice versa, banks left out are often same. During the second (9/2007-4/2008) and third period (4/2008-6/2008) the degree of clusterization is significantly lower, and therefore the hypothesis of no manipulation cannot be rejected. Authors underline that results only flag the possibility of manipulation, instead of proving it. (Abrantes-Metz et al., 2012)

Different, and with limited economic methods, approach is presented by Abrantes-Metz et al. (2011) who use old Benford law (Benford, 1938) for second digit distribution reference and compare it to actual rates. According to Benford law (1938) distribution of second digits in many natural set of number is not evenly distributed. Abrantes-Metz et al. (2011) find periods of time when 1 month dollar Libor second digit significantly deviates from Bedford reference distribution. Benford law is used by Rauch, Goettsche and Mouaaouy (2013) in their study as well, which complements the methods used by Abrantes-Metz et al. (2011). They notify that Abrantes-Metz et al., (2011) use second digit distribution, without taking into account the fact that even first digit is not necessary Benford distributed. Rauch et al. (2013) claim that before studying second digit distribution of Benfords law, the first digit must be confirmed to be Benford compliant. Abrantes-Metz et al. (2011) skipped that stage, and hence, may have fallacious results (Rauch, Goettsche, & Mouaaouy El, 2013).

Rauch et al. (2013) have all currency-maturity pairs of Libor, Euribor, tabor and ISDAFIX rates included in their analysis, a total of 150 rates. Time span is 1999-2012. They compare the distribution of rates to Benford law's distribution, and do the same comparison to credit default swap spreads of respective banks. They find that, in general rates fit Benford law nicely in sterling, dollar and euro. However, rates in currency maturity pairs with lower underlying market volume, for example all rates in New Zealand dollar and Australian dollar, have the most significant deviation from Benfords distribution. Japanese yen and Swizz franc are most deviated of the major currencies. Over time analysis shows that deviations were highest on pre 2008 period, when to their knowledge banks

stopped manipulating as a result of the excessive media attention the issue had attracted. Rauch et al. (2013) conclude their results as follows: from 2002 to 2008 they find evidence of possible manipulation in reference rates. In addition, they find that not only the banks who have been under investigation, but also almost every other bank were part of the manipulation scandal. And besides to Euribor and Libor, also Tibor and some other rate submissions were suspicious. (Rauch, Goettsche, & Mouaaouy El, 2013)

TABLE 3.1 SUMMARY OF BEHAVIOURAL BASED MANIPULATION STUDIES

Study	Methods	Results	Other Conclusions
Chen (2013)	Game theory model implies that Libor is biased downwards.	Does not test against data	Bias increases with credit risk
Snider & Youle (2012)	Banks Bid should cluster around pivotal levels	Data supports their claims. Hence, manipulation.	
Abrantes-Metz et al. (2012)	Cooperative banks submissions should cluster	Find some evidence, which can be caused by manipulation	
Gandhi et al. (2013)	Balance sheet exposure and Libor	Balance sheet explains submission behaviour	Banks have gained over 20 billion as a result of manipulation
Abrantes-Metz et al. (2011b)	Benford's law	Find signs of manipulation	
Rauch et al. (2013)	Improved use of Benford's law	Find suspicious patterns especially in rates of smaller currencies	Other than Libor and Euribor might have been subject to manipulation as well.

3.2 Market Indicator Studies

Despite not being academic publication, the article series in Wall Street Journal (Mollenkamp, 2008; Mollenkamp & Whitehouse, 2008b) is, to my knowledge, a first attempt to quantify the current interest reference rate manipulation. In the study Mollenkamp & Whitehouse (2008) compared individual banks' submissions to credit default swap spreads of respective banks together with risk free rate. They used the lowest panel bank submission as a proxy for risk free rate. They find that at least 5 of 16 Libor panel banks were submitting lower rates than their actual inter bank funding is (Mollenkamp, 2008; Mollenkamp & Whitehouse, 2008b). WSJ article built the base for market based studies of Libor manipulations and had high media publicity.

Probably the first academic studies where possibility of manipulation was noted were from Taylor and Williams (2008b). They conclude that after WSJ's article the rates somewhat seemed to normalize. However, their main focus is not in manipulation but in explaining the in the US interbank markets.

Abrantes-Metz, Kraten, Metz and Seow (2012) followed in 2012, though working paper was public couple of years before. In their study they use screening methods that have been used in many antitrust cases as evidence. They underline the fact that the screening methods do not prove manipulation, but "isolate outcomes that are improbable or anomalous". They provide a hilarious example from 50's: In conductor cable tender seven participants submitted sealed bids that all had exactly same figure in accuracy of eight digits ($198438.24). In that case it was very unlikely that all participants arrived into same result without any collusion.

Abrantes-Metz et al. (2012) have two test in which they compare Libor rates to other measures of interbank funding. In the first test, they use the relation between Federal funds effective rate and different dollar Libors (over "clean" period 1990-2006) to predict Libor for suspected manipulation period (2007-2008). They find that actual Libor does not significantly differ from the predicted values, and hence, it does not indicate manipulation. In the second test, Abrantes-Metz et al. (2012) compare the banks' Libor submissions rank, relative to others, to the rank of credit default swap spread relative

to others. The intuition behind is that if a bank has highest CDS spread, ceteris paribus, it should have the highest Libor submission as well. However, pattern is not found from the data in any of the three periods. What they find is that large banks have relatively high CDS rates given their borrowing costs. Reasons offered are: CDS spreads not ordinal indicator of borrowing cost, sample banks are unusual in unknown manner, or large banks have systemic risks in large banks CDSs is higher. One possible explanation given is volume discount large banks may have in the funding market. They also do analogical comparison against credit ratings of banks, and get similar results. Their final conclusion for the hypothesis related to credit risk is that the null hypothesis of no manipulation cannot be rejected. And as a result, they conclude that their findings flag for the possibility of manipulation. (Abrantes-Metz et al., 2012)

Another study by Kuo, Skeie, & Vickery (2012) compares dollar Libor quotes to bank bid in Federal Reserve Term Auction Facility[7] (TAF) and to Fedwire[8] payments data. The former rate should be lower than Libor, because TAF borrowing requires collateral and is analogical to repo's. Fedwire payments data is obtained via statistical algorithm which sorts interbank loans from the FED's dollar real-time gross settlement payment system for banks. Hence, the algorithm may leave some loans out of count and count in some non-interbank unsecured loans, such as re-purchase agreements. Their findings are following. First of all, in both cases Libor quotes are more clustered then the two other measures, and the difference is strengthened after market turbulence by Bear Sterns of Lehman Brothers. The level of Libor quotes, especially after Lehman collapse, is lower than the level of TAF and Fedwire rates. Kuo, Skeie, & Vickery (2012) do not claim that this is necessarily a result of manipulation, and could also be a result of other causes. Their main conclusion is that the Libor, particularly during market stress, is not optimal

[7] Only auctions before 2008 when the total amount was fixed. http://www.federalreserve.gov/monetarypolicy/taf.htm: In TAF auctions FED allocated fixed amount of liquidity with variable rate, according to bids, to banking sector. Taf auctions were held on average every two weeks.

[8] Fedwire payments data is obtained via statistical algorithm which sorts interbank loans from the FED's dollar real-time gross settlement payment system for banks. Hence, the algorithm may leave some loans out of count and count in some non-interbank unsecured loans, such as re-purchase agreements.

indicator of bank funding, and hence, it is not optimal reference in bank funding risks hedging. (Kuo, Skeie, & Vickery, 2012)

Monticini & Thornton (2013) test the relationship of Libor to rates that reflect the default probability of banks, and test, if a significant change in relationship has occurred. The measure their compare dollar Libor with is certificate of deposit with equal term. During period of 1/2/2004 – 12/31/2010 they found three significant breaks in the relation. The two first brakes is caused by Libor movement downwards, as is assumed to happen due manipulation, and happened in June 14 2005 and August 9 2007 which is in line with the suspected starting period of manipulation in legal investigations. Furthermore, the third break was in upwards direction and offset the two previous ones. The respective date of recovering was 3rd December 2008 which is at the same time the issue was discussed in media. (Monticini & Thornton, 2013)

Brousseau, Chailloux & Durré (2009) study the information content of money market fixings and not the manipulation in particular. They compare reference rate submission's interest rate curve to the derivative market implied interest rate curve. The arbitrage should make these two measures to trade with a small spread. They find that after Lehman collapse arbitrage opportunities rise substantially. They conclude that something unusual happened to reference rates and coordination between the submitters would be a good explanation for that. (Brousseau;Chailloux;& Durré, 2009)

TABLE 3.2 SUMMARY OF MARKET INDICATOR BASED MANIPULATION STUDIES

Study	Methods	Results	Other Conclusions
Mollenkamp & Whitehouse, (2008)	Comparison with CDS spreads	Manipulation	
Taylor & Williams, (2008)	Set market indicators. Main purpose is not to study manipulation	Raise doubts of manipulations	
Abrantes-Metz et al. (2012)	Comparison to Fed Funds	No manipulation	
Abrantes-Metz et al. (2012)	CDS spreads	Suspicious, but not clear	CDS does not explain the Libor alone
Kuo, Skeie, & Vickery (2012)	Comparison with Fed Wire	Clustered differently	Libor not good indicator during market stress
Monticini & Thornton (2013)	Comparison with certificate of deposits	Manipulation. Significant breaks in relation.	
Brousseau, Chailloux & Durré (2009)	Comparison to reference rate derivatives	After Lehman relationship changed. Manipulation could be the explanation.	

3.3 DISCUSSION OF MANIPULATION STUDIES

First of all, in general academic literature is suspicious about the rates. The main differences across the studies is in the degree of certainty. The market based studies mostly try to show the reputation driven manipulation as the measures have too a big error

component to show portfolio driven manipulation, which could be often only a deviation of few basis points from “normal” level.

The forensic studies which use numerical Benford’s law are with the least interest in the scope of this thesis as the valuation of the method requires more knowledge of statistical methods than economics. Though, both studies by Abrantes-Metz et al. (2011b) and Rauch et al. (2013) found strong evidence for manipulative behaviour also in rates that have not been subject to allegation. However, my criticism towards these studies is that if the underlying markets activity of reference rate declines, a submitting bank by definition, has to still report according to the best knowledge of what hypothetical market rates would be. Hence, the non-existence of markets can cause the reference rate fixings’ digits to deviate from Benfords’ natural distribution, but still the behaviour of banks is compliant with the rules. CDS’s markets, to which they compare, does not suffer from the same. Their findings that smaller markets have stronger evidence for manipulation support my claims.

In market measure studies Monticini and Thornton (2013) are the most explicit with their structural break findings. In contrary, Kuo et. Al (2012) agree with the possibility of manipulation, yet they conclude that Libor is not a good indicator during market stress and many factors other than manipulation could have also caused the deviation in the measured used. Similar results are found by Gyntelberg & Wooldridge (2008) who consider the liquidity worries more dominant driver of fixings than credit concerns. Kuo and Skeie (2013) argue that the lack of taking into account the liquidity premiums is common questionable feature of manipulation studies.

The value of market indicator studies in the first place was to flag for the possibility of manipulation, before the regulators stepped in and investigated banks more thoroughly. Regulators were able to access information which was not available for scholars. Nevertheless, the apparent benefit of academic studies post-manipulation period is the ability to build measures or even meters that could be used to trigger any further investigations from regulators or be part of the regulators’ tool kit in supervision. In the current context

these method can be used to study rates after the crisis, or banks who has not been charged yet I.e. grounds which are still unexplored.

In addition to showing manipulation, literature is able to contribute something to the incentive side as well. For example, Chen (2013) shows that the strategic bidding assumption (with some other assumptions) causes Libor bias that grows larger with the "true" rates. In the same spirit Snider and Youle (2012) find that rates cluster around some key levels, which is caused by the trimmed mean mechanism in rate calculation. These findings speak for the need of supervision and regulation in the rate setting process.

After the banks have been charged of manipulation, the obvious question to be asked is, if the rates are now valid? In the next chapter I do my bit and study one of the interest rates with unused methods, though inspired by the WSJ (Mollenkamp & Whitehouse, 2008) article. In theory the knowing of the period of manipulation should give a perspective of what a manipulation looks like. In practice, the financial crisis during the manipulation period makes the conditions unthankful to set up a "laboratory" experiment. Therefore it is hard to observe how manipulative act would alter the relationship of reference rates and given market rate.

4 MARKET DATA ANALYSIS

In the empirical part I will employ “no-arbitrage condition” by comparing Libor rates to the price of buying protection from credit default. This approach is not directly possible for Euribor rates as those rates does not have to, by definition, present submitting banks’ own costs of interbank unsecured funding. Strictly speaking, I will study the long run relationship between credit risk spreads implied by 12 month euro Libor rates and credit default swaps. If markets are functioning and have had time to adjust, these should be equal. If they are not, manipulation is one possible explanation.

One might ask, why I am using CDS markets instead of other short term securities. Is it not so that some money market short term instruments offer almost perfect substitutes for interbank transactions? As was discussed in the first chapter, euro short term money market instruments are often illiquid and the data is not available. On the contrary, CDS market offer a liquid and continuous market indicator of credit risk of a particular bank for given maturity.

4.1 RELEVANT MARKET INSTRUMENTS

4.1.1 CREDIT DEFAULT SWAPS

Vanilla Credit default swap is an agreement between two parties, where one party agrees to pay fixed stream of cash in exchange for protection of principal amount in case the reference entity fails to pay the principal. From now on for convenience, I will refer these parties as protection buyer and protection seller. Market convention is to quote CDS contracts prices as basis points over the principal amount. The price is often referred as a CDS spread. For example, CDS spread of 100 basis points means that protection buyer pays 1 % premium of the principal annually. Only in a case of credit event, like default of the reference entity, the CDS seller is liable for the loss default causes in the principal amount. (Bomfim, 2005)

Most used CDS contracts are single name contracts, which means that the referred entity is, for example a specific company. CDS contracts also vary with respect to the seniority of reference debt and the applied legal framework. The maturities of CDS contracts vary, but the most common are 3, 5 and 10 years. The premium payment convention is

most often on quarterly basis. International Swap and Derivatives Association has defined different types of credit events, which trigger the liability of protection seller: bankruptcy, obligation acceleration, failure to pay, repudiation (reference entity challenges the validity of its debt obligation), and unfavourable restructuring to creditors. (Bomfim, 2005, pp. 67-82)

In the case of a credit event, two conventions on how protection seller can settle its obligation are common. First one is so called physical delivery. In physical delivery the protection seller is obliged to buy the bond subject to credit event for its nominal price from the protection buyer. In cash settlement the protection seller pays the difference between recovery value and face value. Standard way to determine the recovery value is to auction reference debt subject to credit event. (Bomfim, 2005, pp. 67-82)

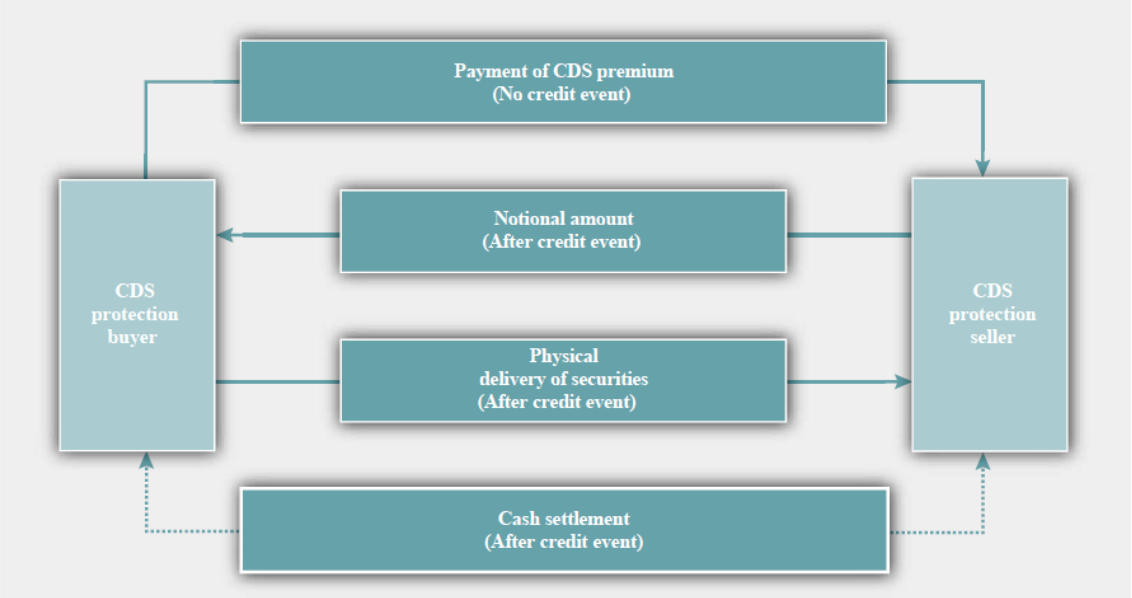

FIGURE 4.1 CDS OVERVIEW (SOURCE: ECB, 2009)

In practice CDS contracts are used in risk control, but they also make it possible to position with reference entity's credit risk, without directly owning its debt. Since initially no principal changes owner, with a particular amount of capital, one can use CDS contracts to get exposure to a bigger amount of credit risk than by owning debt directly. The protection seller has a long position in company's debt, which is analogical to buying the company's bonds. Hence, when short selling of other's debt is not possible, CDS contracts can be used to achieve short position. (Bomfim, 2005, pp. 67-82)

It is obvious that the CDS spread is determined based on the likeliness of credit event and the recovery rate. The valuation of credit risk for debt and derivative markets is often done using structural models or reduced-form models (De Wit, 2006). Former values firms' debt via the implicit default option it is holding whereas latter models takes default as exogenous events, which in turn, can be modelled with jump processes (De Wit, 2006). However, the details of CDS valuation are not in the main scope of this thesis, as I am interested in my approach of the pricing differences of the risk in the two markets, not the true risk. Yet, calculating out the default probability from the CDS and interbank market could be one approach to my problem as well.

CDS market size has been growing substantially in the 2000s (ECB, 2009). According to The International Swaps and Derivatives Assosciation (ISDA, 2013) the conventional measure for market activity used to be notional value of CDS contracts. However portfolio compression, which terminates contracts instead of entering into an offsetting one, has reduced the notional amount. If this effect is taken into account the market have maintained it size and activity in past couple of years (ISDA, 2013). Nevertheless, I will control the CDS market liquidity in my analysis.

The recent discussion about CDS misleading price information and destabilising market effects is interesting, but it should not have an effect on the validity of my methods. Portes suggests (2012) the some entity's CDS prices changes may lead to the change of that entity's cost of funding, which is a kind of twisted causality and price discovery, and a potential source of market instability. However, this does not change the arbitrage condition between the two variables, and hence, it should not be a driver for arbitrage condition violation.

4.1.2 Overnight Indexed Swaps (OIS)

OIS derivative contract is an interest rate swap derivative (Todd, 2006). In OIS derivative contracts one party agrees to pay fixed rate against the average of variable overnight rates (in euros it is Eonia) over the agreed period and notional amount. As the net expected value of contracts must be zero at the moment when it is agreed, it must be that the fixed rate represents the expectations of average overnight rates for the given period (Sengupta & Tam, 2008). As Eonia is basically the shortest possible interest rate,

and the counterparty risk component involved is considered trivial (Sengupta & Tam, 2008). Also in OIS contract itself the credit risk is considered nearly non-existent, as no principal changes owner. In addition, no initial cash is needed, thus funding risk is minimal. Altogether, OIS illustrates the market expectations of geometric average of shortest possible rate over given period, and it contains no term premium. (Todd, 2006)

In practice OIS can be used, for example, to hedge against the variation in overnight rates. This is relatively easy to illustrate when the contract participant is able to invest its principal with Eonia rate. This has been illustrated in figure 4.2, in which it is shown how investor A invests some principal overnight and earns Eonia rate. At the same time investor A enters into an OIS contract, which has the same nominal amount as the principal amount invested. Now the Eonia rate is effectively passed to investor B, who in return pays the fixed rate that was agreed in the beginning. In practice, instead of settling the cash flows every day, cash flows are counted as compounded rate and settled in the end of the contract. The illustration does not take into account the funding costs Investor A has for the principal amount.

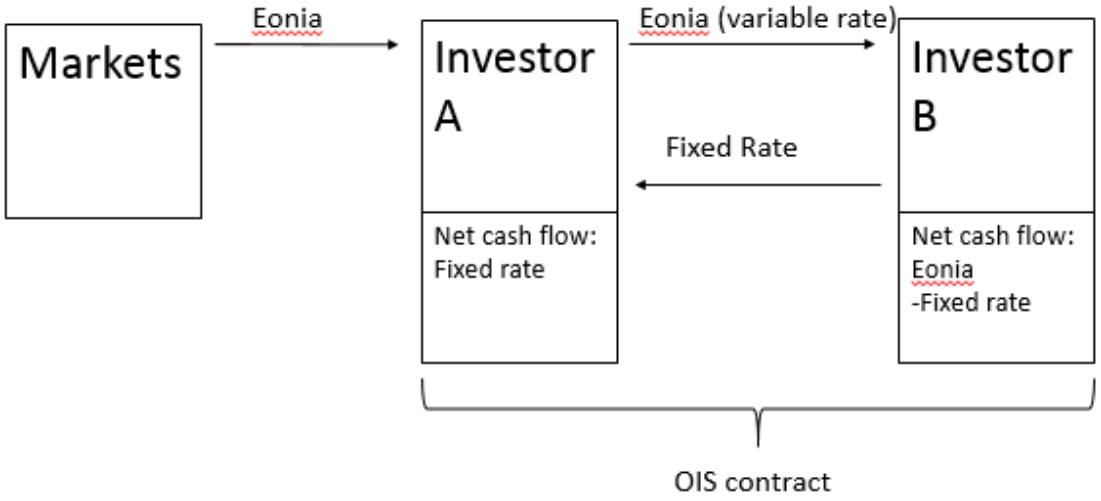

FIGURE 4.2 STYLIZED CASH FLOWS OF OIS

In addition to its technical properties, the OIS market is considered liquid and efficient, which makes it suitable as a risk free indicator. In addition to my thesis, the OIS rate is

also used widely in different money market and interbank studies as a proxy for risk free rate. See e.g. Gefang et al. (2011), Sengupta & Tam (2008), and Kuo et al. (2012).

4.1 Theory of Arbitrage Condition

In the definition of Libor it is required that banks report their own funding costs. Hence the Libor rate and submitter credit risk should have a direct link. Credit risk is the risk investors require against possible payments problems of debtor. Credit risk embedded in Libor is noted especially the academic literature branch, which studies the different risks components of Libor rates (aggregate, not the individual rates) during the crisis[9]. The common feature of these articles is that they use CDS spread as a proxy for credit risk. This approach assumes that Libors' credit spread and CDS are correlated. Unfortunately, this is not necessarily the case, when manipulation o taken into account. By studying individual banks' submissions I can account each bank with market priced CDS spread and compare that to the Libor submissions. I consider the Libor submission somewhat same as a zero coupon bond.

The differences of CDS and interbank implied risk spread are much less discussed in academics than CDS and bond implied risk spread. The latter is recognized in literature as CDS Bond basis. For examples, see De Wit (2006) and Zhu (2006). In a similar manner, for the sake of clarity, I use the term CDS-Libor basis to denote the difference of Libor implied risk and CDS spread. To my best knowledge, that term has not been used in academic literature to date.

CDS and interbank rates arbitrage condition is discussed in paper by Eisenschmid & Tapking (2008). Otherwise similar direct arbitrage analysis is scarce in academic literature. Eisenschmid & Tapking (2008) use repurchase agreement rate (repo rate) as a risk free interest rate. They show that (2008, pp. 15-16) arbitrage condition is simply as is described in equation *1*, given CDS premium payment(ρ), interbank rate (c) and repo rate (r).

[9] For example Smith (2012), Taylor & Williams (2008a,b),and Michaud & Upper (2008),

$$\rho = c - r \tag{4.1}$$

And if it does not hold, I define that as CDS-Libor basis as follows:

$$\rho - (c - r) = Basis \tag{4.2}$$

The main difference between their analysis and mine is that in my model I use OIS as an indicator of risk free rate. From arbitrage point of view, the risk free rate is the rate which is also assumed to be the funding rate of the arbitrager, as banks need cash to exploit the opportunity. I will illustrate the arbitrage possibilities when the basis is non-zero. Similar but more technical illustration is also in the paper by Eisenschmid & Tapking (2008).

When some banks B CDS spread is lower than the Libor implied risk spread (negative basis):

Lending bank A could lend money for bank B at some rate (c). Bank A needs to cash to finance the lending (amount X). Bank A can borrow at rate r by rolling the debt overnight and locking the overall interest rate by entering into an OIS contract. At the end of the loan period this arrangements yields $(c - r) * X$, if the entity has not defaulted. To protect from the default, bank A enters into a CDS deal, which in case of default, compensates any losses of the principal amount (this and other assumptions are discussed in the next subsection). In case the credit event happens, bank loses nothing. If the credit event does not happen, bank A earns $(c - r - \rho) * X$. Hence, it looks like that this profit is earned without risk of losing capital.

CDS spread is higher than Libor implied risk spread (positive basis):

Bank A writes CDS protection over bank B and gets premium ($\rho * X$) at the end of the loan period. If bank B defaults, bank A will lose the amount X. If bank A loans the money to Bank B, it will get ($(c - r) * X < \rho$). However, in case of default, bank will lose its capital (X). Bank A will clearly rather write the CDS which yields more than lend money to bank B. Hence, under perfect markets, the described situation should not happen. In this case any assumptions of the funding rate of lender does not have to be made, as regardless

of its rate (r), the CDS is will always be better option. Unlike in bonds, third party cannot short sell bank B's debt, which is in a form of interbank deposit. However, Libor allows that short-term instruments, like certificate of deposits, are used as a base for rate submissions. Those CD's can be, at least in theory, sold short.

The above illustrations shows that the condition 1 should hold as in the long run arbitragers will exploit the pure profit possibilities. However, the CDS-bond basis literature offers plenty of explanations why there can be deviation from the arbitrage condition and why it is not necessarily zero.

4.1.1 THE CDS-LIBOR BASIS

The exactly same condition as in equation 1 is found with CDSs and bonds (Zhu, 2006), which allows me to exploit the methods used in CDS-bond basis studies quite straightforwardly. CDS-bond basis studies are useful as the academic literature about interbank unsecured rates and CDSs is scarce in quantity. The arbitrage condition does not take into account the drivers which can cause the basis to be non-zero, at least in the short term, but also in the longer term. The CDS Bond basis has been reviewed extensively for example by (Hull, Predescu, & White, 2004, p. 10; De Wit, 2006, pp. 3-12; Zhu, 2006, p. 215; Bühler & Trapp, 2009; Bomfim, 2005). I have listed below the factors that can be generalized to affect at the interbank markets. I have also shortly discussed how these measures are controlled in my thesis, or why they are left out. The discussion of the modelling is in the subsection 4.2.

I. **Funding liquidity risk.** One does not need cash to enter into a CDS contract. Hence, the ability to raise funds can constraint arbitrage possibilities in the interbank deposits. Negative bond basis may exists if lenders are cash constrained i.e. have high rate of refunding. (De Wit, 2006) In terms of arbitrage, using OIS as risk free rate assumes that banks can get funding at OIS rate, which is same as assuming that bank is able to roll its debt overnight for given period. Because this is never certain, as market conditions and banks' ability to get funding can change, risk premium over OIS is required. Often Libor-OIS itself is used as a

proxy for funding risk premium. However, for obvious reasons, this is not possible when I am particularly studying the validity of Libor. The market wide liquidity proxy is discussed in more detail in subsection 4.3.

II. **Risk of basis.** There is a risk that basis exploiter bank needs to terminate the deal prematurely. This could be due to funding needs. If the basis has widened meanwhile, the investor is subject to losses. This factor is hard to measure (De Wit, 2006), but the risk is related to the funding risk: when funding risk is high, locking into basis deals does is not desirable. Hence, the effect is negative, put I assume it is taken into account in funding risk component.

III. **The "hidden" cheapest to deliver option in CDS contracts**: The better the option, the higher must the CDS spread be (Bomfim, 2005, pp. 78-79). Bomfim (2005, p. 79) argues that the value of the option has diminished in recent years.

IV. **Counterparty risk of CDS**: In case of default of reference entity, is the protection seller able to pay the liabilities (Bomfim, 2005, pp. 78-79)? CDS spread must be lower to compensate for this: why would one pay full insurance fee, if there was a possibility that the insurance does not cover the expenses? Counter party risk of CDS protection seller is discussed in detail in Hull & White (2001) and in De Wit (2006). However, the effect is relatively small, and as the issuers are mostly same companies, this effect should be market wide (Hull & White, 2001; De Wit, 2006; Bomfim, 2005).

V. **Mismatches in the accrued cash flows of interbank and CDS market**: CDS convention is quarterly paid premium whereas interbank deposits pay coupon at the end of period. CDS protection seller is only liable of the loss in face value. Coupon payments are excluded. (Bomfim, 2005, pp. 78-79) Provided the credit event does not happen, accrued CDS premium could be matched to equal the bond credit spread and there would be no mismatch. However, the bigger is the probability of credit event, the bigger is the possibility that one ends in the latter scenario where the payoffs differ significantly, because CDS protection seller gets the accrued premiums, ceteris paribus, CDS writer is better off, and hence annu-

alized premium should be smaller than bond credit spread. This effect is endogenous to credit risk. (Bomfim, 2005, pp. 78-79) Nevertheless, I have not taken this into account as, even with high credit spreads, this effect is relatively small.

VI. **The liquidity premiums of CDS markets** and (Bomfim, 2005, pp. 78-79)
And money market (Bomfim, 2005, pp. 78-79). As I later argue, this factor is considered to be most significant factor in driving basis. By market liquidity premium I refer to the cost of liquidating assets. There is no universally agreed proxy for market liquidity. Common ones are market bid-ask spread, market turnover, and amount of price quotations for certain time period. I will use relative bid-offer spread for CDS markets. Money market liquidity premium is embedded in the proxy of the non-default component.

VII. **Tax and other regulatory differences** are hard to quantify and the effect can be in any direction. (Hull, Predescu, & White, 2004, p. 11)

VIII. **Transaction costs** allow for small arbitrage possibilities to exit (De Wit, 2006)

IX. **Portfolio driven manipulation.** As Libor submitter can have incentives to manipulate in any direction, it can make the basis to be positive or negative. However, these effects are small, as the portfolio driven manipulation was often only couple of basis points.

X. **Reputation driven manipulation.** This causes the basis to be positive as Libor has lower credit risk implied component than CDS contracts. Hence, high and persistently positive basis is suspicious.

TABLE 4.1 BASIS FACTORS

Factor	Impact on Basis
Funding liquidity risk	-
Risk of basis	-
Cheapest to deliver option	+
Counterparty risk of CDS issuer	-
Mismatches in cash flows	+
Liquidity premium of CDS markets	+
Liquidity premium of interbank markets	-
Tax and regulatory differences	+/-
Transaction costs	+/-
Portfolio driven manipulation	+/-
Reputation driven manipulation	+

4.2 HOW TO MODEL THE LIBOR-CDS BASIS?

The review of CDS-bond basis literature in subsection 4.1.1 have offered plenty of reasons why the CDS-bond basis does not necessarily have to be zero. The effects are clearly time specific and company specific. However, many studies have found that for most companies the bond-basis in the long run is close to zero (Zhu, 2006; De Wit, 2006), which is verified by co-integration analysis, and also without any role given to the factors listed in table 4.1. Zhu for example finds that price discrepancy correction is about 10 % a day and it normally exists for 2-3 weeks. Zhu (2006), Fontana (2011), and Bai & Collin-Dufresne (2011) state that during normal times, the basis is mainly small positive and there is always idiosyncratic variation. These pre-crisis studies indicate that I could make the assumption that the above mentioned effects do not play significant role, at least

not in the long run. It is tempting to make this assumption, because even getting up with a proxy for most of the factors is challenging.

In studies which try to decompose aggregate Libor-OIS spread into components the spread is often seen as a sum of non-default factors and default factors, though the interaction between them is also regonized. Michaud & Upper (2008) and Eisenschmid & Tapking (2008) claim that especially the liquidity risk spreads have been dominant drivers of unsecured interbank markets during the financial crisis. Taylor and Williams (2008a,b) attribute more on the credit risk. Smith (2012) see both in approximately equal role. Ji (2012) sums that the literature shows evidence in both directions. However, Ji (2012) himself finds evidence that creditworthiness in in smaller role.

The above literature implies that negative CDS-Libor basis could be negative at least during the 2007-2008, as the liquidity premium of money markets is higher, ceteris paribus. At least bond-basis is found to have been mostly negative (persistently) during the crisis (Fontana, 2011). Bai, Collin and Dufresne (2011) find that funding risk, counterparty risk and collateral quality were main reasons for negative basis during the crisis. Hence, the CDS-bond basis literature and money market literature indicate that in the financial crisis market environment at least the liquidity factors should be considered. The other factors should be relatively constant over time or the effect can be regarded small.

All in all, theory clearly points out that in the long run Libor-OIS difference to CDS-spread (the CDS-Libor basis) should be stationary, and likely close to zero. There can be short-run deviation, of which I am not interested in. However, if the basis is non-stationary for a period, which can be considered long enough to not to be regarded as a short run variation, it is possible that some non-default factor of CDS or Libor-OIS spread is causing it. Hence, persistently low or high basis, i.e. deviation from the long run equilibrium, can be observed, even without it being caused by the manipulation.

The biggest problem in my approach to Libor manipulation is that there is no obvious measures for the non-default components. My choices are described and justified in the next subsection.

4.3 Data Description

The data used consists of daily time series beginning from 2004 until the end of 2013. The comprehensive descriptive statistics can be found from Appendix 1. The Libor rate reviewed is 12 month euro rate. Twelve month euro rate is not the most referred rate of Libor panel, but it allows to use one year CDS spreads without the problematic maturity mismatch. Shorter than one year CDS spreads were limitedly available for the banks. I have data access to Libor submissions and CDS quotes for 11 panel banks out of 15 (Abbey National bank had relatively few CDS quotes, so I decided to drop it out). Individual Libor submissions of panel banks are public. CDS data and OIS data is from Bloomberg. For each instrument the daily market close value is used.

CDS bid and offer quotes used are for unsecured senior single name contracts. The currency and technical legal features of contracts are identical for all of the banks, and thus, they do not explain any variation. The CDS spread used in analysis is actually the mid spread, which is the average of bid and offer prices on a given moment of time. The CDS market liquidity proxy is the CDS bid-offer spread divided with the mid spread. This spread to price ratio is less correlated with the CDS spread than the plain bid-offer spread. The high correlation with CDS spread would be very problematic, because likeliness of manipulation is also likely to be positively correlated with CDS spread (higher is the credit risk, the higher is the need to manipulate). Hence, it could have been possible that banks manipulating had been accounted for with a high coefficient of CDS liquidity, but in reality, it was the credit risk component of liquidity proxy that explained the variation. The weakness of the spread to price ratio is that it may overestimate the liquidity conditions when CDS spread is high. To illustrate this: bid offer spread of a one basis point with CDS mid-price of ten basis points gets equal value as spread of hundred basis points with CDS mid-price of thousand basis points. Yet, it seems obvious that in the latter case the market liquidity is lower.

To capture the non-default element of Libor-OIS spreads, I will use Euribor-OIS spread for 12 month Euribor. This choice of proxy has two flaws: it is not banks specific and it has a credit component (of a prime bank). However, the credit component should be

relatively fixed over time, as the hypothetical prime bank which the Euribor is quoted for, should be considered to have excellent credit profile. The Euribor-OIS proxy captures only the variation of the market wide non-default component. Company specific data is not available in required frequency, and the structural methods with interpolation would complicate the analysis and be out of the scope of this thesis.

Data is divided into three periods. The periods are pre-crisis period (4/01/2003 - 7/19/2007), period of manipulation (7/20/2007-12/31/2008), and post-manipulation period (1/01/2009 - 12/13/2013). The start and end dates for period two are obtained from Monticini and Thornton (2013). Periods 1-3 include together 2794 dates of observations. Period one has 1123, period two 379, and period three 1292. Comprehensive descriptive statistics of each variables for each period can be found in appendix 1.

4.4 Methods of Data Analysis

Important concept in time series analysis is the stationarity of a series. A time series is said to be (weakly) stationary if the mean and the covariance between arbitrary lags are not time dependent. In practice times series should be such that the values vary in a constant way around its constant mean. (Tsay, 2002, p. 23)

First I will test the all the series for unit root, to see if they are non-stationary. This is done with Augmented Dickey-Fuller (ADF) test. For each bank appropriate amount of lags is determined by Schwarz information criterion (SIC)[10]. The regression tested for series *x* is presented by equation 4.3. In the equation p is the number of lags determined by SIC. Null hypothesis is that series contains a unit root, which means that in the equation coefficient α gets value zero. Critical values are obtained from simulation results of MacKinnon (1996)[11], as the test statistics do not follow any standard tabulated distribution.

[10] Information criteria, like SIC, demonstrate how small the squared errors are compared to the amount of parameters. The smaller the better. Eviews uses modified version of standard SIC (Brooks, 2008, pp. 232, 236)

[11] This is the standard of Eviews statistical program

$$\Delta x_t = \alpha x_{t-1} + \sum_{i=1}^{p} \beta_i \Delta x_{t-i} + u_t \qquad 4.3.$$

For non-stationary series the long term relationships is studied by using co-integration analysis as is proposed by Engle & Granger (1987). Series are said to be co-integrated if they are non-stationary but a linear combination of the series is stationary (Engle & Granger, 1987). My two series are CDS credit spread and Libor-OIS (*c-r*) for each bank. According to previous section of this thesis, the theory proposes that in the long run in equation 2 the basis is close to 0, which implies that the linear combination vector is (1,-1). Hence equation 3 coefficients get values $\alpha = 0$ and β = 1.

$$\rho_t = \alpha + \beta(c_t - r_t) + \varepsilon_t \qquad 4.4.$$

To test for co-integration, I simply test if the error term (here it is equal to the basis) is stationary for each bank. To test if there has been changes, I test for the unit root separately for the three different periods. If unit root test statistic is lower than the critical value for given confidence level the null-hypothesis of unit root can be rejected, and it follows that the series can be said to be co-integrated. Similar residual based co-integration analysis for CDS-bond basis is conducted by De Wit (2006). In addition to predetermined co-integration vector, I use fully modified ordinary least square method (FMOLS is the standard estimation method of co-integration in Eviews computer program) to estimate the parameters, and then test the residual for stationarity. This is called Engel-Granger two step method.

According to Gregory & Hansen (1996, pp. 102-103) dummy variables can be included in the co-integration analysis. The process is relatively straightforward when the timing of structural breaks are known. With dummy variables, one can allow for level shift, trend shift and regime shift in co-integrated process. The idea is that even though co-integration is considered to represent long-term relationship of non-stationary variables, it is possible that during the review period series are not co-integrated but during the sub-periods series are co-integrated (1996, pp. 102-103). This is likely case if manipulation has happened as it would most likely cause a different mean for different peri-

ods. Applying Gregory & Hansen (1996, p. 103) I would classify that as a level shift. Manipulation could also cause a regime sift in the model. This effects can be modelled by adding dummy variables to interact with beta coefficient. I include three dummy d_i variables in the equation to allow for structural change. For period *i* d_i gets value 1 and for other periods it gets value 0. I estimate beta –terms in the following equation by using FMOLS:

$$\rho_t = \sum_{j=1}^{3} d_j \beta_{1i} + \sum_{j=1}^{3} d_j \, \beta_{2i}(c_t - r_t) + \varepsilon_t \qquad 4.6.$$

In the third co-integration estimation the liquidity variables of CDS for each bank and market wide money markets liquidity variable are included. I will use the theory implied coefficient for the term $(c_t - r_t)$ as I did in the equation. This is equal as estimating the FMOLS (discussion of FMOLS in the end of this subsection) for

$$\rho_t - (c_t - r_t) = + \sum_{j=1}^{3} d_j \beta_{1j} LIQ_{CDS} + \sum_{j=1}^{3} d_j \beta_{2j} \, LIQ_{MM} + \varepsilon_t \qquad 4.7.$$

And for clarity

$$\rho_t - (c_t - r_t) = BASIS_t \qquad 4.8.$$

For both of the equations 6 and 7 I will run a unit root test to see if the residuals are stationary, and thus, the series co-integrated.

The reputation driven manipulation story proposes that banks did not want to separate themselves from other banks with their Libor submissions. Hence, it implies that Libor submissions of banks should be co-integrated together. To test for this, I test for co-integration relationship between banks and the final Libor rate, which is the trimmed average all submissions. If banks are contributing honestly, we should find banks having persistently high (low) CDS to submit higher (lower) Libors and hence, the series of those banks should not be co-integrated.

As was mentioned above, I will use FMOLS methods to estimate the co-integration coefficients. According to Eviews 7 User's Guide (Quantitative Micro Software, 2010, p.

220) ordinary OLS estimations is not recommended as its results are non-Gaussian, asymptotic biased, and asymmetric. In OLS analysis the interference of co-integration coefficients is not feasible. FMOLS method fixes the long run correlation problem between the co-integrating equation and stochastic regressors. This is done via semi-parametric bias correction. (Quantitative Micro Software, 2010, p. 223).

4.5 Results

The non-stationary tests for variables are included in appendix 2. The results show that the Libor-OIS spread and CDS-spread are non-stationary for all of the 11 banks. Averages of CDS-Libor basis, Libor-OIS, and CDS spreads are listed in table 4.2. Basis of banks are drawn in figure 4.3 and also individually in appendix 3. For number of the banks the period two included a time span when no CDS-data was not available. Thus, figure 4.3 has a gap in the middle.

Table 4.2 Descriptive Statistics

	Average Basis (%)				***Average CDS (%)***				***Average Libor(%) – OIS(%)***			
	Period				**Period**				**Period**			
Bank	**1-3**	**1**	**2**	**3**	**1-3**	**1**	**2**	**3**	**1-3**	**1**	**2**	**3**
Barclays	0.1	0.0	-0.3	0.2	0.6	0.0	0.7	0.8	0.49	0.07	0.96	0.72
Citibank	0.5	0.0	0.1	1.0	0.9	0.1	1.0	1.6	0.47	0.07	0.94	0.69
Credit Suisse	-0.1	0.0	-0.5	-0.1	0.5	0.1	0.5	0.7	0.53	0.06	0.99	0.80
Deutsche Bank	-0.1	0.0	-0.5	-0.1	0.4	0.1	0.5	0.7	0.50	0.06	0.94	0.75
HSBC	-0.1	0.0	-0.6	-0.1	0.4	0.1	0.4	0.5	0.46	0.07	0.94	0.66
JP Morgan	-0.1	0.0	-0.5	-0.1	0.4	0.1	0.4	0.5	0.46	0.07	0.92	0.65
Lloyds	0.3	0.0	-0.3	0.6	0.7	0.0	0.1	1.3	0.49	0.07	0.94	0.73
Rabo	-0.1	0.0	-0.9	-0.1	0.4	0.0	0.5	0.6	0.50	0.06	0.95	0.67
RBS	0.3	0.0	-0.3	0.6	0.8	0.0	0.7	1.3	0.51	0.08	0.95	0.75
Societe Generale	0.3	0.0	-0.7	0.5	0.7	0.1	0.6	1.2	0.52	0.09	0.93	0.68
UBS	0.1	0.0	-0.3	0.2	0.5	0.0	0.7	0.9	0.48	0.07	0.92	0.70
Variance of means	0.05	0.00	0.07	0.14	0.04	0.00	0.05	0.14	0.001	0.000	0.000	0.002

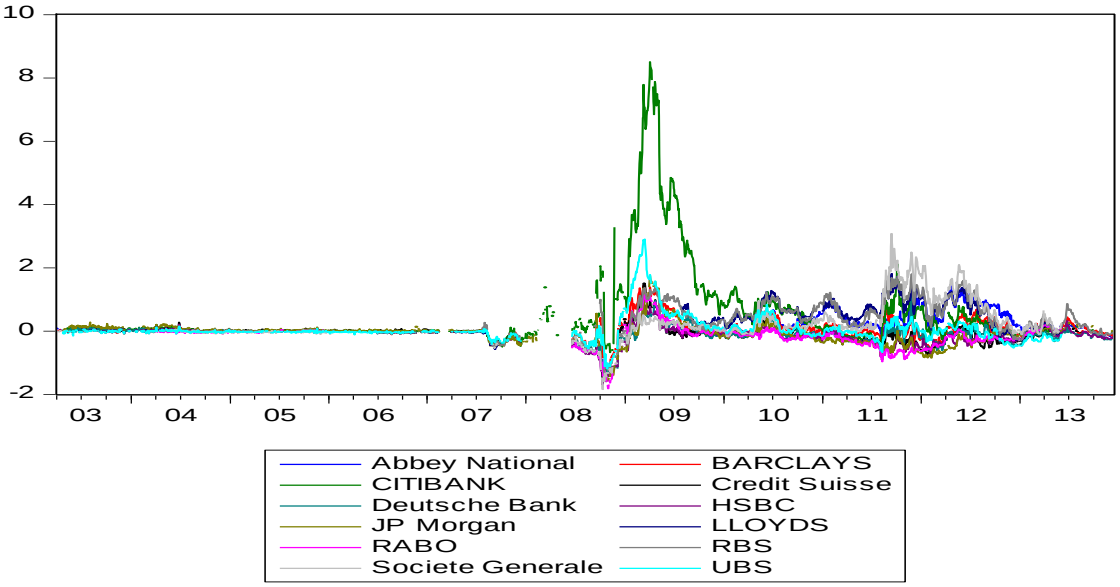

FIGURE 4.3 BANKS CDS-LIBOR BASIS (%)

Average basis of panel banks was very low until the June of 2007 when financial market turbulence begun. During that time the average CDS and LIBOR-OIS spread was also relatively flat. In period two (7/2007-12/2008) the basis plunged almost for all of the banks. In the third period the basis has been mainly positive for most of the banks. The variation of Libor-OIS spread is low in each of the periods, whereas the variation of CDS and basis is higher in 2nd and 3rd period.

In the table 4.3 are the results of the null-hypothesis of no co-integration as is defined in equation 4.3. The test is done for each period together and individually. The table 4.3 shows that for the period 2 only one bank passes the co-integration test at 1 % confidence level. Test for all periods 1-3 shows that 3 banks pass the co-integration test at 1 % level, 8 at 5 % level, and one at 10% level. To sum up, 9 banks pass the test at least at 10% level. Results as is shown in table 4.2 and 4.3 are in align with the discussion in subsection 4.2 of this thesis, which indicated that during the period 2 basis could be persistently negative. Negative basis and non-stationarity could be caused by the liquidity factors, not necessarily the manipulation. Moreover, the basis should be positive in case the reputation driven manipulation is the only factor driving the basis. The test for first period is omitted as the CDS and LIBOR-OIS series were stationary during that period.

TABLE 4.3 CO-INTEGRATION TEST RESULTS WITH (1,-1) CO-INTEGRATING VECTOR

Bank/Period	***2***	***3***	***1-3***
Barclays	No	Yes ***	Yes ***
Citibank	No	No	No
Credit Suisse	No	Yes **	Yes **
Deutsche Bank	No	Yes ***	Yes ***
HSBC	No	Yes **	Yes **
JP Morgan	No	Yes **	Yes **
Lloyds	No	Yes **	Yes **
Rabo	No	No	No
RBS	Yes ***	Yes **	Yes ***
Societe Generale	No	Yes **	Yes **
UBS	No	No	Yes *

The null of no-cointegration is rejected at level *<0.10 **<0.05 ***<0.01

TABLE 4.4 ESTIMATED COEFFICIENTS AND CO-INTEGRATION TEST

	Beta			**Constant**			**Co-integration over period 1-3**	**Observa-tions**
Bank/Period	**1**	**2**	**3**	**1**	**2**	**3**		
Barclays	0.4	-0.6	0.7	0.2	5.4	0.2	Yes***	2167
Citibank	0.5	-1.2	1.3	0.5	8.9	0.2	No	2415
Credit Suisse	0.5	-0.6	0.7	0.2	5.6	0.0	Yes***	2102
Deutsche Bank	0.3	-0.5	0.6	0.3	4.6	0.1	Yes***	2310
HSBC	0.2	-0.4	0.5	0.2	3.6	0.1	Yes***	1969
JP Morgan	0.2	-0.3	0.4	0.3	2.7	0.2	Yes***	2302
Lloyds	1.6	-1.8	1.8	0.0	15.5	-0.2	Yes***	1700
Rabo	0.0	-0.1	0.5	1.0	2.4	0.1	No	1570
RBS	0.4	-0.8	0.9	0.5	6.5	0.3	Yes**	2145
Societe Gene-rale	-1.2	1.3	1.6	6.8	0.9	0.0	Yes***	1629
UBS	0.3	-0.7	0.8	0.3	5.8	0.0	Yes*	2230

The null of no-cointegration is rejected at level *<0.10 **<0.05 ***<0.01

Table 4.4 contains the results of equation 4.6 which allowed for trend and regime shifts in the estimation. Now the p-values of co-integration test improve and with 7 banks the null hypothesis can be rejected at 1 % level. However, the beta-coefficient, which should

in light of theory be close to 1, changes its sign with almost all of the banks in second period. Also the constant term, gets very large values - especially in period 2.

The unit root test reveals (appendix 2) that the co-integration equation as is in 4.8, cannot be estimated for the first and third period as the CDS liquidity series are stationary for all of the banks. Hence, I estimate it only for the period two. Results of co-integration test, in which market wide non-default factor and individual CDS-liquidity factor are included, are presented in table 4.5. Results show that only three banks out of 11 pass the test. All of them pass also with the highest significance level. Besides, the sign of estimated MM-liquidity factor for each bank is the same and it has the theory implied negative sign (see subsections 4.1 and 4.2 of this thesis). The CDS Liquidity factor got very small values for all of the banks, and the MM liquidity factor, was co-integrated and barely changed when the estimation was done without the CDS-liquidity proxy. In addition, CDS factor alone was not co-integrated with the basis. Hence CDS liquidity is denoted as 0 for each of the three banks.

TABLE 4.5 CO-INTEGRATION OF BASIS, CDS LIQUIDITY. MONEY MARKET LIQUIDITY IN PERIOD 2

	Barclays	Citibank	Credit Suisse	Deutsche Bank	HSBC	JP Morgan	Lloyds	Rabo	RBS	Societe Generale	UBS
Period 2 co-integration	No	No	No	No	No	Yes***	No	Yes***	Yes***	No	No
CDS Liquidity						0		0	0		
Money Market Liquidity						-0.47		-0.66	-0.31		
Observations	129	210	130	133	109	191	31	51	126	77	194

The null of no-cointegration is rejected at level *<0.10 **<0.05 ***<0.01

I will also repeat the test for banks which had the basis non-stationary in the period 3. I have omitted the CDS-liquidity variable, as it was stationary during the period for all of the three banks. Table 4.6. Shows that the market wide money market liquidity proxy is not able to explain the non-stationarity of those three banks in period 3. This was highly

expected as it would have been likely that then also the other banks would have had a non-stationary basis during the period 3 – exactly like they had in period 2.

TABLE 4.6 CO-INTEGRATION OF BASIS AND MONEY MARKET LIQUIDITY IN PERIOD 3

	Citibank	Rabo	UBS
Period 3 co-integration	No	No	No
Money Market Liquidity			
Observations	2036	1091	1078

The null of no-cointegration is rejected at significance level:
*<0.10 **<0.05 ***<0.01

Table 4.7 shows the results of Libor and individual banks Libor submissions co-integration test. The table shows interestingly how in period one all the banks had very highly significant co-integration with the Libor rate. In periods two and three only three and two banks respectively do not pass the co-integration test.

TABLE 4.7 CO-INTEGRATION TEST RESULTS OF LIBOR AND INDIVIDUAL LIBOR SUBMISSIONS

Bank/Period	1	2	3
Barclays	Yes***	Yes ***	Yes ***
Citibank	Yes ***	Yes **	Yes ***
Credit Suisse	Yes ***	No	Yes **
Deutsche Bank	Yes ***	Yes ***	Yes ***
HSBC	Yes ***	Yes ***	No
JP Morgan	Yes ***	No	Yes **
Lloyds	Yes ***	No	Yes **
Rabo	Yes ***	Yes ***	Yes ***
RBS	Yes ***	Yes ***	Yes **
Societe Generale	Yes ***	Yes **	Yes ***
UBS	Yes ***	Yes *	No

The null of no-cointegration is rejected at significance level: *<0.10 **<0.05 ***<0.01

4.6 Discussion of the Results

In figure 4.4 is plotted (Y-axis) the average CDS-spread and (X-axis) the average CDS-Libor basis of each bank. In figure 4.4 the Y-axis is changed to Libor-OIS spread. A trend line (OLS) is drawn for each period's dots to illustrate the relationship between the two variables. The numbers are from the table 4.2. The figure 4.4 illustrates that a high CDS-spread average is associated with a high basis average. Whereas the opposite does not hold for Libor-OIS spread: the trend lines in figure 4.5 are relatively flat.

These result indicate that the Libor-OIS spread for individual bank poorly takes into account the credit risk implied by the CDS spread. The variation of Libor-OIS spreads averages is not either similar with the variation of CDS spreads in period 2 or 3, as they are totally different in size. Even this simple comparison of basic descriptive statistics raises questions about Libor submissions validity from counterparty risk perspective.

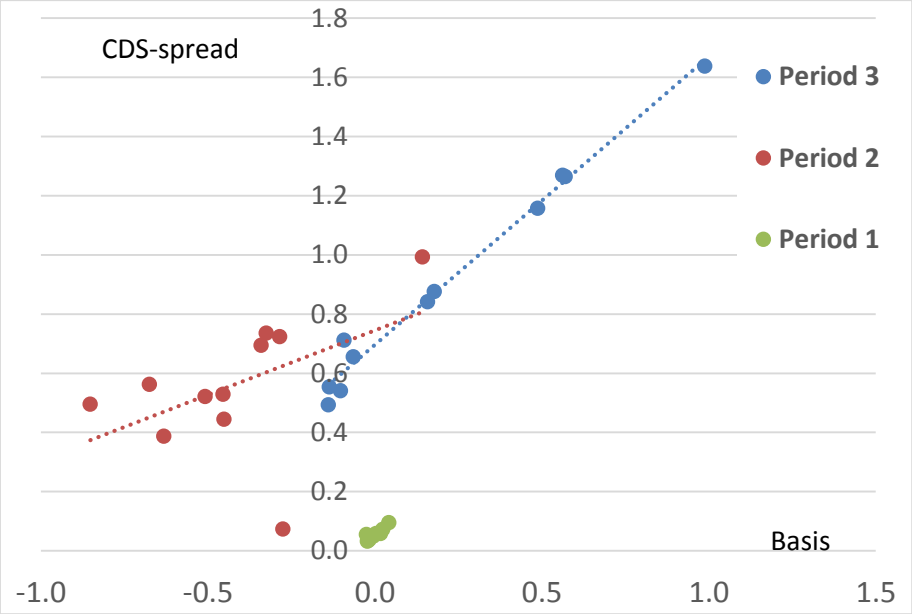

Figure 4.4 Average basis (%) and CDS spread (%)

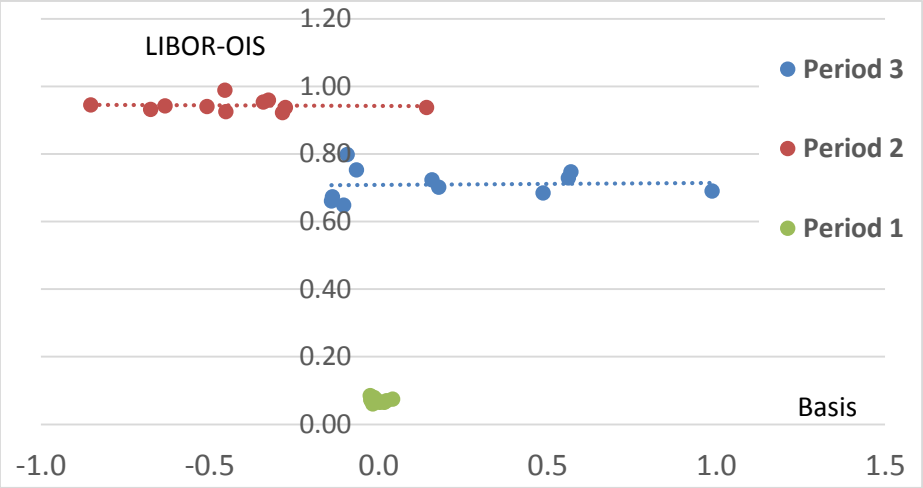

FIGURE 4.5 AVERAGE BASIS (%) AND LIBOR-OIS (%)

The (1,-1) co-integration test results in table 4.6 reveal that the process somewhat changed during the period 2 as only one of the banks pass the co-integration test. In that period the basis turned negative for almost all of the banks. The general negative basis observed in period 2 is in line with other studies of CDS bond basis and also of the money market component studies discussed in subsection 4.1. Those studies accounted the rose of Libor-OIS spread to be caused by the growth in funding risk and liquidity premium, and to lesser extent of credit risk. Thus, negative basis does not solely prove that a bank is not manipulating.

Similar conclusions can be made based on the results (table 4.4) of the co-integration test of period specific coefficients and constants (dummy variables). In the first period co-efficient vary very much. This could be because the CDS spreads are so small (average for all of the banks is less than 0,10 %) that the LIBOR-OIS spread does not incorporate practically any credit risk. In period two the estimated coefficients turn into negative, which seem to be against theory, but is actually explained by omitted variable: the money market non-default component. However, the period 3 variation is not explained by the money market nor the CDS market non-default component, and hence, especially bigger coefficients than 1 seem suspicious.

Adding the market wide money market non-default component proxy in to the model explained the deviation from the long run equilibrium only for three banks. Besides, as the liquidity factor coefficient was estimated separately for every bank, it should have

captured to some extent also company specific drivers, which vary together with the market wide factor. Hence, the failure to pass the test, can be accounted for company specific factors that are not correlated with the market specific factors, one of which, is the intentionally low submitting. Unfortunately, due to the extraordinary environment during the financial crisis, the results from period 2 should be interpreted with extra caution. Also the lack of observations over the period two can cause some incoherent features in the test. Therefore the results of banks with small number of observations in period 2 (Lloyds for example who does not pass the test and Rabo who does) should not be interpreted as strong evidence in any direction.

The co-integration test of Libor and individual banks' submissions (table 4.7) indicates that the submissions are moving together with Libor. Interestingly enough, banks which failed the co-integration test were among those who had also the lowest CDS spread i.e. the credit risk. This could be explained by the trimmed average mechanism of Libor calculation, as was discussed in the subsection 4.4. The lowest 25 % (and highest) of submissions do not directly affect the level of Libor as they are trimmed away. Hence, if some banks are constantly trimmed away (like banks with the lowest credit risk should, ceteris paribus, be the ones with lowest Libor submission) they are not necessarily co-integrated with the actual Libor. Furthermore, we could observe similar behaviour also in the high end of the Libor submissions. In other words, banks which have persistently high CDS and submit, ceteris paribus, accordingly persistently high Libor, should be persistently among submissions that are trimmed away, and thus, do not necessarily have to be co-integrated with the actual Libor. However, this is not the case at all. Only in the third period HSBC is among the banks with highest CDS and fails the co-integration test. These results are evidence for the case that banks submissions are closely in the other, and are not affected by the CDS rates, at least not in the high end (of CDS rates).

I have formed a table (4.8), in which the above results are combined. The first row describes the individual test. It is important to note that the test are not independent of each other and the ”weight as evidence” of the tests are not necessarily equal. Hence, the table should be regarded mainly as an illustration and wrap up of tests done.

Table 4.8 clearly illustrates that some banks failed the tests more often than others. The consistent failure of tests is suspicious. These results suggests, that banks were submitting lower than actual rates in period two, but also in period 3. Hence, the reputational manipulation part of scandal seems to be more widespread than what is suggested by the fact that only Barclays is caught of submitting lower than actual rates. The evidence is especially strong in the case of Citibank.

Even though the manipulation was discussed in public already in the end of 2008, the highest basis are observed after that (in the early 2009, see figure 4.3 and appendix 3). For example, the highest individual basis of observation period is of Citibank's in 4/02/2009 when the basis was 8.51 %! On that date Citibank submitted 1.77 % Libor submission while markets priced maturity matched protection from its credit risk at 9.4 %. Thus it seems unlikely that Citibank answered according to its best knowledge to the Libor question "what is the rate it would get (unsecured) funding if it was asked to do so". Citibank has also failed all of the co-integration tests.

TABLE 4.8 SUMMARY OF TESTS

Test	Positive basis	Fails (1,-1) co-integration test	Fails estimated Co-integration, or beta-co-efficient > 1	Fails co-integration test with non-default factors	High CDS together with co-integration between own submissions and Libor
Bank/ Applies for periods	**3**	**1-3**	**3**	**2**	**2-3**
Citibank	x	x	x	x	x
Lloyds	x		x	x	x (period 3)
Societe Generale	x		x	x	x
Barclays	x			x	x
UBS		x (period 3)		x	x (period 2)
Rabo		x	x		
RBS	x				x
Credit Suisse				x	
Deutsche Bank				x	
HSBC				x	
JP Morgan					

To sum up the results: the descriptive statistic imply that banks with higher CDS rates have higher basis. Banks in the top CDS range are also the ones which fail most co-integration. These results speaks for the fact that banks were reporting unrealistic funding rates. The individual bank submission analysis was carried out by testing multiple different co-integration tests. I will not try to quantify the amount of manipulation. Instead of that, I conclude that we have JP Morgan in the one end, passing all the tests, and Citibank in the other end, who fails all the tests. Drawing a line between manipulative bank and honest bank is difficult to justify. However, Barclays which we know is guilty of manipulation, is only in the mid class, and therefore, it seems likely that manipulation was more widespread than what can be considered based on investigations carried by authorities. In addition, the table 4.1 shows that banks individual submissions, even with the banks with high credit risk, are mutually co-integrated.

The biggest challenges of my analysis were to find relevant proxies for the non-default elements of CDS and Libor-OIS spreads. First of all, the CDS market liquidity proxy was not significant in any test carried out. However, I find it unlikely that the liquidity factor is totally spurious, but it could be that it underestimates the true positive basis. However, I doubt this could explain as big basis as was observed for many banks.

The possible factors presented in table 4.1 that are not included (as the impact was considered small and fixed), were implying both positive and negative basis. Hence, it is hard to assess the possible outcome the factors would have, if those could be taken into account. Thus I have to assume their effects are fixed and relatively small as I argued. This assumption is least likely to hold for the counterparty risk of CDS protection seller, given the high overall credit risk on the markets. The counterparty risk of CDS issuer has negative effect on the basis, which would imply even more manipulation. Counterparty risk is very hard to control as the credit risk of protection sellers is most likely correlated with the manipulation.

The money market non-default element Euribor-OIS spread has at least two deficits: it only captures the market wide variation and has credit risk element embedded as well.

However, I argue that these are not very serious flaws. First, the market wide variation should correlate strongly with the individual variation to large extent, and second, the credit risk element only makes it easier for banks to pass the co-integration tests.

Another criticism towards the results is that unit root test could be weak. That means that I reject unit root, which exists, or other way around. One way to tackle this would be confirmatory analysis (Brooks, 2008) in which, unit roots tests are supplemented with stationarity tests. I did some tentative analysis and the results were in line. However, I have not included them in to this thesis as it would complex the presentation of results. Furthermore, having multiple tests (table 4.8) showing coherent evidence speaks for the robustness of the tests.

The results are obtained for one year Libor euro, which is far less followed and referred rate than, for example, 3 month USD Libor. However, this should only make the signalling incentive of Euro Libor submissions less significant. Hence, it seems unlikely that in more active rates the manipulation was less severe, given that there are banks which have incentive to manipulate.

To get supporting evidence for my results, further studies could repeat the empirical analysis to other currencies and maturities. Also, improving the existing and adding more basis factors could be path worth of walking. In addition, studying the CDS-basis of short term securities could reveal something that is not found in CDS-bond basis studies.

5 CONCLUSIONS

Interbank reference rates Libor and Euribor are important financial institutions. Unfortunately, the declining activity in the underlying unsecured interbank markets have risen the question of their validity and representativeness subject to suspicion. Market developments have led to a situation, in which hundreds of billions of contracts in nominal value are tied in to rates, of which underlying market does not exist. In addition to the representativeness validity issues, the rates have been subject to manipulation.

As was discussed in chapter 2, the manipulation happened in two forms. Measured in official allegations, the more widespread was the portfolio driven manipulation. In that form the panel banks' submitted rates that increased the profits of banks' derivative investments. The other form of manipulation was reputation driven, and officially, it has only been related to Barclays' Libor submissions. The incentive to reputation driven manipulation was to avoid negative media publicity.

The lawsuits carried by the regulators are still ongoing. The fact that Barclays was the only one found guilty of submitting lower than actual rates, was contradictory to the general opinion and to some degree even with academic studies. The academic studies related to the manipulation, in general, found evidence of manipulation - the difference of the studies was mostly in the degree of certainty that the manipulation was concluded to have happened. Most of the studies were carried out before the authorities' investigations became public. Thus they lack the luxury of knowing the results from the investigations.

I approached the Libor validity by studying the co-integration of CDS and Libor-OIS spreads of the Euro Libor panel banks in 2003-2013. The co-integration analysis captures the long-run relationship of the two measures. Due to this, only the reputational type of manipulation could be captured as the portfolio driven manipulation did not last longer than one day at a time. It also explains why JP Morgan was able to pass all the tests, despite the fact that it is one of the banks that has been found guilty of portfolio driven manipulation.

My empiric results contributes in the ongoing discussion of Libor validity and manipulation investigations in couple of ways. First, I found evidence that the manipulation was more widespread than what it considered by the regulators in the period of manipulation (start of 2007 until the end of 2008). Second, the submitted rates of some banks have been unrealistic even after the manipulation period (2009-). This was especially true for banks with high credit risk.

My results are in line with the previous academic studies to the extent the comparison is meaningful. By not meaningful, I refer to the fact that other studies did not point out, excluding non-academic WSJ article (Mollenkamp &Whitehouse, 2008), specific banks. Also the time period studied was different. First of all, in this thesis and in the academic studies in general evidence of manipulation was found. Second, some scholars found interestingly similar results as I did. For example, Snider and Youle (2012) concluded that manipulation was widespread and happened longer than has been initially suspected. They have arrived to same results as I have, but with different method. Metz-Abrantes et al. (2011) conclude that the order of banks' CDS rates is not good predictor of the order of Libor submissions. Again, something I found. The game theory framework by Chen (2013) proposes that there is a "Libor bias", which grows when the dispersion of "true rates" increases. Libor bias means that the Libor is always lower than the actual Libor, because the banks in the high end submit too low rates. I got evidence that supports this theory, as the banks with high CDS seemed to be the ones who were manipulating. However, this might be a pure coincidence: even a simple incentive to submit rate close to other submissions could yield similar results as the Chen's (2013) game theory framework. Thus, I argue that to get further support for the Chen's (2013) theory, more specific tests against data should be conducted.

The WSJ article (Mollenkamp &Whitehouse, 2008) deserves few thoughts, as the methods inspired mine. Mollenkamp & Whitehouse (2008) have some of the same names in the list of suspects as I have, one of those is the Citigroup, which failed all my co-integration tests. The direct comparison of numbers is not feasible as the study was done to USD Libor and mine is to euro, thus the panel banks are different. However, one interesting fact is that JP Morgan is in the WSJ's list of suspects, but in my analysis JP Morgan

passed all the tests. This could be due to the fact that WSJ's analysis was done only on snapshot basis, and it did not allow for possible short term deviation nor liquidity effects. Those effects were allowed in my co-integration testing. Though it cannot be excluded that the dollar Libor could have different co-integration test results.

The discussion of reference rate reform is ongoing and many of the recommendations given in Wheatley's and EBA-ESMA recommendations are implemented already. One often suggested silver bullet to fix the rates is the transaction based reference rate system. This system has some drawbacks of which not the least is, as was discussed in chapter 1, the lack of transactions. This problem is true especially during periods of market stress.

Thus, as Wheatley's report (2012b) and many other reports hint, it is likely that expert judgment will always be part of the reference rates calculation. Against this fact, my methods and results can be applied to contribute to the reform as well. First of all, my analysis reveals that the Libor system did not function properly during the turbulent market environment beginning in 2007, which was possibly because of the reputation fears. Hence, the implemented delaying of individual rate submissions publication is justified. However, this does not necessarily remove the incentive totally. To further address this problem, the empirical tools I employed in this thesis could be used as a back testing tool. Even without controlling the non-default components of Libor-OIS and CDS spread, the concept of CDS-Libor basis is useful as a simple stress barometer of Libor quality: high absolute level of the basis could trigger authorities to conduct further investigations. Furthermore, if in the future we have a menu of different reference rates, an idea present in BIS report (2013, p. 16), my methods could be employed in quality control of all the reference rates that contain credit risk.

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APPENDIX 1: Descriptive Statistics

Bank + number of the period

CDS ASK

	BARCLAYS1	BARCLAYS2	BARCLAYS3	CITI-BANK1	CITI-BANK2	CITI-BANK3	CREDIT_SUISSE1	CREDIT_SUISSE2	CREDIT_SUISSE3	DEUTSCHE_BANK1	DEUTSCHE_BANK2	DEUTSCHE_BANK3	HSBC1	HSBC2	HSBC3
Mean	0.05	0.78	0.88	0.09	1.07	1.72	0.08	0.57	0.75	0.08	0.57	0.69	0.07	0.48	0.52
Median	0.05	0.63	0.71	0.08	0.72	1.27	0.07	0.30	0.60	0.06	0.43	0.53	0.07	0.37	0.41
Maximum	0.24	2.13	2.63	0.20	5.52	9.42	0.33	1.97	2.84	8.49	1.51	2.55	0.27	1.08	1.87
Minimum	0.02	0.07	0.17	0.02	0.05	0.18	0.03	0.08	0.07	0.03	0.05	0.05	0.03	0.07	0.05
Std. Dev.	0.02	0.61	0.54	0.04	1.05	1.82	0.02	0.53	0.50	0.29	0.41	0.45	0.03	0.31	0.36
Skewness	2.89	0.70	1.03	1.06	1.33	2.23	3.16	1.43	1.37	28.88	0.74	0.82	1.24	0.77	1.35
Kurtosis	20.32	2.16	3.31	2.79	4.32	7.98	24.74	3.93	5.05	846.00	2.31	2.94	6.74	2.26	4.63
Jarque-Bera	10106.14	19.29	231.78	191.19	99.12	2185.81	16960.28	61.31	572.76	25911808.00	20.41	145.32	452.27	20.78	534.28
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	36.28	135.37	1134.68	93.03	288.00	2015.49	62.53	92.39	877.72	68.15	104.82	881.04	35.04	81.23	669.42
Sum Sq. Dev.	0.38	63.14	374.12	1.34	295.66	3867.71	0.45	45.41	294.51	71.71	31.21	265.28	0.57	15.89	166.46
Observations	728.00	173.00	1290.00	1006.00	270.00	1175.00	794.00	163.00	1171.00	871.00	185.00	1283.00	538.00	171.00	1284.00

CDS ASK

	JP_MORGAN1	JP_MORGAN2	JP_MORGAN3	LLOYDS1	LLOYDS2	LLOYDS3	RABO1	RABO2	RABO3	RBS1	RBS2	RBS3	SOCIETE_GENERALE1	SOCIETE_GENERALE2	SOCIETE_GENERALE3	UBS1	UBS2	UBS3
Mean	0.12	0.48	0.59	0.05	0.09	1.31	0.05	0.55	0.59	0.06	0.75	1.31	0.08	0.61	1.21	0.05	0.76	0.92
Median	0.10	0.35	0.44	0.05	0.09	1.23	0.05	0.39	0.49	0.07	0.56	1.23	0.08	0.54	0.88	0.04	0.61	0.69
Maximum	0.30	1.80	2.68	0.20	0.12	3.19	0.07	1.62	2.24	0.24	2.92	3.45	0.21	1.26	4.47	0.23	2.30	4.02
Minimum	0.05	0.06	0.12	0.02	0.04	0.08	0.04	0.10	0.11	0.02	0.07	0.09	0.04	0.11	0.21	0.03	0.07	0.06
Std. Dev.	0.05	0.36	0.44	0.02	0.02	0.72	0.01	0.37	0.41	0.02	0.59	0.75	0.02	0.29	0.90	0.02	0.63	0.71
Skewness	1.21	0.84	1.97	1.49	-0.82	0.48	-0.80	1.50	1.94	0.93	1.31	0.54	0.39	0.54	1.43	3.67	0.80	1.74
Kurtosis	3.50	2.89	7.55	9.48	3.11	2.56	3.15	5.23	6.83	9.88	4.76	2.58	4.25	2.85	4.08	30.01	2.49	6.68
Jarque-Bera	236.52	27.84	1772.85	1510.51	3.84	45.83	43.28	53.19	1416.12	1470.72	76.35	72.45	58.13	5.48	443.01	29237.62	26.04	1216.01
Probability	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
Sum	106.59	114.11	687.07	34.35	3.08	1275.15	20.22	49.94	671.43	44.36	136.60	1693.99	50.17	67.23	1385.30	42.58	168.76	1047.33
Sum Sq. Dev.	2.73	30.20	231.69	0.32	0.01	498.69	0.01	12.20	188.97	0.38	63.69	725.14	0.35	9.09	918.53	0.24	86.83	569.80
Observations	925.00	236.00	1174.00	713.00	34.00	971.00	400.00	91.00	1146.00	695.00	183.00	1291.00	644.00	111.00	1144.00	896.00	222.00	1138.00

CDS BID

	BARCLAYS1	BARCLAYS2	BARCLAYS3	CITI-BANK1	CITI-BANK2	CITI-BANK3	CREDIT_SUISSE1	CREDIT_SUISSE2	CREDIT_SUISSE3	DEUTSCHE_BANK1	DEUTSCHE_BANK2	DEUTSCHE_BANK3	HSBC1	HSBC2	HSBC3
Mean	0.03	0.68	0.80	0.05	0.94	1.56	0.04	0.50	0.67	0.04	0.49	0.62	0.04	0.35	0.46
Median	0.02	0.59	0.64	0.05	0.60	1.12	0.04	0.25	0.52	0.03	0.38	0.47	0.03	0.31	0.36
Maximum	0.21	1.96	2.44	0.12	5.13	8.90	0.22	1.79	2.64	8.45	1.37	2.38	0.19	0.96	1.71
Minimum	0.01	0.04	0.14	0.02	0.04	0.14	0.01	0.04	0.05	0.01	0.02	0.04	0.01	0.04	0.03
Std. Dev.	0.02	0.54	0.50	0.02	0.95	1.72	0.02	0.49	0.47	0.29	0.38	0.43	0.03	0.25	0.33
Skewness	5.17	0.80	0.99	1.34	1.35	2.25	3.19	1.41	1.38	29.32	0.83	0.83	1.89	1.12	1.31
Kurtosis	42.87	2.43	3.20	5.26	4.48	8.01	20.57	3.90	5.09	863.60	2.49	2.96	10.02	3.35	4.48
Jarque-Bera	51457.91	22.72	211.87	514.93	105.37	2176.64	11559.86	59.22	588.63	27003394.00	22.99	145.62	1423.94	33.57	487.12
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	18.89	127.66	1034.32	53.09	248.92	1797.81	30.95	81.11	789.84	33.98	89.73	792.43	19.39	54.72	596.93
Sum Sq. Dev.	0.25	55.04	326.39	0.33	241.27	3409.78	0.46	39.22	255.05	70.99	26.74	233.51	0.39	9.40	143.35
Observations	728.00	189.00	1288.00	1006.00	266.00	1153.00	794.00	163.00	1176.00	871.00	185.00	1272.00	538.00	156.00	1286.00

CDS BID

	JP_MOR-GAN1	JP_MOR-GAN2	JP_MOR-GAN3	LLOYDS1	LLOYDS2	LLOYDS3	RABO1	RABO2	RABO3	RBS1	RBS2	RBS3	SOCIETE_GENER-ALE1	SOCIETE_GENER-ALE2	SOCIETE_GENER-ALE3	UBS1	UBS2	UBS3
Mean	0.08	0.41	0.50	0.02	0.06	1.22	0.02	0.43	0.52	0.03	0.66	1.22	0.03	0.51	1.10	0.02	0.69	0.84
Median	0.07	0.29	0.36	0.02	0.06	1.15	0.02	0.33	0.42	0.03	0.50	1.16	0.03	0.48	0.80	0.02	0.55	0.62
Maximum	0.23	1.26	2.42	0.11	0.11	3.02	0.04	1.46	2.04	0.17	2.62	3.25	0.18	1.12	4.10	0.15	2.01	3.78
Minimum	0.02	0.04	0.08	0.01	0.01	0.04	0.01	0.05	0.08	0.01	0.04	0.06	0.01	0.08	0.15	0.00	0.03	0.03
Std. Dev.	0.03	0.32	0.41	0.01	0.02	0.68	0.01	0.34	0.37	0.02	0.54	0.71	0.01	0.28	0.83	0.02	0.59	0.66
Skewness	1.46	0.68	1.97	0.86	-0.24	0.48	-0.36	1.55	1.96	2.95	1.28	0.54	3.97	0.32	1.42	3.26	0.77	1.79
Kurtosis	5.51	2.32	7.64	4.24	3.28	2.56	2.31	5.31	6.90	23.19	4.61	2.59	36.65	2.55	4.07	24.12	2.41	6.96
Jarque-Bera	614.29	23.25	1807.39	132.26	0.51	45.77	16.69	73.66	1454.20	12806.43	70.00	72.25	32065.02	3.45	438.92	18241.42	25.11	1339.23
Probability	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
Sum	76.24	99.44	585.29	17.14	2.54	1190.44	9.26	51.00	593.03	22.56	120.72	1571.76	20.66	67.84	1262.58	16.56	152.25	942.61
Sum Sq. Dev.	1.18	24.30	193.65	0.16	0.02	456.19	0.02	13.90	159.36	0.22	53.88	646.30	0.13	10.21	790.17	0.24	77.22	490.45
Observations	992.00	241.00	1171.00	707.00	40.00	975.00	400.00	118.00	1144.00	695.00	183.00	1291.00	644.00	134.00	1145.00	896.00	222.00	1128.00

Libor

	BAR-CLAYS1	BAR-CLAYS2	BAR-CLAYS3	CITI-BANK1	CITI-BANK2	CITI-BANK3	CREDIT_SUISSE1	CREDIT_SUISSE2	CREDIT_SUISSE3	DEUTSCHE_BANK1	DEUTSCHE_BANK2	DEUTSCHE_BANK3	HSBC1	HSBC2	HSBC3
Mean	2.81	4.79	1.31	2.81	4.77	1.28	2.80	4.82	1.38	2.80	4.77	1.34	2.81	4.77	1.25
Median	2.37	4.76	1.31	2.37	4.72	1.28	2.37	4.75	1.40	2.37	4.73	1.33	2.38	4.73	1.26
Maximum	4.61	5.54	3.03	4.60	5.55	3.02	4.59	5.65	3.20	4.59	5.50	3.20	4.60	5.53	3.00
Minimum	1.92	3.06	0.37	1.91	3.04	0.38	1.91	3.20	0.40	1.91	3.22	0.45	1.92	3.03	0.35
Std. Dev.	0.76	0.49	0.60	0.77	0.50	0.58	0.76	0.48	0.62	0.76	0.47	0.56	0.76	0.50	0.59
Skewness	0.93	-0.93	-0.01	0.92	-0.83	0.00	0.92	-0.52	-0.03	0.93	-0.85	0.05	0.93	-0.89	0.09
Kurtosis	2.38	4.56	2.07	2.37	4.34	2.17	2.38	3.69	2.22	2.39	4.33	2.37	2.38	4.49	2.13
Jarque-Bera	175.28	90.71	46.25	174.62	70.17	36.30	174.86	24.15	32.41	176.11	71.62	21.70	175.15	83.81	42.04
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	3097.29	1782.26	1665.20	3097.08	1774.38	1623.37	3089.73	1793.17	1760.47	3087.13	1775.39	1701.86	3093.98	1775.87	1585.98
Sum Sq. Dev.	644.87	90.11	464.18	649.17	93.60	428.85	641.01	84.60	482.41	640.44	82.06	404.56	641.29	92.04	439.87
Observations	1103.00	372.00	1272.00	1103.00	372.00	1272.00	1102.00	372.00	1272.00	1102.00	372.00	1271.00	1102.00	372.00	1272.00

Libor

	JP_MOR-GAN1	JP_MOR-GAN2	JP_MOR-GAN3	LLOYDS 1	LLOYDS 2	LLOYDS 3	RABO1	RABO2	RABO3	RBS1	RBS2	RBS3	SOCIETE_GENER-ALE1	SOCIETE_GENER-ALE2	SOCIETE_GENER-ALE3	UBS1	UBS2	UBS3
Mean	2.81	4.76	1.23	2.81	4.77	1.31	2.97	4.78	1.26	2.82	4.79	1.33	3.01	4.76	1.27	2.81	4.75	1.29
Median	2.38	4.72	1.25	2.37	4.74	1.33	2.69	4.73	1.26	2.39	4.74	1.39	2.74	4.74	1.26	2.38	4.67	1.31
Maximum	4.58	5.48	2.97	4.60	5.51	3.01	4.57	5.53	3.03	4.61	5.53	3.03	4.61	5.60	2.87	4.59	5.52	3.05
Minimum	1.94	2.99	0.27	1.93	3.00	0.34	1.97	3.09	0.37	1.94	3.06	0.38	2.05	2.90	0.35	1.93	3.08	0.46
Std. Dev.	0.76	0.50	0.61	0.76	0.51	0.60	0.78	0.49	0.58	0.76	0.49	0.61	0.78	0.53	0.58	0.76	0.50	0.53
Skewness	0.92	-0.97	-0.08	0.93	-1.00	-0.10	0.57	-0.84	0.02	0.93	-0.87	-0.09	0.56	-0.98	-0.04	0.93	-0.71	0.18
Kurtosis	2.36	4.68	2.11	2.38	4.62	2.08	1.82	4.47	2.27	2.39	4.44	2.06	1.82	4.61	2.02	2.38	4.06	2.41
Jarque-Bera	173.68	101.58	43.64	176.00	102.99	46.50	94.81	77.14	28.18	176.13	78.57	48.24	92.77	100.05	51.02	175.44	48.33	24.92
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	3102.12	1769.54	1570.37	3095.49	1774.19	1671.92	2521.62	1777.12	1601.42	3105.37	1780.24	1695.12	2525.36	1772.02	1615.39	3093.00	1768.74	1636.42
Sum Sq. Dev.	638.20	91.56	468.02	643.10	97.77	454.62	517.09	88.00	423.14	640.13	89.44	470.10	505.49	103.78	425.62	639.00	92.92	356.23
Observations	1103.00	372.00	1272.00	1102.00	372.00	1272.00	849.00	372.00	1272.00	1103.00	372.00	1272.00	839.00	372.00	1272.00	1101.00	372.00	1270.00

OIS and EURIBOR

	OIS1	OIS2	OIS3	EURIBOR1	EURIBOR2	EURIBOR3

Mean	2.74	3.82	0.59	2.81	4.78	1.33
Median	2.31	4.10	0.62	2.38	4.73	1.32
Maximum	4.53	4.67	1.68	4.59	5.53	3.03
Minimum	1.83	1.54	-0.01	1.93	3.05	0.47
Std. Dev.	0.77	0.77	0.42	0.76	0.50	0.57
Skewness	0.92	-1.70	0.58	0.93	-0.87	0.05
Kurtosis	2.37	4.88	2.61	2.39	4.43	2.14
Jarque-Bera	175.65	237.29	79.45	176.15	78.54	39.95
Probability	0.00	0.00	0.00	0.00	0.00	0.00
Sum	3070.90	1448.81	756.09	3096.99	1773.01	1693.14
Sum Sq. Dev.	656.71	223.69	231.25	640.49	90.85	408.47
Observations	1121.00	379.00	1292.00	1103.00	371.00	1272.00

CDS-LIBOR Basis

	BARCLAYS1	BAR-CLAYS2	BAR-CLAYS3	CITI-BANK1	CITI-BANK2	CITI-BANK3	CREDIT_SUISSE1	CREDIT_SUISSE2	CREDIT_SUISSE3	DEUTSCHE_BANK1	DEUTSCHE_BANK2	DEUTSCHE_BANK3	HSBC1	HSBC2	HSBC3
Mean	-0.02	-0.33	0.16	0.02	0.14	0.99	0.02	-0.45	-0.09	0.00	-0.51	-0.07	0.00	-0.63	-0.14
Median	-0.02	-0.32	0.08	0.01	-0.04	0.42	0.01	-0.37	-0.12	0.00	-0.41	-0.11	-0.01	-0.55	-0.15
Maximum	0.19	0.43	1.43	0.21	3.28	8.51	0.28	0.33	1.52	0.16	0.04	1.11	0.22	0.11	0.83
Minimum	-0.11	-1.46	-0.70	-0.09	-0.68	-0.58	-0.07	-1.64	-0.85	-0.09	-1.51	-0.69	-0.08	-1.69	-0.91
Std. Dev.	0.03	0.38	0.34	0.04	0.62	1.69	0.03	0.44	0.32	0.04	0.39	0.26	0.04	0.43	0.25
Skewness	1.51	-0.85	1.24	1.04	1.59	2.43	2.05	-0.98	1.52	0.86	-1.00	1.01	1.09	-0.65	0.73
Kurtosis	9.29	3.88	5.07	3.91	5.78	8.74	14.80	3.35	7.55	4.02	3.08	4.77	5.97	2.85	5.01
Jarque-Bera	1473.65	26.00	553.46	212.60	197.01	2726.82	5128.72	26.55	1438.14	143.32	30.33	378.67	302.87	11.95	323.54
Probability	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	-13.91	-55.74	200.74	23.66	37.63	1141.31	13.40	-73.23	-106.77	3.19	-93.04	-82.28	-2.46	-106.89	-176.66
Sum Sq. Dev.	0.68	24.68	145.29	1.81	101.27	3317.99	0.74	30.50	118.96	1.15	27.29	83.15	0.80	30.67	76.25
Observations	726.00	171.00	1270.00	994.00	265.00	1156.00	789.00	161.00	1152.00	865.00	183.00	1262.00	536.00	169.00	1264.00

CDS-LIBOR Basis

	JP_MOR-GAN1	JP_MOR-GAN2	JP_MOR-GAN3	LLOYDS1	LLOYDS2	LLOYDS3	RABO1	RABO2	RABO3	RBS1	RBS2	RBS3	SOCIETE_GENER-ALE1	SOCIETE_GENER-ALE2	SOCIETE_GENER-ALE3	UBS1	UBS2	UBS3
Mean	0.04	-0.45	-0.10	-0.02	-0.28	0.56	-0.02	-0.85	-0.14	-0.01	-0.34	0.57	-0.03	-0.67	0.49	-0.02	-0.29	0.18
Median	0.02	-0.37	-0.12	-0.03	-0.41	0.53	-0.02	-0.69	-0.16	-0.01	-0.33	0.50	-0.03	-0.56	0.23	-0.02	-0.28	0.05
Maximum	0.28	0.56	1.75	0.15	0.05	1.81	0.09	0.12	1.17	0.17	1.00	1.81	0.14	-0.17	3.08	0.15	0.63	2.91
Minimum	-0.09	-1.57	-0.85	-0.10	-0.58	-0.30	-0.11	-1.82	-0.97	-0.10	-1.35	-0.43	-0.11	-1.84	-0.39	-0.16	-1.19	-0.67
Std. Dev.	0.05	0.39	0.40	0.03	0.23	0.42	0.03	0.47	0.35	0.03	0.40	0.46	0.03	0.40	0.62	0.03	0.35	0.54
Skewness	1.16	-1.34	1.52	1.10	0.19	0.25	0.48	-0.39	0.93	0.72	-0.17	0.35	1.02	-1.19	1.49	1.06	-0.31	2.36
Kurtosis	3.84	4.63	7.33	6.23	1.22	2.58	4.35	2.44	5.09	6.24	4.22	2.32	7.24	3.36	4.32	9.74	3.97	9.79
Jarque-Bera	233.30	94.27	1346.00	449.83	4.68	16.73	41.57	3.01	366.95	362.74	12.13	50.38	363.11	26.47	498.04	1851.92	12.14	3188.38
Probability	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	38.21	-104.43	-119.67	-15.27	-9.39	536.94	-6.38	-66.49	-154.15	-9.21	-61.75	723.57	-9.92	-73.57	548.96	-20.40	-62.70	199.30
Sum Sq. Dev.	2.65	35.06	180.81	0.64	1.70	165.34	0.26	16.83	137.30	0.68	29.03	264.81	0.32	17.22	433.71	0.61	27.03	330.11
Observa-tions	916.00	231.00	1155.00	710.00	34.00	956.00	365.00	78.00	1127.00	693.00	181.00	1271.00	394.00	109.00	1126.00	890.00	220.00	1120.00

APPENDIX 2: Unit root tests

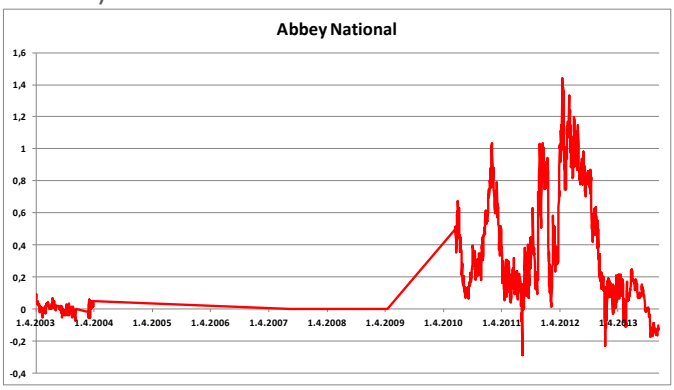
Unit root tests

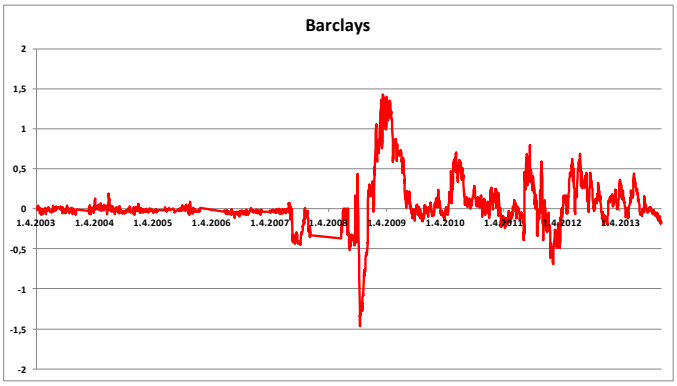
CDS MID	**MAXLAG=2**		**ADF test statistic p-value**	
Bank \ Period	**1**	**2**	**3**	**1-3**
barclays	0.00	0.88	0.12	0.05
citibank	0.34	0.99	0.48	0.50
credit_suisse	0.00	0.99	0.18	0.17
deutsche_bank	0.00	1.00	0.12	0.03
hsbc	0.20	0.67	0.25	0.14
jp_morgan	0.01	0.04	0.01	0.02
lloyds	0.02	0.13	0.37	0.41
rabo	0.05	0.97	0.18	0.19
rbs	0.00	0.18	0.35	0.08
societe_generale	0.02	0.78	0.33	0.30
ubs	0.00	0.97	0.33	0.29

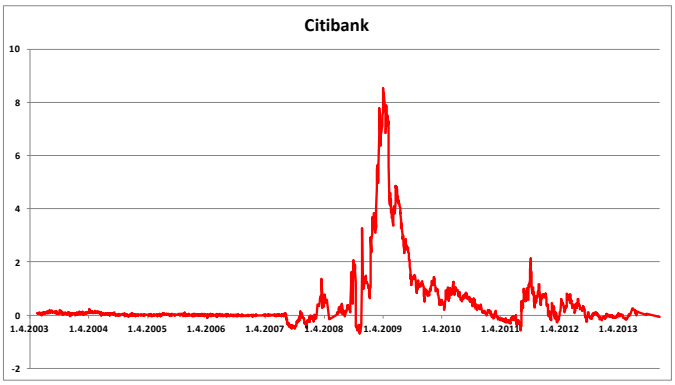
LIBOR-OIS	**MAXLAG=2**		**ADF test statistic p-value**	
Bank \ Period	1	2	3	**1-3**
barclays	0.00	0.67	0.26	0.54
citibank	0.00	0.66	0.27	0.50
credit_suisse	0.00	0.71	0.28	0.55
deutsche_bank	0.00	0.73	0.14	0.52
hsbc	0.00	0.63	0.26	0.53
jp_morgan	0.00	0.61	0.28	0.50
lloyds	0.00	0.61	0.35	0.49
rabo	0.00	0.61	0.20	0.47
rbs	0.00	0.67	0.36	0.57
societe_generale	0.00	0.52	0.36	0.53
ubs	0.00	0.72	0.16	0.52

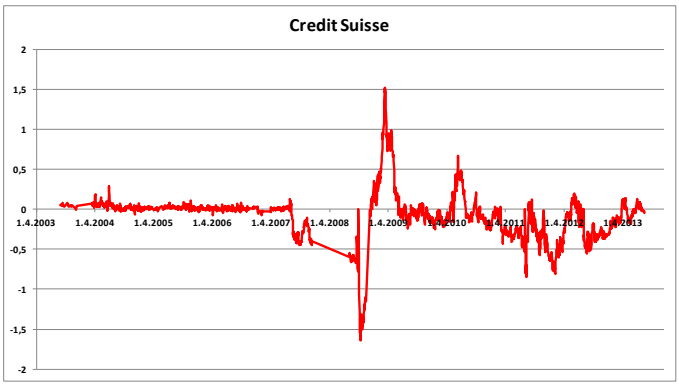
CDS Liquidity	**MAXLAG=2**		**ADF test statistic p-value**	
Bank \ Period	1	2	3	**1-3**
barclays	0.07	0.96	0.00	0.00
citibank	0.35	0.00	0.05	0.00
credit_suisse	0.00	0.97	0.00	0.00
deutsche_bank	0.00	0.00	0.00	0.00
hsbc	0.00	0.95	0.00	0.00
jp_morgan	0.05	0.24	0.00	0.00
lloyds	0.00	0.08	0.00	0.00
rabo	0.18	0.98	0.00	0.00
rbs	0.00	0.11	0.00	0.00
societe_generale	0.00	0.88	0.02	0.00
ubs	0.00	0.00	0.09	0.00

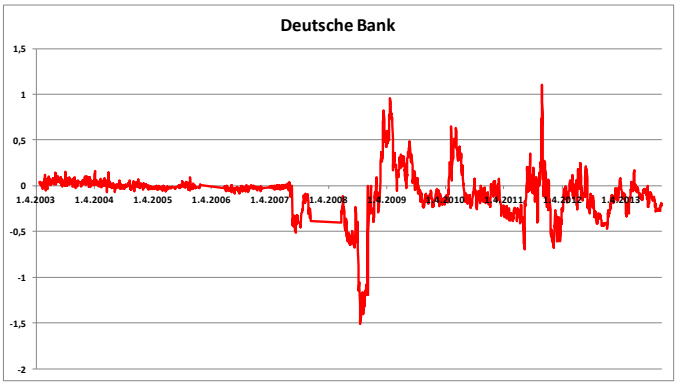
Appendix 3. CDS Libor Basis of Libor panel banks over (4/1/2003-13/12/2013) (note different scales in vertical-axis)

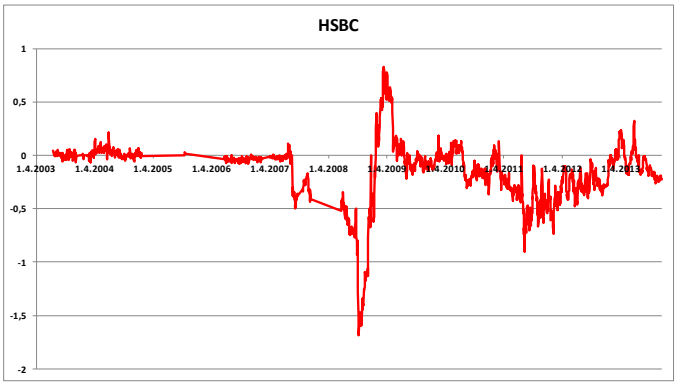


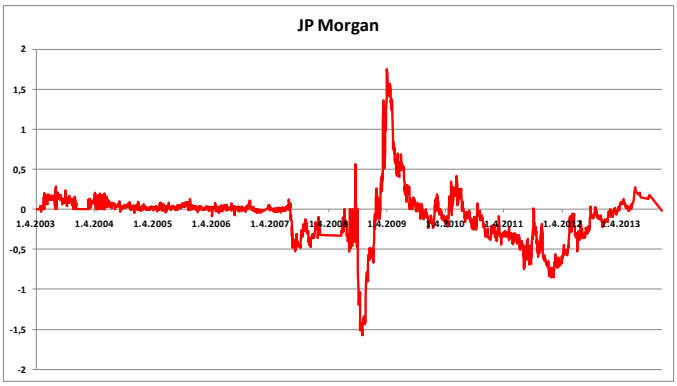


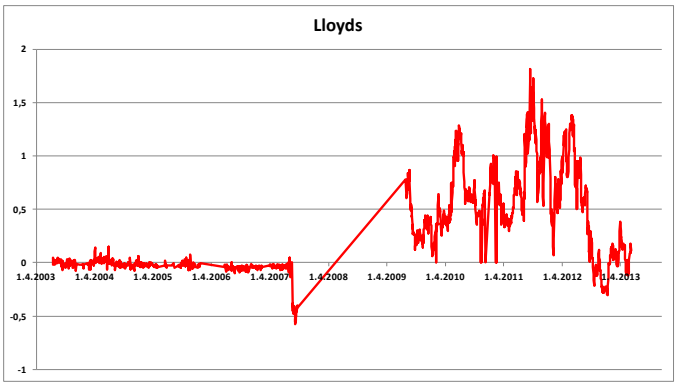


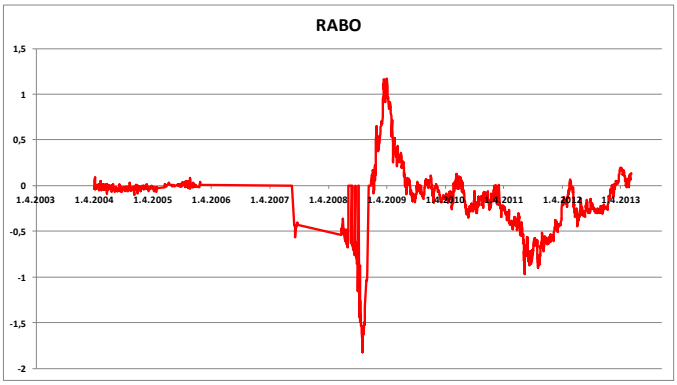


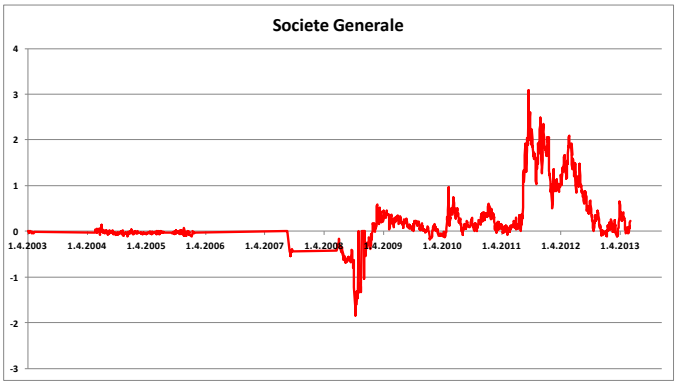


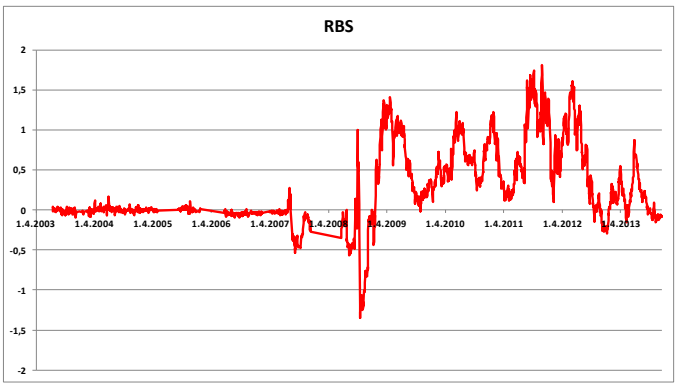


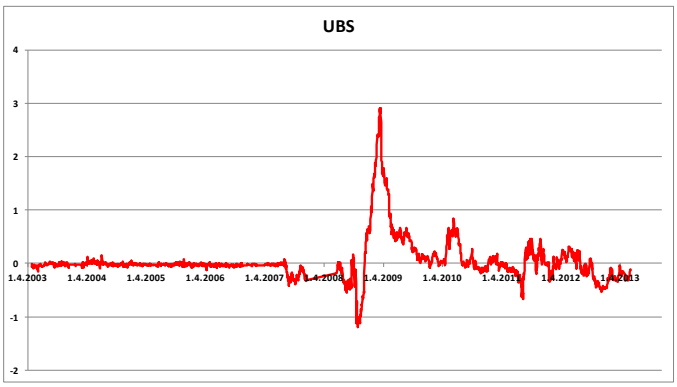





RABO
1,5
1
0,5
0
-0,5
-1
-1,5
-2
1.4.2003
1.4.2004
1.4.2005
1.4.2006
1.4.2007
1.4.2008
1.4.2009
1.4.2010
1.4.2011
1.4.2012
1.4.2013


Societe Generale
4
3
2
1
0
-1
-2
-3
1.4.2003
1.4.2004
1.4.2005
1.4.2006
1.4.2007
1.4.2008
1.4.2009
1.4.2010
1.4.2011
1.4.2012
1.4.2013


RBS
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
1.4.2003
1.4.2004
1.4.2005
1.4.2006
1.4.2007
1.4.2008
1.4.2009
1.4.2010
1.4.2011
1.4.2012
1.4.2013


UBS
4
3
2
1
0
-1
-2
1.4.2003
1.4.2004
1.4.2005
1.4.2006
1.4.2007
1.4.2008
1.4.2009
1.4.2010
1.4.2011
1.4.2012
1.4.2013