Are Interest Rate Fixings Fixed? An Analysis of Libor and Euribor

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First Version: December 12, 2012
This Version: January 15, 2013

Abstract

The London Interbank Offered Rate (Libor) and the Euro Interbank Offered Rate (Euribor) are two key market benchmark interest rates used in a plethora of financial contracts with notional amounts running into the hundreds of trillions of dollars. The integrity of the rate-setting process for these benchmarks has been under intense scrutiny ever since the first reports of attempts to manipulate these rates surfaced in 2007. In this paper, we analyze Libor and Euribor rate submissions by the individual panel banks and shed light on the underlying manipulation incentives by quantifying their potential effects on the final rate set (the "fixing"). Furthermore, we explicitly take into account the possibility of collusion between several market participants. Our setup allows us to quantify such effects for the actual rate-setting process that is in place at present, and compare it to several alternative rate-setting procedures. We find that such alternative rate fixings, and larger sample sizes, could significantly reduce the effect of manipulation. Furthermore, we discuss the role of the particular questions asked of the panel banks, which are different for Libor and Euribor, and examine the need for a transaction database to validate individual submissions.

Keywords: Money markets, Libor, Euribor, manipulation, collusion

JEL classification: G01, G14, G18

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1 Introduction

One of the most important developments during the depths of the global financial crisis following the collapse of Lehman Brothers on September 15, 2008 was the initial discussion about the possible manipulation of the London Interbank Offered Rate (Libor) and its financial cousin, the Euro Interbank Offered Rate (Euribor), two key market benchmark interest rates. Although there had been prior conjectures of this possibility, new reports received heightened attention against the backdrop of jittery financial markets following the Lehman bankruptcy. Since spot and derivatives contracts with notional amounts running into the hundreds of trillions of dollars are linked to Libor and related benchmarks, any serious questions about the integrity of these rates could potentially cause massive chaos in global markets (see, e.g., the discussion in Wheatley (2012a)).

Given the nervousness in the market at the time, the British Bankers' Association (BBA) and the Bank of England (BoE) tried to reassure the market about the integrity of the rate-setting process. Although the attention of market participants shifted elsewhere for a while, there were persistent rumors, and even press reports, about the investigation, and possible prosecution, of the panel banks that submit quotes to the BBA. The matter resurfaced in the financial headlines in the summer of 2012, when the Commodities and Futures Trading Commission (CFTC), the futures markets regulator in the United States, announced that it was imposing a $200 million penalty on Barclays Bank plc for attempted manipulation of, and false reporting concerning, Libor and Euribor benchmark interest rates, from as early as 2005.[1] As part of the non-prosecution agreement between the US Department of Justice and Barclays, communications between individual traders and rate submitters were made public, providing evidence of manipulations of the reference rates on particular days. Investigations in different jurisdictions, some of which started in 2009, are still ongoing and the

[1]In December 2012, UBS AG also settled for a substantial penalty of $1.5 billion as a consequence of its role in manipulating global benchmark interest rates.

results of an independent review led by Martin Wheatley, discussing potential changes to the Libor benchmark rates at a general level, were presented recently in the UK.

In this paper, we analyze the individual submissions of the panel banks for the calculations of the respective benchmark rates (the "fixings"), in detail, for the time period January 2005 to June 2012. We discuss and explore the incentives for and potential effects of manipulations. Furthermore, we explicitly take into account the possibility of collusion between several market participants. Our setup allows us to quantify such effects for the actual rate-setting process in place at present, and compare it to several alternative rate-fixing procedures. Moreover, we can directly quantify the effect of the panel size on manipulation outcomes. These results allow us to comment on important details of the rate-setting process, as well as on broader questions, such as the use of actual transaction data as an alternative information source.

The BBA is the organization responsible for setting Libor. It does so with the assistance of Thomson Reuters, the calculation agent, based on submissions of daily rates by a panel of banks. Euribor is set in a similar manner under the aegis of the European Banking Federation (EBF). The rate set is the trimmed mean of the submissions from the panel banks, after dropping around 15% to 25% of the observations at the highest and lowest ends of the sample.[2]

A dispassionate appraisal of the events of the past few years and the discussion among market professionals, journalists and regulators suggests that two conceptually distinct issues became conflated in the heat of the discussion. The first relates to the potential for manipulation of Libor and Euribor, which are both determined by similar methodologies, but under the supervision of different bodies, under the current method of eliciting quotes from a given panel of banks. This issue naturally leads to a discussion of how the effect of manipulation might be mitigated, if not eliminated, by the use of an alternative definition of the rate, without altering the method of collecting the basic data from the

[2] A more detailed definition will be provided in Section 2.

panel of banks. The second and logically separate issue relates to changing the nature of the data themselves, for example, by only collecting data on *actual* transactions rather than quotes and, thus, introducing greater transparency and reliability into the process. The latter would be a much more fundamental change, and raises additional questions about how the liquidity of the rates for different maturities and currencies would be affected, given the restriction of being based on transactions data.

Within the context of the current rate setting process, there are three potential factors that affect the cross-sectional and time-series variation in the submissions, which, in turn, influence the computation of the trimmed mean for the rate that is set. The first is the variation in the credit quality of the banks represented by the panel. Depending on the particular question asked to the panel banks, which is different for Libor and Euribor, the rate submitted by a bank reflects, to a certain degree, the credit risk premium built into the borrowing rates.[3] If the banks have very different credit qualities in the judgment of the market, the rates submitted could reflect this variation. The second is the variation in the liquidity position of the banks in the panel, which reflects their need for additional funding. If some banks are flush with funds, while others are starved for them, the rates they submit should be very different. The third is due to the potential manipulation of the rates as has been alleged, and even demonstrated in at least some cases, as a result of regulatory and legal action. Unfortunately, it is impossible to disentangle the effect of manipulation from the credit risk and liquidity effects, without detailed data on the other two effects. Since these factors are difficult to measure without detailed internal data from the banks, it is virtually impossible to prove concrete manipulation based only on the rate submissions (see, e.g., Abrantes-Metz et al. (2012)). However, it is possible to ask a more fundamental question based solely on the contribution data, relating to the *potential for manipulation*, given the historical pattern of rate submissions. This analysis would take the credit risk and liquidity factors

[3]See Section 2 for details on the underlying questions in the rate setting process.

as given, and focus purely on the question of how one or more panel members, acting individually or in concert, can influence the rate that is finally set.

In this paper, we concentrate on the potential for manipulation and investigate several related questions, in the context of three different rates, the Australian Dollar Libor (AUD Libor), US Dollar Libor (USD Libor) and Euribor, for the three-month tenor. The purpose of choosing these three rates for our empirical analysis is to get an idea of the extent to which the panel size, as well as the rate-setting process and the question asked of the panel banks, affects the final rate that is set. The number of panel banks is the smallest for AUD Libor (7 banks) and the largest for Euribor (43 banks), with USD Libor lying in between (18 banks).[4] Also, the questions asked for Euribor and Libor submissions are quite different, as will be discussed later on.

Our empirical analysis consists of three parts. First, we examine how closely individual submissions are related to the final rate that is set. Specifically, we estimate how often an individual bank's submission is below, within, and above the window that is used for the calculation of the trimmed mean. Furthermore, we analyze the stationarity of individual submissions with respect to the final rate. Second, we compute the effect on the rate, of actions by one bank seeking to move the rate in the direction it desires.[5] We repeat this exercise for collusive action by two or three banks to move the rate. We analyze the differences in the effects of manipulation, for different panel sizes and different methodologies used to elicit rate submissions. Third, we quantify such effects for alternative rate-fixing procedures that have been discussed in the literature, in the press, or by regulators (see, e.g., Wheatley (2012a)).

We find that the rate submissions of the individual banks in the panels exhibit high cross-sectional variation. On average, the range between the lowest and highest submissions is 11.57 bp for AUD Libor, 12.38 bp for USD Libor and 15.86 bp for Euribor. Furthermore, the composition of the set of panel

[4]These panel sizes correspond to the last day of sample period, i.e., June 29, 2012.

[5]The bank may wish to do so, either to influence the market's perception of its credit quality or its liquidity, or to influence the profitability of its existing trading positions linked to these reference rates.

banks whose submissions fall within the calculation window, after eliminating contributions at the highest and lowest ends, is also volatile. For the AUD and USD Libor panels, the submissions of most panel banks are within the calculation window around 50% of the time. For the Euribor panel, this figure is around 70%. Thus, banks reporting the highest and lowest rates often change over time. Furthermore, we can show that banks that are not in the calculation window switch regularly between being below or above it. This result is confirmed when comparing the individual submissions to the final rate. Thus, given the volatile nature of the submissions of individual banks, the detection of concrete manipulations on individual days will be close to impossible. Indeed, the related literature (see, e.g., Abrantes-Metz (2012)) can only provide weak evidence when trying to pin down concrete manipulations. Along the same lines, the evidence used in the prosecution of banks does not focus on the analysis of individual rate submissions. Rather, the investigations focus on communications between the alleged manipulators in the form of email messages and telephone conversations.

Therefore, to address our main research question, we focus on the potential effect of manipulations in the rate-setting process, taking into account the incentives for individual banks to do so. Taking the observed submission as given, we quantify the effects on the final rate of one, two or three banks changing their submissions in order to manipulate the rate in a certain direction. Our results clearly document that, although a trimmed mean is used, even manipulation by one bank would result in an average rate change of 1.13 bp (AUD Libor), 0.45 bp (USD Libor) and 0.17 bp (Euribor). Obviously, the collusion of several banks increases this effect: three banks could have an effect of 3.47 bp (AUD Libor), 1.50 bp (USD Libor) and 0.54 bp (Euribor). Given the tremendous sizes of the outstanding amounts of spot and derivatives contracts linked to these reference rates, banks can profit even from basis point changes.[6] Furthermore,

[6]For example, as of September 30, 2008, Deutsche Bank calculated that it could make or lose 68 million euros for a basis point change in Libor or Euribor. A Wall Street Journal article claimed that the bank made $654 million in 2008, profiting from small changes in these benchmark interest rates, see Eaglesham (2013).

these results clearly show that the panel size plays a crucial role in the potential effect of manipulation. Euribor has the highest number of contributing banks (43 vs. 7 and 18) and the incentive to manipulate it is considerably smaller than that for AUD Libor and USD Libor.

In addition, we analyze the potential effect of manipulations of alternative rate-setting processes discussed in the related literature (see, e.g., Wheatley (2012a)). We consider two actual alternatives — the median of the submitted rates and a random draw — and compare the effects to those obtained when using the untrimmed and trimmed mean. We confirm that, indeed, the use of an untrimmed mean leads to the highest incentive for manipulation. Compared to the trimmed mean, the random draw alternative does not reduce the average effect of the potential manipulations; however, the outcome becomes more volatile. Interestingly, the use of the median of the submitted rates, an extreme version of the trimmed mean, substantially reduces the incentive for manipulation. The effect on the final rate is lower by approximately one third compared to the trimmed mean and random draw methodologies. Thus, we find evidence that switching the rate-setting process to median rates, a relatively simple change, could substantially reduce the incentive for manipulation in most cases.

Overall, we show that the cross-sectional dispersion of individual submissions is high, i.e., screening for manipulation is hindered by the presence of noise in the data. Considering the potential effects of manipulation, we find that both the panel size and the calculation method influence such incentives, i.e., a large panel size and median rates substantially reduce the effects of individual banks on the final rate. Altough a change in the calculation methodology could be implemented fairly easily, increasing the panel size for the Libor rates, under the current setup, could be more challenging. Given that banks are explicitly asked about their own funding rate for Libor, enlarging the sample might introduce even more heterogeneity, in terms of credit, liquidity, and outstanding positions, across the panel banks. Thus, increasing the sample size might only be reasonable when asking about the money market funding costs of a (hypothetical) prime bank, as in the case of the Euribor.

As indicated, we consider the collection of data on *actual* transactions rather than quotes as an entirely separate issue, as it would completely change the nature of the data generation process. Thus, a transaction-based reference rate can only be discussed after analyzing in detail the underlying liquidity of the money market. However, we find a clear need for an extensive transparency project that will make transaction reporting to a central database mandatory. This would be, at least, a first step in validating individual rate submissions, and thus might enable a data-driven identification of manipulation. Such a transparency project could be introduced in a similar way as for the US corporate bond market and the US fixed-income securitized product market, two important over-the-counter (OTC) markets (see, e.g., Friewald et al. (2012) for details).

The remainder of the paper is organized as follows: In Section 2, we discuss the details of the rate-setting process for Libor and Euribor. Section 3 presents the relevant literature and motivates our research questions. In Section 4, we describe our data set. Section 5 presents the results and discusses the impact of potential manipulation, including the effects for alternative rate-fixing procedures. Section 6 concludes.

2 Description of the Rate Setting Process

In this section, we outline the institutional details and the methodology for the calculation of the reference rates. Overall, the general methodologies used for calculating the Libor and the Euribor are similar. However, they differ in several ways that could affect the possible impact of manipulations. Both Libor and Euribor reference rates are published daily, for a range of maturities, and are based on the submissions of a pre-defined set of panel banks.

The Libor reference rates are set under the auspices of the BBA, with the assistance of Thomson Reuters, the calculation agent. Reference rates are published for ten currencies and fifteen maturities (or tenors).[7] On every London business day between 11:00 and 11:10 a.m., the individual submissions are received by the calculation agent. For each currency, there exists an individual panel of banks contributing to all tenors. (A bank may submit rates for multiple currencies.) The smallest panel size is 6 banks, for SEK and DKK, and the largest panel is 18 banks, for USD. A bank has to base its contribution on answering the following question:

Libor 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?" (British Bankers' Association, 2012)

In the currently prevailing routine, all panel banks submit contributions on each day. Based on the individual submissions, a trimmed mean is calculated for each currency and tenor by discarding the top and bottom 25% of the contributions. The final rates are rounded to five digits and distributed by midday London time.[8]

The Euribor reference rates are set under the aegis of the EBF. Again, Thomson Reuters is the screen service provider, and is responsible for computing and also publishing the final rates. Reference rates are available for fifteen tenors (1W, 2W, 3W and 1M, 2M, ..., 12M). Panel banks are required to directly submit their contributions, no later than 10:45 a.m. CET on each day. On June 29, 2012 the panel consists of 43 banks. A bank has to base its contribution on the following implicit question:

[7] The ten currencies are the British Pound (GBP), US Dollar (USD), Japanese Yen (JPY), Swiss Franc (CHF), Canadian Dollar (CAD), Australian Dollar (AUD), Euro (EUR), Danish Krone (DKK), Swedish Krona (SEK) and New Zealand Dollar (NZD). The fifteen tenures comprise O/N (or S/N), 1W, 2W and 1M, 2M, ..., 12M.

[8] Note that changes to this setup are currently planned, based on the Wheatley report (Wheatley, 2012a). Initial changes will be based on the discontinuation of certain Libor currencies and tenors. As our data set is from the time *before* the potential implementation of these recommendations, we focus on the actual Libor calculation for this time period.

Euribor Question: "Contributing panel banks must quote the required euro rates to the best of their knowledge; these rates are defined as the rates 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." (European Banking Federation, 2012)

Not all panel banks have to submit contributions to the reference rates on each day. Under normal conditions, at least 50% of the panel banks must quote in order to establish the Euribor. Based on the individual submissions, a trimmed mean is calculated for each tenor by discarding the top and bottom 15% of the contributions. The final rates are rounded to three digits and are distributed by 11:00 a.m. CET.

Both Libor and Euribor are ostensibly designed to be robust to outliers and manipulation. This is done using the trimmed mean approach, described above, i.e., a specific number of contributions are discarded, before the final fixing is calculated as the average of the remaining contributions. The exact number of excluded panel banks depends on the original panel size but can be approximately 50% (top and bottom 25%) for Libor and 30% (top and bottom 15%) for Euribor. The exact number excluded for different panel sizes and the applied rounding approaches are shown in Tables 1 and 2.

[Tables 1 and 2 about here.]

Obviously, this approach makes Libor and Euribor robust with respect to outliers. However, there seems to be a rather common misconception that it is not possible for a single contributing bank, by submitting a high or low rate, to manipulate the final fixing. The crucial flaw in this argument is as follows: If just one bank changes its contribution, e.g., instead of truthfully reporting a low rate it reports a high rate, then, even though this contribution will be discarded, it will nonetheless shift the set of banks that contribute to the trimmed mean by one bank, in the direction of including a panel bank with a higher rate, and discarding one with a lower rate.

[Table 3 about here.]

Table 3 shows this effect based on an example of the rate setting for the three month AUD Libor on June 29, 2012. In the first row, we show the contributions submitted by the seven panel banks on that day. For the given panel size, the lowest and highest contributions are excluded in the trimming process. Thus, Libor is calculated as the average of the contributions of the remaining five banks, i.e., banks 2 to 6. In the second row, we show the effect of a change in a single contribution on the final Libor fixing. If the bank with the lowest contribution instead submits a contribution equal to that of the bank with the highest contribution, then the calculation panel used to determine the Libor fixing will be shifted. Bank 1 will move to the top of the (sorted) panel and its contribution will be excluded during the trimming process. Instead of Bank 1, Bank 2 will now be excluded on the lower end, and Bank 7 will enter the calculation panel. Consequently, in calculating the average, the contribution of Bank 2 (3.99) will be replaced by the contribution of Bank 7 (4.03). This will increase the Libor fixing by 0.8 bp.

This example applies to both the Libor and the Euribor, as both use a trimmed mean approach. However, two important interconnected differences should be highlighted when comparing Libor and Euribor rates. First of all, we can observe quite large differences in the panel sizes. Whereas Euribor currently relies on 43 banks, some Libor rates are only based on 6 banks and, even for USD, the currency with the largest panel size, it is only 18 banks. The second difference is related to the different questions asked for the Libor and Euribor. Whereas Libor is defined to reflect the average of all panel banks' individual borrowing rates, Euribor is designed to represent the rate at which deposits are offered from one (hypothetical) prime bank to another.[9] Absent manipulation, the Libor approach has the advantage that contributions should have a one-to-one relation to the rates on the actual transactions of a particular bank.

[9]More recently, questions have been raised about the precise definition of a "prime bank" and the need to make it more explicit.

However, this comes at the disadvantage of incorporating the individual credit and liquidity risk of the banks in the reference rate. Thus, for Libor to be meaningful, the selection of the panel banks is more crucial than for Euribor. Of course, this limits the number of banks that can potentially be included in the panel. Therefore, it is particularly interesting to compare incentives to manipulate between the Libor and Euribor rates.

3 A Review of the Literature

Even though Libor and similar benchmarks have recently received considerable media attention, so far there are surprisingly few papers available, by academics or practitioners, that have investigated manipulation attempts and the proposals for reform; presumably, much of the research is still in progress. Only one paper does provide some early indirect evidence on manipulation: In a Wall Street Journal article published shortly after the onset of the financial crisis, Mollencamp and Whitehouse (2008) claim that banks submitted low Libor rates to avoid signaling their own deteriorating credit quality. They use CDS spreads to construct an alternative benchmark and conclude that, compared to these estimates, the actual Libor rates were too low.

However, using CDS data might lead to noisy estimates, as CDS spreads are not necessarily perfect proxies for short-term credit quality. Moreover, as pointed out in Abrantes-Metz et al. (2012), there are other factors, such as liquidity, that influence CDS spreads, particularly in crisis periods. Given these shortcomings, Abrantes-Metz et al. (2012) focus on the ordinal information contained in CDS spreads and check whether contributors with high CDS spreads also report higher Libor rates. In addition, they compare Libor to other short-term funding rates, e.g., the federal funds effective rate. They do find patterns that hint at possible abnormalities, but conclude that there is no clear evidence to support the allegation of the manipulation of Libor rates. In another study, Abrantes-Metz et al. (2011) suggest that the conjecture of abnormal levels of the aggregate Libor calculation is supported by the data: Libor rates do not follow Benford's law for the second-digit distribution. However, none of these results, which focus directly on observed Libor rates, allow us to identify concrete manipulations, especially window-dressing effects, i.e., the reporting of particularly low rates.

Snider and Youle (2010) expand on the results by Mollencamp and Whitehouse (2008) and focus on a second — potentially even more important — incentive for manipulation. Given the large notional volumes referencing Libor (and, of course, other reference rates like Euribor), panel banks could have substantial incentives to manipulate Libor submissions so as to move the fixing in their favor. Snider and Youle (2010) argue that, given the incentives for manipulation due to portfolio effects, a bunching effect around particular points should be observed, i.e., contributions just above or below the cut-off points used for the trimming procedure should be observed with higher frequency.[10] The authors also find evidence for this particular behavior. Furthermore, Abrantes-Metz et al. (2012) analyze the participation rate of each individual panel bank, i.e., the frequency with which a bank's quote is not discarded in the outlier elimination process, and find that, from August 2007 onwards, the composition of the panel within the window is less stable than before then. However, given the unknown positions of the contributing banks, it is unclear in which direction a bank might want to manipulate Libor, making the detection of concrete manipulation by particular banks almost impossible to prove.

The second strand of the literature deals with possible reforms and improvements to the Libor rate-setting process. Following the Libor manipulations by several large investment banks, Martin Wheatley has been requested by the UK government to lead an expert group tasked with identifying improvements and amendments to the current Libor fixing process, including institutional details surrounding the Libor contribution process. The initial discussion paper (see

[10]The theoretical explanation for this effect is based on the costs of misreporting, and the panel banks' ability to predict the cut-off point. Thus, given that lowering the Libor submissions below the predicted cut-off point would only lead to higher costs, with no additional manipulation effect, banks will only manipulate their contributions to this extent.

Wheatley (2012b)) raised several questions that have triggered strong responses from the industry. The final version of the Wheatley Review (Wheatley, 2012a) argues very much in favor of reforming the current Libor rather than replacing it with a new benchmark. It is suggested that the number of tenors and currencies of Libor submissions be reduced, and that panel banks be required to keep records of their actual transactions to permit validation by regulatory authorities. Furthermore, the impact of the panel size and alternative rate-setting methods are discussed at an abstract level, rather than with a detailed empirical analysis. In contrast to these suggestions, Abrantes-Metz and Evans (2012) propose changes that would increase the importance of transaction-based data in the rate-setting process, by forcing panel banks to commit to trade at the reported rates. However, this proposal can be empirically evaluated only once detailed transaction data become available.

In this paper, we focus on the quantification of the potential effects of manipulated individual contributions on the final rate, i.e., we explore the incentive for manipulation. Furthermore, we test, in detail, how these effects change when alternative rate-setting procedures are implemented, including suggestions mentioned in the Wheatley report. Even though the discussed papers hint at possible manipulation attempts, no other paper has yet extensively analyzed the potential impact of manipulations on the final rate, to the best of our knowledge. Libor, as well as Euribor, are, in principle, designed to be more robust to manipulation attempts than simple, untrimmed averages. However, as explained in Section 2, they are not immune to manipulation attempts by even a single bank.[11] Clearly, the selection of the panel and the rate-setting process influence the manipulation impact that this procedure can have on the benchmark interest rates. We fill the gap in the literature by quantifying the potential impact of manipulation on the current procedure.

[11] Abrantes-Metz and Evans (2012) also show this with a simple example.

4 Data Description

In this paper, we focus on three reference rates in order to analyze potential manipulation incentives: AUD Libor, USD Libor and Euribor. These rates differ substantially in terms of their respective contributing bank panel sizes, allowing us to study this aspect in detail. We choose the AUD Libor as it is a liquid currency with one of the smallest panel sizes of all the Libor rates (7 banks, on June 29, 2012).[12] The USD Libor has the largest panel size of all Libor rates (18 banks) and is one of the most widely referenced rates in global markets. The third reference rate we investigate is Euribor, which, compared to all Libor rates, features a very large panel size (43 banks). Moreover, Euribor panel banks are not asked to contribute their own funding rate but rather that of a *hypothetical* prime bank. Thus, whereas Libor contributions potentially differ more because of individual panel banks' credit quality and liquidity, Euribor contributions should essentially only differ because of each panel bank's estimation error in determining the "true" funding rate of a prime bank.

For these three reference rates, we focus on the three-month tenor. This maturity is an important reference point for many derivatives contracts and loans that are linked to these rates. Thus, manipulation incentives might be particularly pronounced for this tenor. However, we plan to analyze all tenors and currencies in future research.

Our data set comprises the daily individual contributions of all panel banks and the final reference rates, for the time period from January 2005 to June 2012. Data for Libor rates and contributions are obtained from Bloomberg, while Euribor rates and contributions are published by the EBF on its Euribor website. We exclude a few days with data errors for which we cannot reproduce the final fixings using the individual contributions provided by Bloomberg or

[12] The panel sizes for DKK and SEK are even smaller, but these currencies are not as widely used as other currencies. In fact, Libor rates for both currencies will be discontinued, following the implementation of the recommendations of Wheatley (2012a).

EBF. The most common reasons are missing contributions from individual panel banks and apparent data errors. In total, we have 1895 days available.[13]

As manipulations may have commenced as early as 2005, we cover the whole relevant time period, including a few calm years prior to the beginning of the recent financial crisis, and the years since. Thus, this data set offers the possibility to study manipulation effects based on different panel sizes, underlying funding rate questions and economic conditions.

5 Results

5.1 Descriptive Statistics

This section provides summary statistics for the reference rates and the submitted contributions by the individual panel banks for the AUD Libor, USD Libor and Euribor. Figures 1–3 show the time series of the three reference rates. Furthermore, we present within these figures the cross-sectional standard deviation of the individual contributions, the range (i.e., the difference between the highest and lowest contribution) as well as the panel size on each day.[14]

[Figures 1–3 about here.]

The three time-series of the reference rates paint a similar picture, with an increase in the interest rates from 2005 until mid-2007, and a rapid decrease following the financial crisis. Analyzing the individual contributions, we find that, for AUD and USD Libor, the panel sizes stay basically unchanged; it is only at the end of the observation period that the panel size for AUD reduces from 8 to 7 banks and that for USD Libor increases from 16 to 18 banks. Interestingly, the number of banks actually submitting to the Euribor panel on a given day is more volatile over time, for two reasons: First of all, the panel size changes more often and, second, not all banks submit every day. However,

[13] We exclude 5 days for the AUD Libor, 21 days for the USD Libor, and 38 days for the Euribor, due to missing data and apparent errors.

[14] The panel size represents the actual number of submitted contributions.

even the smallest actual panel contains 37 banks, which is twice the size of the panel for USD Libor.

Analyzing the cross-sectional standard deviation and the range of quotes, we find that, particularly during the financial crisis, the dispersion of the individual contributions is quite high. For example, around the time of the Lehman default, the range of quotes, i.e., the difference between the highest and lowest contribution, is above 100 bp for AUD and USD Libor, and just below this value in the case of Euribor. Considering the full sample period, the range between the lowest and highest submissions is 11.57 bp for AUD Libor, 12.38 bp for USD Libor and 15.86 bp for Euribor, on average. The standard deviations show basically identical findings. Note that, even for Euribor, the cross-section of contributions is volatile, even though all contributing banks are submitting their estimates of the funding costs for a hypothetical prime bank in this case.

Given that the cross-sectional contributions are quite dispersed, a question arises as to whether the contributions of the individual banks are more stable over time. In this respect, it is particularly interesting to look at whether the relative position of one bank compared to the other banks changes over time. If the credit and liquidity risk of an individual bank, or its error in estimating the relevant funding costs, do not vary much over time, then manipulations could be detected by identifying banks whose relative positions change, e.g., reporting a low rate one day and a high rate the next.

To analyze this issue, in Tables 4–6 we show the frequencies of being in the calculation panel (i.e., the bank's contribution not being discarded in the trimming process), for all panel banks and for all three reference rates, as well as of being below and above the calculation panel. All these frequencies are shown for the whole time period and for two subperiods: the period from January 2005 to June 2007 and the crisis period from July 2007 to June 2012.

[Tables 4–6 about here.]

Overall, we find that banks switch regularly between being in the calculation panel and being discarded. Looking at the frequencies for the AUD Libor banks, UBS has the lowest frequency of being in the calculation panel at 41% and HSBC the highest at 76%. Most of the banks are in the calculation panel on around 50% of all days, which is basically identical to the percentage of banks included in the calculation panel. Roughly the same result is found for the USD Libor and Euribor. The only difference for Euribor is that the frequencies are generally higher as only 30% of all submissions are discarded in this case. These results also hold, in general, when analyzing the two subperiods. However, here we find that, in the crisis periods, some banks are discarded from the calculation panel with higher frequencies, potentially because of credit or liquidity risk issues.

Turning to the frequencies of being outside the calculation panel, we find that banks often have similar frequencies of being above and below, i.e., typically, banks show no pattern of being discarded from the calculation panel because of reporting rates that are always too high or always too low. For example, for the AUD Libor, Deutsche Bank is in 21% of all cases below and in 23% of all cases above the calculation panel. The results for USD Libor and Euribor are quite similar. Again, only in the crisis periods do we find that the frequencies of some banks are biased in one direction.

The reported frequencies provide a first indication of the time-series volatility of individual contributions. However, the observed frequencies could arise because of long-term movements in the individual contributions, i.e., a particular contribution could be several months above the calculation panel, then some months in the calculation panel and, finally, below the other quotes. Thus, in the next step we explore the day-to-day changes in the individual rates.

[Tables 7–9 about here.]

To analyze this issue, we explore the time-series of the ranks of the contributions and of the differences between the actual bank contributions and the final rate. Tables 7–9 present the mean and standard deviation of the daily absolute rank changes for each bank for the three reference rates. Note that we normalized the rank by the panel size to be able to compare the results across currencies, i.e., the highest contribution has rank one. Again, we present results for the whole time period and the two subperiods. Analyzing AUD Libor banks, the daily absolute rank change of a bank is around 13.5% of the panel size (e.g., HSBC has the lowest average rank change with 6.1% and HBOS has the highest with 18.3%). Thus, the daily change in rank is quite high for all banks. The standard deviation is around 15.8% and shows the same variation as the mean across banks. These numbers are similar in both subperiods. However, we observe somewhat smaller average rank changes in the crisis period of around 12.9%, potentially because of more pronounced differences in credit or liquidity risk. We find similar results for USD Libor and Euribor panel banks. Overall, the observed rank changes indicate that basically all banks have frequent rank changes. Figure 4 shows the time-series of the rank for representative panel banks, i.e., we present two banks per reference rate, however, the patterns for the other banks are similar. These time-series confirm that the rank of an individual bank's rate submissions is quite volatile on a day-to-day basis.

[Figure 4 about here.]

Focussing on the differences between the actual bank contributions and the final rate, we define for every day, t, the spread over Libor/Euribor, s_t, as the difference between an individual contribution, $c_{i,t}$, of bank i, and the final interest rate fixing, f_t, on that day.

$$s_{i,t} = c_{i,t} - f_t \tag{1}$$

Figure 5 shows the time series evolution of the spread over AUD Libor, USD Libor and Euribor for the same representative panel banks as before. The results confirm that individual panel banks' contributions are volatile and show high degree of day-to-day variation. In addition, it happens rather frequently that banks go from being below the final fixing to being above from one day to the next.

[Figure 5 about here.]

As already mentioned, this variation in ranks as well as spreads makes detecting manipulation attempts virtually impossible. Therefore, we focus on quantifying the potential effect of manipulation in our main analysis. Furthermore, given these results we find a clear need for mandatory transaction reporting to a central data repository, with public dissemination with a delay, to ensure greater transparency. This mechanism would be a first step toward validating individual rate submissions, and thus, might allow a data-driven identification of manipulation. Similar transparency projects have been implemented for different OTC markets in the last decade: In the US corporate bond market since 2004, the US municipal bond market since 2005, and the US fixed-income securitized product market since 2011, reporting of all transactions by broker/dealers is mandatory. Many studies have analyzed these transparency projects and documented the positive effects of increased transparency.[15] Thus, transparency in the underlying money markets would certainly foster confidence among market participants in the reliability of important benchmark interest rates.

5.2 A First Look at Manipulation

In this section, we quantify the effects of potential manipulation based on the actual rate-setting process currently in place. We present results for one bank seeking to move the rate in a particular direction and then repeat this analysis for the collusive action of two or three banks. As we analyze AUD Libor, USD Libor and Euribor, we can compare the effects on rate fixing of different sample sizes and the underlying questions asked in eliciting the submissions from the panel banks.

[15] See, e.g., Bessembinder et al. (2006), Green (2007), Green et al. (2007), Goldstein and Hotchkiss (2007) and Friewald et al. (2012).

We use the following approach to quantify the possible effects of manipulation: For each day, we start with the observed individual contributions by the panel banks as well as the rate fixing. Then, we change the lowest observed contribution, making it equal to the highest observed contribution, for the case of a manipulation by one bank (see Table 3 for an example).[16] The difference between the observed (historic) benchmark rate and the resulting benchmark rate after changing this one contribution is our measure of the potential effect of manipulation. Of course, different approaches could have been chosen, e.g., by changing the lowest contribution within the calculation panel or the contribution in the center of the calculation panel (or by randomly drawing one contribution and changing it). However, we think that our approach offers important insights, for two reasons: First, we are interested in the potential incentive to manipulate the reference rate in a certain direction. This incentive is obviously maximized at the lower and upper ends of the range of contributions. Second, given the substantial volatility we document in the individual contributions, we consider it reasonable to assume that, if manipulation is considered by a bank, it will make use of the full range of potential values in order to maximize the impact on the reference rate. Note that we use the same approach when considering the manipulation incentive for two or three banks, i.e., we set the lowest two (or three) contributions equal to the highest observed contribution.

[Figure 6 about here.]

Figure 6 shows the time-series of the impact of the manipulations for the three reference rates by one, two and three banks. Our results clearly show that, even though a trimmed mean is used, manipulation attempts by one bank can have significant effects: on average 1.13 bp for AUD Libor, 0.45 bp for USD Libor and 0.17 bp in the case of Euribor. Thus, the reference rates are not at all robust to manipulation, even by a single bank. Furthermore, we find that (as expected) the effect of manipulations increases significantly when

[16] Note that a potential manipulation in the opposite direction, i.e., setting the highest contribution equal to the lowest value, results in basically identical effects.

there is collusion between several banks, e.g., the average effect for USD Libor increases to 0.94 bp (two banks) and 1.50 bp (three banks), respectively. In addition, the time-series show that the incentive to manipulate became much more pronounced during the financial crisis, as the range of individual contributions increased (as discussed in Section 5.1). Thus, we find that the average manipulation effect of three banks in the time window January 2005 to June 2007 compared to the time window July 2007 to June 2012 is 1.25 bp versus 4.58 bp for AUD Libor, 0.16 bp versus 2.15 bp for USD Libor and 0.12 bp versus 0.74 bp for Euribor.

In addition, these results allow us to discuss the effect of the panel size on the manipulation effects. We find the expected result that the manipulation effect is largest in the case of the AUD Libor, at 3.47 bp for three banks, and smallest in the case of Euribor, at 0.55 bp, again for three banks. Thus, constructing a reference rate based on the information provided by larger panels reduces the incentive for individual banks to manipulate the final rate. We will present a more detailed discussion of the panel size in the next section, after discussing manipulation effects for alternative rate-setting processes.

Overall, we find significant incentives to manipulate the reference rates under the current rate-setting process. This incentive is particularly strong in the case of small panel sizes and where collusion with other banks is possible. However, our results clearly document that even a single bank can have an important impact. Furthermore, we find that manipulation incentives were particularly strong during the financial crisis, as the range of individual submissions increased due to increased heterogeneity among the panel banks with regard to credit and funding risk.

5.3 Alternative Rate Fixings

In this section, we analyze three alternative rate-fixing methodologies and discuss how they influence the potential for manipulation. The first alternative is simply the untrimmed mean, which we include so as to have a naive benchmark.

In addition, we consider two other rate-setting processes as real alternatives to the present method, and will focus our analysis on these results. Here, we look at the median and a random draw of the individual contributions. The use of the median of the submissions is an obvious alternative, as it is the numerical value separating the higher half of a sample from the lower half, i.e., the importance attached to outliers is reduced. In the random draw approach the individual submissions are first trimmed according to the current rules and then one of submissions in the calculation panel is randomly selected and represents the final rate for this day. The motivation behind this approach is to make the prediction of the final rate for the manipulating banks more difficult. Both methods are briefly mentioned in the Wheatley report (see Wheatley (2012a)) as potential improvements on the present rate-setting process. We report the results for the present process (the trimmed mean) in this section as well, to allow a direct comparison of the methods.

We use the same procedure to evaluate the effects of potential manipulations under these alternative rate-setting procedures that we applied earlier for the trimmed mean. In other words, we change the one, two or three lowest contributions by individual banks, setting them equal to the highest observed contribution and then calculate the resulting (manipulated) benchmark rate and compare it to the original rate given the applied rate-setting procedure. In the case of the random draw approach, we define the random number selecting the relevant submission to be the same in the original and the manipulated set, i.e., the same position within the calculation panel is drawn for the manipulated set. Thus, we assume that the randomly drawn position is not influenced by the submitted values, which should obviously not be the case.

[Table 10 about here.]

Table 10 reports the time-series average and standard deviation of the manipulation effects. Starting with the manipulation effect of one bank, we find the following results: First of all, we can confirm that the untrimmed mean indeed offers the highest incentive to manipulate, for all reference rates. For example, for USD Libor, the effect is 0.74 bp for the untrimmed mean versus 0.45 bp for the trimmed mean. Interestingly, we find that the median provides the smallest incentive, for all reference rates: For example, for Euribor, 0.08 bp for the median versus 0.17 bp for the trimmed mean. The random draw method basically provides the same level of manipulation incentives as the trimmed mean. However, the standard deviation of the manipulation incentive increases, i.e., the outcome of a manipulation attempt becomes more volatile. For example, for AUD Libor, the standard deviation is 1.28 bp for the trimmed mean and 1.98 bp for the random draw.

Analyzing the manipulation effects in the case of collusion by two or three banks provides interesting insights as well. Focusing first on the USD Libor and Euribor, we find (as expected) that, for all alternative rate-setting processes, the manipulation effects increase with the number of colluding banks. The increases from one to two or three banks are comparable to the increases discussed in the case of the trimmed mean (see Section 5.2). Furthermore, we find bascially the same results as in the case of one bank, when comparing the different rate-setting processes: The untrimmed mean offers the highest incentive, whereas the median offers the lowest. Again, a random draw is comparable to the trimmed mean but with higher standard deviation. These findings provide two important results: First of all, the use of the median rather than the trimmed mean would reduce the manipulation incentives significantly. That is, for USD Libor, in the case of two manipulating banks, the effect falls from 0.95 to 0.66 bp, and in the case of three banks from 1.50 to 1.14 bp. For Euribor we find similar effects: manipulation incentives decrease from 0.35 to 0.18 bp in the case of two banks and from 0.54 to 0.27 bp in the case of three banks. Second, the panel size is an important driver of the manipulation incentives under the alternative rate-setting procedures. For the median in the case of two (three) banks, we find effects of 0.66 bp (1.14 bp) for USD Libor versus 0.18 bp (0.27 bp) for Euribor.

Thus, we find smaller impacts on the final rate for Euribor, where the largest panel is used.

When analyzing the same incentives in the case of collusion for the AUD Libor, we find important differences that are related to the smaller sample sizes. These differences allow us to discuss the alternative rate-setting procedures in more detail. The main difference in the findings is that, when three banks collude (which means three out of seven or eight banks manipulate, in the case of AUD Libor), the untrimmed mean provides the lowest incentive, whereas the median provides the highest incentive to manipulate. This result can readily be explained by the small sample size. The median is only effective in eliminating outliers as long the underlying distribution of the individual contributions is approximately symmetric. Obviously, with three out of eight values falsely reporting at the upper end of the contributions, this is not the case any more. Therefore, the median is not effective in mitigating manipulation effects in this case. A similar effect can be observed for the trimmed mean, as well. Thus, this result demonstrates that, for a very small sample size, the effect of collusion cannot be mitigated by the rate-setting procedure that is chosen. In this case, the sample size needs to be increased so that, if a reasonable number of banks colluded, it would still be a small subset of the whole sample.

Overall, we find that the panel size and the calculation method used to determine the final rate are important factors affecting manipulation incentives. A large panel size and median rates can significantly reduce these incentives. We assume that a change in the rate-setting process could be implemented fairly easily for all reference rates, whereas a change in the overall panel size might be more difficult to implement in the case of Libor. As discussed in Section 2, banks are asked about their specific funding costs in the Libor submission process. Thus, an increase in the panel size could increase the heterogeneity of the overall sample with respect to credit and liquidity risk. This problem does not arise in the case of Euribor, as the contributing banks are asked about the funding costs of a hypothetical prime bank. Therefore, prior to enlarging the panel size for a particular reference rate, the information being asked of the specific banks should be reconsidered so as to avoid unwanted effects.

6 Conclusion

Market reference interest rates such as Libor and Euribor, or their regional variants in Tokyo and other financial centers, play an important role in many financial contracts around the world. The integrity of these instruments, and of the markets, themselves, depends crucial on the confidence that market participants place in the reliability and veracity of these rates. Unfortunately, developments in London and in other global financial centers have shaken this confidence, due to widespread allegations of manipulation in recent years. While prosecutors are currently engaged in taking action against the purported manipulators, regulators, including the Bank of England and the European Central Bank, are grappling with the issue of how to reform the rate–setting process, without creating too much confusion about the nature of the contracts, or inducing potential litigation among contracting parties that use these rates as benchmarks in their contracts. We believe that our analysis provides useful additional findings for this reform.

In this paper, we quantify and explore the incentives and potential effects of manipulations for Libor and Euribor, in detail. The focus of our study is on the analysis of the individual submissions of the panel banks for the calculations of the respective benchmark rates for the time period January 2005 to June 2012. We present results for the AUD Libor, USD Libor and Euribor, based on the three month tenure, as representative examples. In our analysis, we explicitly take into account the possibility of collusion between several market participants. Furthermore, our setup allows us to quantify potential manipulation effects for the actual rate-setting process in place at present, and compare it to several alternative rate-fixing procedures. Moreover, we can directly analyze the effect of the panel size and the underlying methodology for eliciting rate submissions on manipulation outcomes.

Our results show that the cross-sectional volatility of individual submissions is high, i.e., the screening for manipulation is hindered by the presence of noise in the data. In line with the related literature, we find that, in this case, the detection of concrete manipulations by particular banks based solely on their submissions is almost impossible to prove. Thus, in our main research question, we focus on the *underlying incentive* for manipulation. We quantify the potential effects of manipulations on the final fixing for different benchmark rates and rate-setting procedures by considering simultaneous manipulation attempts by up to three banks. Overall, we find that the panel size and the calculation method significantly influences such incentives, i.e., a large panel size and the use of the median of the submissions (instead of the currently applied trimmed mean approaches) substainally reduce the effects of individual banks on the final rate. Furthermore, we show that other proposed alternative rate-setting processes do not reduce manipulation incentives. Although a change in the calculation methodology could be implemented fairly easily, the increase in the panel size for the Libor rates in its current setup could be more difficult. Given that banks are explicitly asked about their own funding rate for Libor, enlarging the sample might introduce even more heterogeneity, in terms of credit, liquidity, and outstanding positions, across panel banks. Thus, increasing the sample size might only be feasible when asking about the money market funding costs of a (hypothetical) prime bank as in the case of the Euribor.

There could potentially be other improvements made to the rate-setting process that have not been analyzed in this paper. One possibility is a mix of transactions and quote data, where the most liquid benchmark rates in terms of maturity and currency are set using actual transactions, and the spreads over these for the other currencies and maturities are set using quotes based on our reformed methodology. Such alternatives can be analyzed once a complete transaction data set is available. Thus, we find a clear need for such an extensive transparency initiative making transaction reporting to a central database mandatory, as it would at least lead to the first step in validating individual rate submissions, and thus, might allow a data-driven identification of manipulation attempts.

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Figures

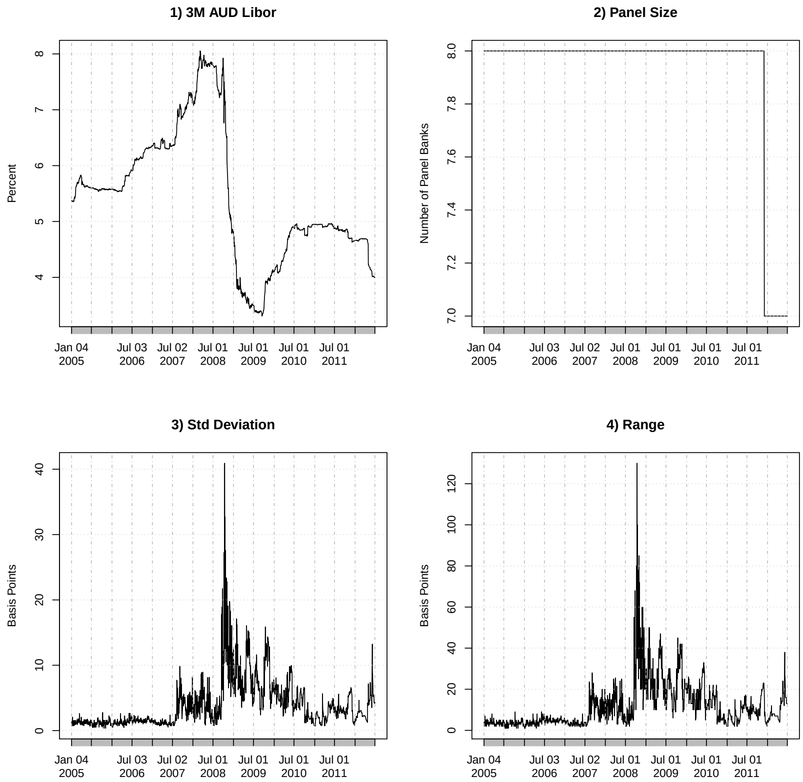

Figure 1: This figure shows the summary plots for the three month AUD Libor. Subfigure 1 shows the time-series of this reference rate. Subfigure 2 presents the panel size of banks contributing to the AUD Libor. Based on the individual contributions, subfigures 3 and 4 show the cross-sectional standard deviation and the range, i.e., the difference between the highest and the lowest contribution, on each day. Our data set contains the reference rate and the underlying contributions, obtained from Bloomberg for the time period from January 2005 to June 2012.

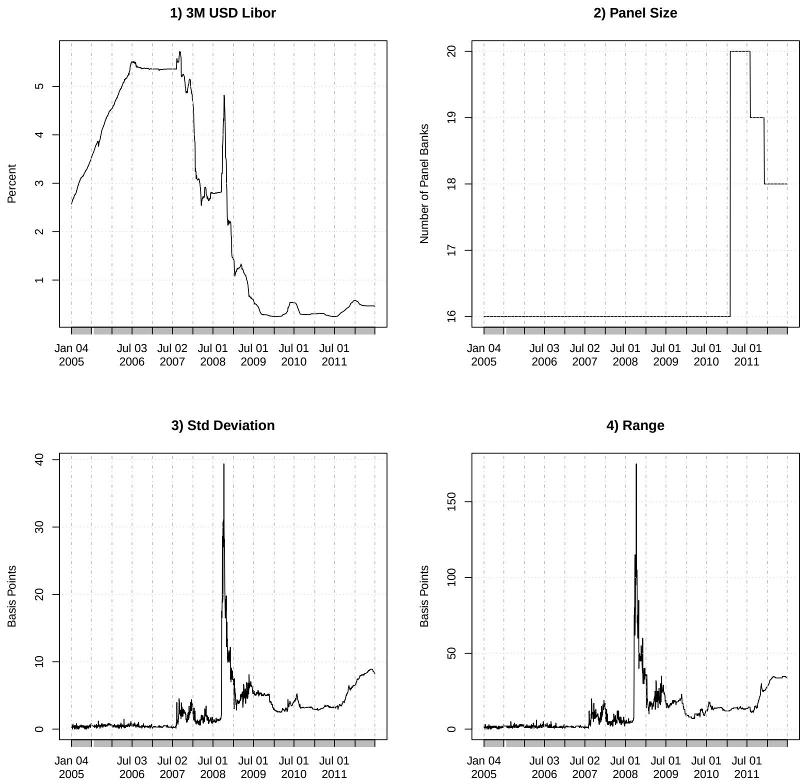

Figure 2: This figure shows the summary plots for the three month USD Libor. Subfigure 1 shows the time-series of this reference rate. Subfigure 2 presents the panel size of banks contributing to the USD Libor. Based on the individual contributions, subfigures 3 and 4 show the cross-sectional standard deviation and the range, i.e., the difference between the highest and the lowest contribution, on each day. Our data set contains the reference rate and the underlying contributions, obtained from Bloomberg for the time period from January 2005 to June 2012.

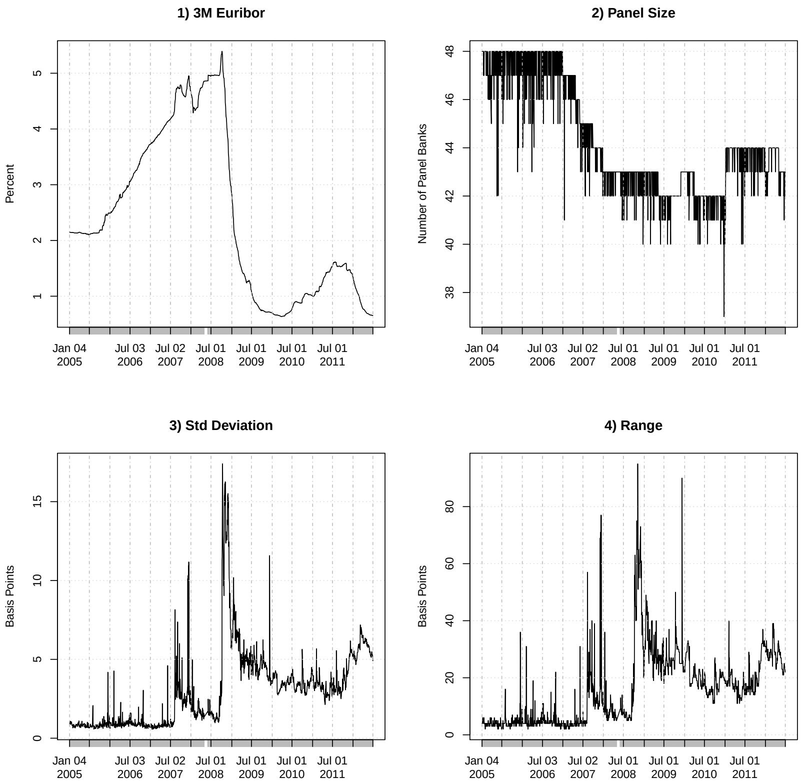

Figure 3: This figure shows the summary plots for the three month Euribor. Subfigure 1 shows the time-series of this reference rate. Subfigure 2 presents the panel size of banks contributing to the Euribor. Based on the individual contributions, subfigures 3 and 4 show the cross-sectional standard deviation and the range, i.e., the difference between the highest and the lowest contribution, on each day. Our data set contains the reference rate and the underlying contributions, obtained from the European Banking Federation for the time period from January 2005 to June 2012.

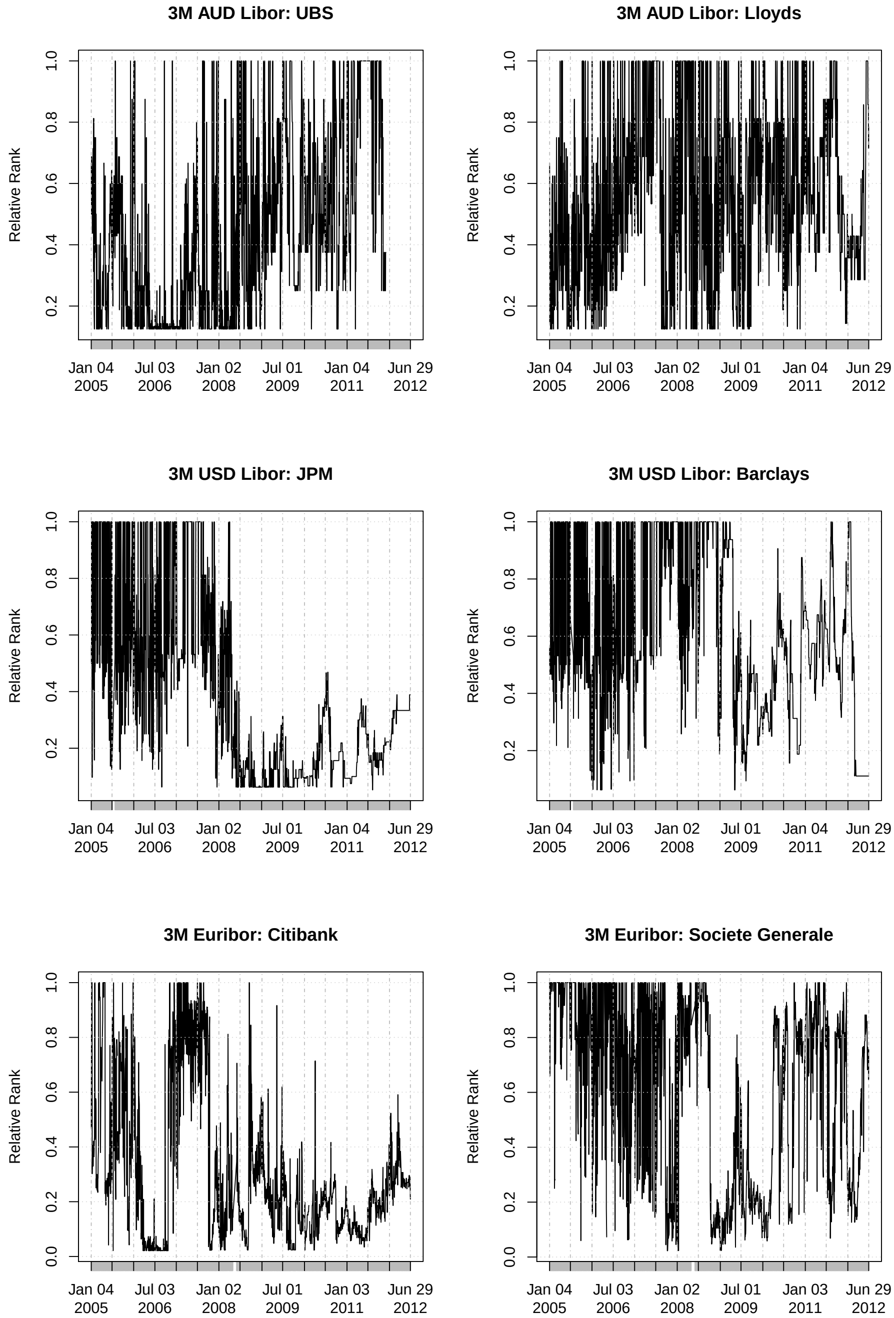

Figure 4: This figure shows the evolution of the ranks of selected panel banks' contributions for the three month AUD Libor, USD Libor and Euribor over time. To make the results comparable accross currencies, we standardize the ranks such that the bank with the highest rank (i.e., highest contribution) has a rank of 1. For each reference rate we present the results for two representative panel banks. Our data set contains the reference rates and the underlying contributions, obtained from Bloomberg and the European Banking Federation for the time period from January 2005 to June 2012.

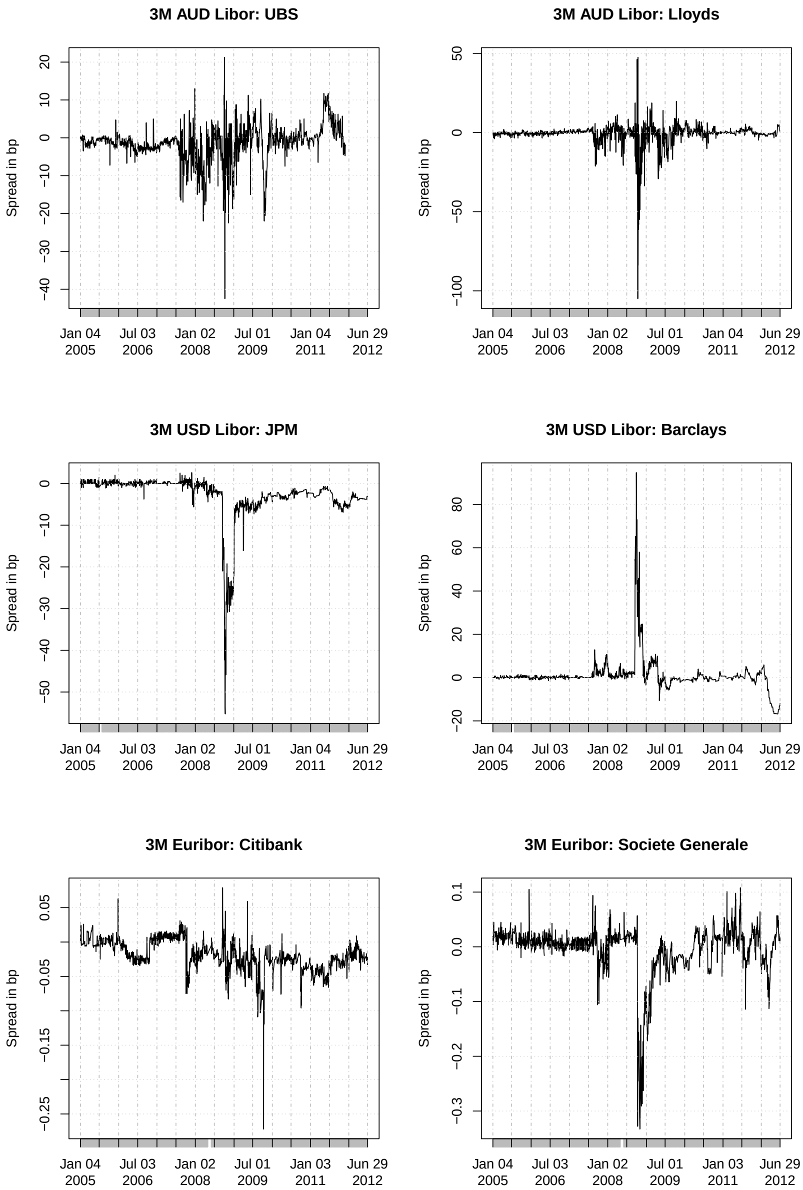

Figure 5: This figure shows the difference between the individual contributions of selected panel banks and the final fixings for the three month AUD Libor, USD Libor and Euribor over time. For each reference rate we present the results for two representative panel banks. Our data set contains the reference rates and the underlying contributions, obtained from Bloomberg and the European Banking Federation for the time period from January 2005 to June 2012.

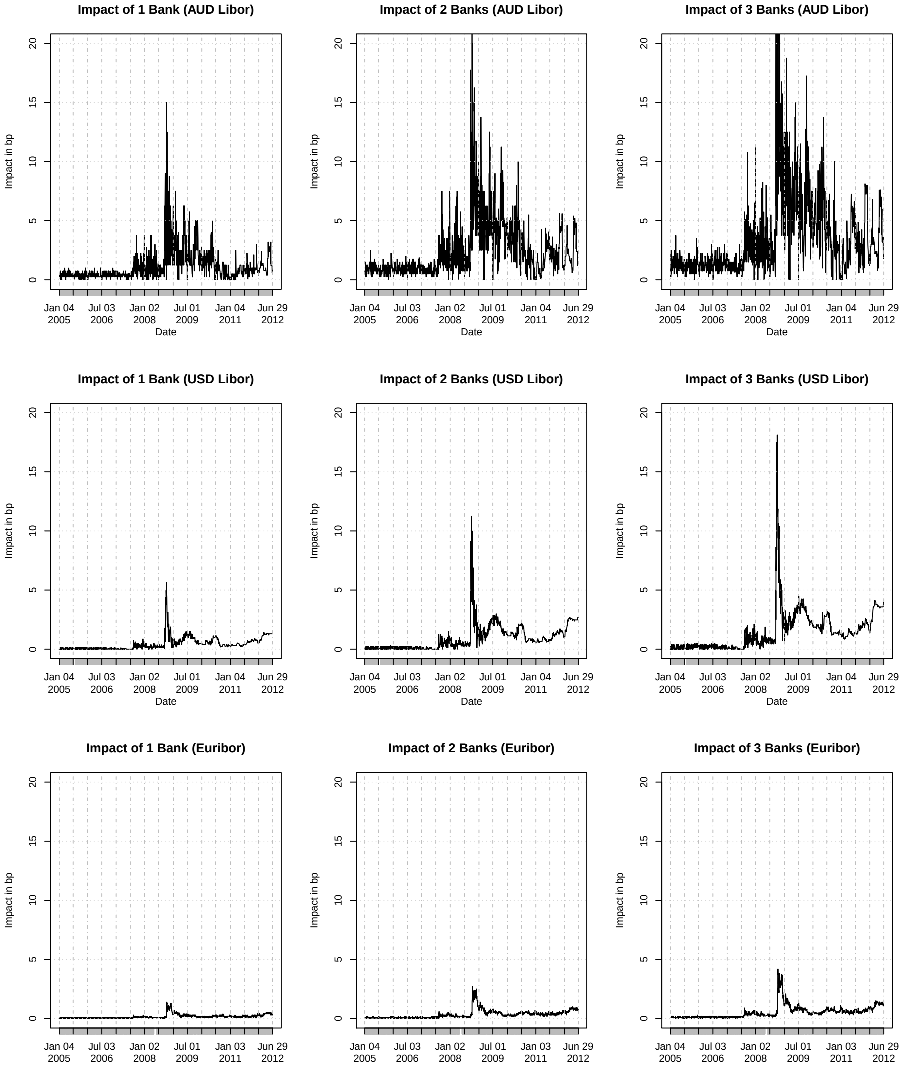

Figure 6: This figure shows the potential manipulation impact using the current rate setting methodology for the three month AUD Libor, USD Libor and Euribor. For each day, we report the impact one, two or three colluding banks could have on the final fixing. We use the following approach to quantify these effects: We start out with the observed individual contributions by the panel banks to the final rate. Then, we change the lowest observed contribution, making it equal to the highest observed contribution, for the case of a manipulation by one bank. The difference between the observed (historic) benchmark rate and the resulting benchmark rate after changing this one contribution is our measure of the potential effect of manipulation. We use the same approach when considering the manipulation incentive for two or three banks, i.e., we set the lowest two (or three) contributions equal to the highest observed contribution. Our data set contains the reference rates and the underlying contributions, obtained from Bloomberg and the European Banking Federation for the time period from January 2005 to June 2012.

Tables

Panel size	Nr. of excluded banks
6 - 7	1
8 - 10	2
11 - 14	3
15 - 18	4
19 - 20	5

Table 1: This table shows the number of excluded banks' submissions on each side of the Libor panel given the selected panel size. In principle, the highest and lowest 25% of all submissions are excluded. However, a particular rounding approach is applied for non-integer numbers. For example for a panel of size 7, the highest and lowest contribution are excluded, although 25% of the panel represent 1.75 contributions. This approach ensures that not more than 55% of the submissions are removed.

Panel size	Nr. of excluded banks
12 - 16	2
17 - 23	3
24 - 29	4
30 - 36	5
37 - 43	6
44 - 45	7

Table 2: This table shows the number of excluded banks' submission on each side of the Euribor panel given the selected panel size. In principle, the highest and lowest 15% of all submissions are excluded. The common method of rounding is applied to non-integer number. For example for a panel of size 18, the three highest and three lowest contributions are excluded.

Bank 1	Bank 2	Bank 3	Bank 4	Bank 5	Bank 6	Bank 7	Bank 1
3.90	3.99	4.00	4.00	4.01	4.02	4.03	
	3.99	4.00	4.00	4.01	4.02	4.03	4.03

Table 3: This table shows the calculation of the three month AUD Libor rate on June 29, 2012. On this day the AUD Libor panel consisted of 7 banks. Thus, the highest and lowest contributions were removed in the trimming process. The first row shows the actual contributions on that day. The contributions of banks 2–6 are used to calculate the Libor rate, yielding a final fixing of 4.004%. In the second row we illustrate the effect on this rate if a single contribution is different (e.g., because of manipulation). If the bank with the lowest contribution (Bank 1) instead submits a contribution equal to that of the bank with the highest contribution (Bank 7), the fixing on that day is then the average of the contributions of banks 3–7, i.e., the calculation window shifts by one bank. In this case the final fixing is 4.012%, an increase of 0.8 bp.

Bank	in Panel			below Panel			above Panel		
	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012
Barclays	0.54	0.71	0.51	0.11	0.09	0.12	0.20	0.05	0.23
Commonwealth Bank	0.61	0.42	0.70	0.21	0.37	0.13	0.09	0.07	0.10
Deutsche Bank	0.45	0.48	0.43	0.21	0.08	0.27	0.23	0.30	0.20
HBOS	0.44	0.39	0.51	0.05	0.06	0.03	0.37	0.41	0.32
HSBC	0.76		0.76	0.21		0.21	0.00		0.00
JPM	0.55	0.63	0.52	0.20	0.07	0.25	0.13	0.12	0.13
Lloyds	0.58	0.56	0.58	0.16	0.17	0.16	0.14	0.12	0.15
National Australia	0.52	0.72	0.41	0.28	0.06	0.41	0.09	0.04	0.11
RBS	0.49	0.47	0.50	0.07	0.05	0.07	0.31	0.33	0.30
UBS	0.41	0.29	0.47	0.39	0.59	0.27	0.18	0.12	0.21

Table 4: This table shows the frequencies for all panel banks to be in or out of (above/below) the subset used for calculating the three month AUD Libor. As the cross-sectional standard deviation of the contributions was very low before the onset of the financial crisis, we report our results for the full time period, the time period before the financial crisis (January 2005 to June 2007) and the time period of the financial crisis from July 2007 onwards. The first three columns show the frequencies of being in the panel used for calculating the trimmed mean. Tied contributions were assigned proportionately here. The columns labeled *below Panel* and *above Panel* show the percentage of days a banks' contribution was strictly below and above this panel, respectively. Our data set contains the reference rate and the underlying contributions, obtained from Bloomberg for the time period from January 2005 to June 2012.

Bank	**in Panel**			**below Panel**			**above Panel**		
	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012
Abbey National	0.54	0.54		0.03	0.03		0.02	0.02	
Bank of Nova Scotia	0.84		0.84	0.13		0.13	0.00		0.00
Bank of Tokyo	0.39	0.40	0.39	0.05	0.15	0.01	0.46	0.28	0.55
Barclays	0.51	0.47	0.52	0.11	0.10	0.12	0.24	0.16	0.27
BNP Paribas	0.42		0.42	0.00		0.00	0.51		0.51
BoA	0.58	0.32	0.70	0.23	0.30	0.20	0.15	0.42	0.03
Credite Agricole CIB	0.13		0.13	0.00		0.00	0.83		0.83
Citibank	0.61	0.62	0.61	0.20	0.06	0.27	0.03	0.06	0.02
CSFB	0.63	0.63	0.62	0.08	0.04	0.11	0.15	0.05	0.19
Deutsche Bank	0.39	0.42	0.38	0.42	0.31	0.47	0.15	0.31	0.07
HBOS	0.61	0.59	0.64	0.03	0.03	0.03	0.10	0.04	0.20
HSBC	0.34	0.53	0.25	0.48	0.10	0.67	0.03	0.06	0.02
JPM	0.34	0.50	0.27	0.46	0.08	0.65	0.04	0.12	0.01
Lloyds	0.75	0.57	0.84	0.07	0.05	0.07	0.03	0.03	0.03
Norinchuckin	0.30	0.32	0.30	0.11	0.28	0.02	0.57	0.40	0.64
Rabobank	0.53	0.55	0.52	0.31	0.10	0.41	0.05	0.10	0.02
RBC	0.80	0.60	0.88	0.05	0.10	0.03	0.06	0.09	0.05
RBS	0.32	0.31	0.32	0.24	0.44	0.15	0.41	0.32	0.46
Societe Generale	0.56		0.56	0.06		0.06	0.33		0.33
Sumitomo	0.62		0.62	0.00		0.00	0.32		0.32
UBS	0.56	0.58	0.55	0.24	0.12	0.30	0.12	0.12	0.11
West LB	0.45	0.60	0.36	0.02	0.05	0.01	0.37	0.04	0.57

Table 5: This table shows the frequencies for all panel banks to be in or out of (above/below) the subset used for calculating the three month USD Libor. As the cross-sectional standard deviation of the contributions was very low before the onset of the financial crisis, we report our results for the full time period, the time period before the financial crisis (January 2005 to June 2007) and the time period of the financial crisis from July 2007 onwards. The first three columns show the frequencies of being in the panel used for calculating the trimmed mean. Tied contributions were assigned proportionately here. The columns labeled *below Panel* and *above Panel* show the percentage of days a banks' contribution was strictly below and above this panel, respectively. Our data set contains the reference rate and the underlying contributions, obtained from Bloomberg for the time period from January 2005 to June 2012.

Bank	in Panel			below Panel			above Panel		
	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012
ABN Amro	0.68	0.73	0.62	0.07	0.05	0.09	0.14	0.06	0.22
AIB Group	0.49	0.79	0.34	0.01	0.03	0.00	0.40	0.02	0.59
Banca Intesa	0.86	0.80	0.90	0.02	0.01	0.03	0.01	0.01	0.01
Banca MPS	0.86	0.70	0.94	0.03	0.07	0.01	0.06	0.12	0.03
Banco Bilbao	0.43	0.13	0.59	0.26	0.53	0.13	0.40	0.73	0.24
Banco Santander	0.76	0.79	0.74	0.07	0.05	0.08	0.08	0.03	0.11
Bank of Ireland	0.86	0.77	0.91	0.03	0.05	0.02	0.03	0.04	0.02
Bank of Tokyo Mitsubishi	0.52	0.31	0.63	0.34	0.38	0.32	0.18	0.52	0.00
Banque Postale	0.65		0.65	0.12		0.12	0.19		0.19
Barclays	0.70	0.78	0.65	0.16	0.06	0.22	0.07	0.05	0.08
Bayern LB	0.63	0.43	0.72	0.24	0.39	0.16	0.13	0.28	0.05
BCEE	0.84	0.81	0.85	0.07	0.01	0.10	0.01	0.01	0.00
Belfius	0.66	0.77	0.59	0.02	0.01	0.02	0.22	0.02	0.34
BNL	0.76	0.76		0.06	0.06		0.05	0.05	
BNP Paribas	0.48	0.57	0.44	0.35	0.27	0.39	0.12	0.17	0.10
Capita	0.87	0.87	0.90	0.00	0.00	0.00	0.00	0.00	0.02
Cecabank	0.63	0.74	0.57	0.08	0.06	0.09	0.19	0.07	0.24
CGD	0.68	0.80	0.62	0.01	0.01	0.01	0.22	0.01	0.32
CIC	0.60	0.59	0.60	0.18	0.18	0.18	0.15	0.19	0.13
Citibank	0.54	0.50	0.57	0.34	0.33	0.34	0.08	0.21	0.01
Commerzbank	0.86	0.67	0.96	0.06	0.15	0.01	0.04	0.09	0.01
Credite Agricole CIB	0.69	0.80	0.64	0.16	0.01	0.23	0.05	0.02	0.06
Danske Bank	0.80	0.79	0.80	0.07	0.01	0.09	0.04	0.01	0.06
Deutsche Bank	0.36	0.42	0.32	0.42	0.40	0.43	0.24	0.32	0.20
Dexia	0.71		0.71	0.09		0.09	0.17		0.17
Dresdner Bank	0.83	0.77	0.92	0.02	0.03	0.01	0.02	0.01	0.02
DZ Bank	0.61	0.75	0.55	0.15	0.07	0.19	0.14	0.07	0.18
Erste Bank	0.43	0.73	0.28	0.02	0.07	0.00	0.45	0.09	0.63
Fortis	0.63	0.55	0.70	0.11	0.19	0.03	0.25	0.27	0.22
HSBC	0.65	0.68	0.64	0.22	0.11	0.27	0.09	0.16	0.05
HVB	0.78	0.78		0.06	0.06		0.05	0.05	
ING	0.85	0.77	0.89	0.04	0.05	0.04	0.04	0.06	0.04
JPM	0.56	0.72	0.48	0.31	0.06	0.44	0.03	0.08	0.00
KBC	0.79	0.82	0.78	0.02	0.03	0.01	0.11	0.02	0.16
la Caixa	0.97		0.97	0.00		0.00	0.02		0.02
LB Baden-Württemberg	0.77	0.71	0.81	0.09	0.10	0.08	0.06	0.06	0.06
LB Berlin	0.90	0.81	0.94	0.02	0.04	0.01	0.02	0.02	0.02
LB Hessen-Thüringen	0.76	0.80	0.74	0.01	0.03	0.00	0.12	0.03	0.17
Natexis	0.69	0.71	0.61	0.09	0.08	0.13	0.11	0.09	0.19
National Bank of Greece	0.83	0.82	0.84	0.01	0.01	0.00	0.07	0.02	0.10
Natixis	0.68	0.62	0.71	0.10	0.18	0.06	0.17	0.17	0.17
Nordea	0.92	0.80	0.99	0.00	0.01	0.00	0.00	0.01	0.00
Nord LB	0.74	0.72	0.74	0.11	0.11	0.11	0.08	0.09	0.07
Pohjola	0.95		0.95	0.04		0.04	0.00		0.00
Rabobank	0.63	0.77	0.57	0.26	0.03	0.38	0.01	0.02	0.01
RBI	0.82	0.80	0.83	0.07	0.00	0.10	0.01	0.00	0.01
RBS	0.84		0.84	0.09		0.09	0.05		0.05
Sanpaolo IMI	0.90	0.90		0.00	0.00		0.00	0.00	
Societe Generale	0.56	0.43	0.62	0.19	0.29	0.14	0.23	0.40	0.14
Svenska	0.89	0.82	0.92	0.01	0.02	0.00	0.03	0.02	0.03
UBI Banca	1.00		1.00	0.00		0.00	0.00		0.00
UBS	0.59	0.73	0.52	0.22	0.08	0.29	0.10	0.05	0.13
Unicredit	0.87	0.80	0.90	0.03	0.02	0.04	0.02	0.02	0.02
West LB	0.77	0.70	0.80	0.04	0.10	0.01	0.12	0.09	0.13

Table 6: This table shows the frequencies for all panel banks to be in or out of (above/below) the subset used for calculating the three month Euribor. As the cross-sectional standard deviation of the contributions was very low before the onset of the financial crisis, we report our results for the full time period, the time period before the financial crisis (January 2005 to June 2007) and the time period of the financial crisis from July 2007 onwards. The first three columns show the frequencies of being in the panel used for calculating the trimmed mean. Tied contributions were assigned proportionately here. The columns labeled *below Panel* and *above Panel* show the percentage of days a banks' contribution was strictly below and above this panel, respectively. Our data set contains the reference rate and the underlying contributions, obtained from the European Banking Federation for the time period from January 2005 to June 2012.

Bank	**Mean** Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	**StdDev** Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012
Barclays	0.137	0.199	0.124	0.164	0.162	0.161
Commonwealth Bank	0.177	0.151	0.190	0.174	0.148	0.184
Deutsche Bank	0.113	0.128	0.105	0.146	0.143	0.147
HBOS	0.183	0.176	0.194	0.184	0.191	0.172
HSBC	0.062		0.062	0.090		0.090
JPM	0.120	0.195	0.087	0.159	0.185	0.134
Lloyds	0.162	0.183	0.152	0.184	0.171	0.189
National Australia	0.148	0.184	0.127	0.163	0.153	0.165
RBS	0.136	0.156	0.126	0.163	0.158	0.164
UBS	0.116	0.096	0.127	0.157	0.133	0.168

Table 7: This table shows the mean and standard deviation of the daily absolute rank changes for the panel banks contributing to the three month AUD Libor. To make the results comparable accross currencies, we standardize the ranks such that the bank with the highest rank (i.e., highest contribution) has a rank of 1. For example, a rank change of 0.25 means that a bank's rank change corresponds to a quarter of the panel. Our data set contains the reference rate and the underlying contributions, obtained from Bloomberg for the time period from January 2005 to June 2012.

Bank	Mean			StdDev		
	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012
Abbey National	0.273	0.273		0.258	0.258	
Bank of Nova Scotia	0.020		0.020	0.031		0.031
Bank of Tokyo	0.089	0.178	0.047	0.157	0.219	0.087
Barclays	0.102	0.209	0.051	0.168	0.225	0.096
BNP Paribas	0.016		0.016	0.030		0.030
BoA	0.117	0.213	0.070	0.193	0.265	0.121
Credite Agricole CIB	0.008		0.008	0.022		0.022
Citibank	0.098	0.181	0.058	0.147	0.191	0.098
CSFB	0.106	0.178	0.071	0.153	0.188	0.118
Deutsche Bank	0.117	0.205	0.075	0.179	0.215	0.140
HBOS	0.187	0.211	0.151	0.190	0.209	0.148
HSBC	0.102	0.205	0.053	0.170	0.226	0.104
JPM	0.095	0.210	0.040	0.168	0.230	0.083
Lloyds	0.106	0.197	0.062	0.159	0.208	0.104
Norinchuckin	0.084	0.168	0.043	0.154	0.212	0.092
Rabobank	0.119	0.211	0.074	0.179	0.220	0.134
RBC	0.101	0.199	0.063	0.151	0.201	0.105
RBS	0.095	0.158	0.064	0.160	0.197	0.128
Societe Generale	0.026		0.026	0.051		0.051
Sumitomo	0.009		0.009	0.020		0.020
UBS	0.109	0.213	0.059	0.165	0.213	0.104
West LB	0.113	0.194	0.064	0.165	0.204	0.112

Table 8: This table shows the mean and standard deviation of the daily absolute rank changes for the panel banks contributing to the three month USD Libor. To make the results comparable accross currencies, we standardize the ranks such that the bank with the highest rank (i.e., highest contribution) has a rank of 1. For example, a rank change of 0.25 means that a bank's rank change corresponds to a quarter of the panel. Our data set contains the reference rate and the underlying contributions, obtained from Bloomberg for the time period from January 2005 to June 2012.

Bank	Mean			StdDev		
	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012	Jan 2005 Jun 2012	Jan 2005 Jun 2007	Jul 2007 Jun 2012
ABN Amro	0.134	0.141	0.127	0.165	0.163	0.167
AIB Group	0.111	0.200	0.066	0.157	0.184	0.119
Banca Intesa	0.089	0.141	0.063	0.105	0.137	0.072
Banca MPS	0.122	0.147	0.109	0.131	0.151	0.118
Banco Bilbao	0.064	0.054	0.069	0.108	0.113	0.105
Banco Santander	0.109	0.158	0.084	0.133	0.158	0.110
Bank of Ireland	0.111	0.149	0.092	0.121	0.139	0.106
Bank of Tokyo Mitsubishi	0.067	0.082	0.059	0.090	0.097	0.085
Banque Postale	0.126		0.126	0.150		0.150
Barclays	0.117	0.180	0.085	0.140	0.162	0.115
Bayern LB	0.134	0.140	0.131	0.150	0.155	0.147
BCEE	0.098	0.135	0.079	0.117	0.138	0.100
Belfius	0.094	0.120	0.078	0.121	0.121	0.119
BNL	0.150	0.150		0.147	0.147	
BNP Paribas	0.104	0.156	0.077	0.152	0.185	0.125
Capita	0.167	0.165	0.191	0.150	0.149	0.161
Cecabank	0.105	0.173	0.070	0.132	0.163	0.097
CGD	0.072	0.103	0.057	0.092	0.094	0.086
CIC	0.110	0.151	0.090	0.148	0.171	0.130
Citibank	0.072	0.106	0.054	0.113	0.141	0.091
Commerzbank	0.133	0.218	0.090	0.157	0.202	0.107
Credite Agricole CIB	0.109	0.146	0.090	0.139	0.141	0.135
Danske Bank	0.116	0.105	0.121	0.146	0.092	0.167
Deutsche Bank	0.077	0.137	0.047	0.128	0.157	0.099
Dexia	0.114		0.114	0.153		0.153
Dresdner Bank	0.116	0.125	0.103	0.113	0.121	0.100
DZ Bank	0.144	0.222	0.104	0.175	0.198	0.148
Erste Bank	0.094	0.160	0.061	0.140	0.161	0.114
Fortis	0.161	0.174	0.148	0.180	0.172	0.186
HSBC	0.101	0.161	0.074	0.134	0.164	0.108
HVB	0.124	0.124		0.120	0.120	
ING	0.119	0.166	0.095	0.140	0.162	0.121
JPM	0.082	0.149	0.049	0.117	0.152	0.078
KBC	0.120	0.175	0.092	0.145	0.157	0.131
la Caixa	0.079		0.079	0.091		0.091
LB Baden-Württemberg	0.088	0.134	0.066	0.102	0.124	0.079
LB Berlin	0.119	0.139	0.108	0.132	0.129	0.133
LB Hessen-Thüringen	0.113	0.192	0.073	0.134	0.176	0.083
Natexis	0.179	0.171	0.217	0.183	0.180	0.190
National Bank of Greece	0.126	0.185	0.096	0.143	0.168	0.119
Natixis	0.113	0.153	0.092	0.146	0.167	0.130
Nordea	0.112	0.166	0.085	0.117	0.153	0.081
Nord LB	0.109	0.176	0.076	0.136	0.165	0.103
Pohjola	0.083		0.083	0.080		0.080
Rabobank	0.120	0.211	0.077	0.164	0.194	0.126
RBI	0.108	0.138	0.092	0.120	0.135	0.108
RBS	0.076		0.076	0.089		0.089
Sanpaolo IMI	0.135	0.135		0.126	0.126	
Societe Generale	0.116	0.182	0.083	0.163	0.208	0.124
Svenska Handelsbanken	0.123	0.171	0.100	0.135	0.163	0.112
UBI Banca	0.057		0.057	0.049		0.049
UBS	0.102	0.174	0.066	0.138	0.172	0.099
Unicredit	0.124	0.171	0.101	0.135	0.161	0.114
West LB	0.122	0.167	0.096	0.132	0.156	0.108

Table 9: This table shows the mean and standard deviation of the daily absolute rank changes for the panel banks contributing to the three month Euribor. To make the results comparable accross currencies, we standardize the ranks such that the bank with the highest rank (i.e., highest contribution) has a rank of 1. For example, a rank change of 0.25 means that a bank's rank change corresponds to a quarter of the panel. Our data set contains the reference rate and the underlying contributions, obtained from the European Banking Federation for the time period from January 2005 to June 2012.

Method	Banks	AUD Libor Mean	AUD Libor Std	USD Libor Mean	USD Libor Std	Euribor Mean	Euribor Std
Untrimmed Mean	1	1.459	1.446	0.737	0.891	0.367	0.304
	2	2.474	2.380	1.338	1.622	0.679	0.559
	3	3.277	3.118	1.881	2.278	0.966	0.799
Trimmed Mean	1	1.131	1.275	0.447	0.572	0.172	0.179
	2	2.424	2.421	0.945	1.146	0.349	0.356
	3	3.471	3.407	1.497	1.820	0.536	0.545
Median	1	0.982	1.354	0.270	0.454	0.083	0.239
	2	2.133	2.544	0.655	0.962	0.177	0.383
	3	3.823	3.848	1.138	1.561	0.273	0.465
Random Draw	1	1.109	1.981	0.487	1.028	0.180	0.446
	2	2.433	3.181	0.977	1.684	0.370	0.725
	3	3.480	3.968	1.456	2.029	0.542	0.928

Table 10: This table shows the mean and standard deviation of the potential manipulation impacts for various rate–setting procedures, for the three month AUD Libor, USD Libor and Euribor evaluated for each day. We compare the methodology currently applied (i.e., a trimmed mean), with an untrimmed mean, the median and a random draw. We use the following approach to quantify the manipulation effects for a given methodology: We start out with the observed individual contributions by the panel banks to the final rate. Then, we change the lowest observed contribution, making it equal to the highest observed contribution, for the case of a manipulation by one bank. The difference between the original benchmark rate given the applied rate-setting procedure and the resulting benchmark rate after changing this one contribution is our measure of the potential effect of manipulation. We use the same approach when considering the manipulation incentive for two or three banks, i.e., we set the lowest two (or three) contributions equal to the highest observed contribution. Our data set contains the reference rates and the underlying contributions, obtained from Bloomberg and the European Banking Federation for the time period from January 2005 to June 2012.