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LIBOR Games:
Means, Opportunities and Incentives to Deceive

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Abstract

This paper adopts a game-theoretical approach to analyse the LIBOR fixing mechanism. Several non-zero-sum LIBOR Games are modelled and then solved using a standard Bayes Nash solution. It is shown that collusive behaviour between LIBOR panel banks, or between banks and money market brokers, can lead to LIBOR fixings that deviate from what could be regarded as the true funding costs of the banks. However, collusive behaviour is not a prerequisite for such outcomes. Assuming players (banks) are rational and act out of self-interest, their endowments (such as LIBOR-indexed derivatives portfolios), or the stigma attached by signalling a relatively high funding cost, can provide LIBOR panel banks with sufficient incentives to submit quotes deviating from their actual funding cost. The trimming process, widely regarded as a hurdle for outright and single-handed manipulation, is shown to be overwhelmingly ineffective. Moreover, binding rules or constraints introduced in order to enhance transparency provide disappointing results. In sum, it is argued that the LIBOR games are characterized by an inherent structure whereby banks have the means, opportunity and incentive to submit deceptive quotes, leading to outcomes (LIBOR fixings) that deviate from the true average of the banks funding cost. Banks are given the chance to influence the LIBOR in a direction that is beneficial to them - stemming from the exclusive privilege to be able to play this game, in other words to participate in the LIBOR fixing process.

1. LIBOR Manipulation?

The issue of possible manipulation of the London Interbank Offered Rate (LIBOR) first received media attention when it was raised by Mollenkamp & Whitehouse (2008) in the Wall Street Journal in May 2008. The authors argued that some LIBOR panel banks had deliberately quoted LIBOR rates that were too low to be justified by their credit standing reflected in the credit default swap (CDS) market. Although the article did not claim outright manipulation, it argued that banks 'may have been low-balling their borrowing rates to avoid looking desperate for cash'.

The actual LIBOR fixing mechanism is simple. A designated calculation agent collects the submitted quotes from the individual LIBOR panel banks before noon. The trader or other bank person at the cash desk or treasury submits his or her quote from the bank terminal, and the other banks do the same without being able to see each others' quotes. During a short period, the calculation agent audits and checks the quotes for obvious errors and then conducts the 'trimming' – the omission the highest and lowest quotes (the number which depends on the sample size). Thereafter, the arithmetic mean is calculated, rounded to the specified number of decimals and published at a certain time mid-day (British Bankers Association, 2012).

Although the LIBOR is an observable benchmark, the individually submitted LIBOR quotes do not need to correspond to the actual funding cost faced by the panel banks. The integrity of the LIBOR fixing mechanism is thus based upon the assumption that the banks reveal the truth. The assumption that the LIBOR itself is based upon actual market transactions is in fact central to previous attempt to decompose the LIBOR into current and expected future interest rates, credit and liquidity risk. Decomposing money market risk premia (such as the LIBOR-OIS spread) in the recent literature has almost become synonymous with assessing the effectiveness of central bank policy in dealing with the current global financial crisis.[2]

The contents of the Wall Street Journal article gave support to anecdotal evidence from active market participants, who had been claiming that the LIBOR systematically deviated from observable money market transactions. Already in the early days of the current global financial crisis, numerous market participants began to observe that, despite the LIBOR beginning to rise substantially; it was still significantly lower than where the money market *de facto* appeared to be trading - or at least ought to have been trading had there been enough market liquidity. For instance, traders found it inconceivable that some banks that were practically shut out of interbank funding (such as UBS and several other large European banks) submitted LIBOR quotes at levels well below where the market reportedly was trading. However, the British Bankers Association

[2] See for instance Bank of England, 2007; McAndrews, Sarkar & Wang, 2008; Poskitt, 2011; Schwartz, 2010.

(BBA), which oversees the LIBOR fixing mechanism, took a defensive stance versus these claims and defended the integrity of the process. No evidence of manipulation was found after an internal investigation had been conducted, but the BBA nonetheless promised more governance and scrutiny (British Bankers Association, 2008).

Nonetheless, in 2011, regulators and financial supervisors in several countries began investigating alleged LIBOR manipulation by traders and money market brokers directly or very closely linked to the fixing process. Although the investigations are still ongoing and only some conclusions have been made so far, initial reports pointed two, but interlinked, angles in the investigation process. One related to possible collusion between two or more banks in the LIBOR rate setting process aimed at influencing the fixing in their favour, as this might enable them to surpass the hurdle of the so-called trimming process.[3] The second angle related to the possible pressure put by banks on money market brokers to influence the LIBOR fixing. Thus, third-party voice brokers, acting as middle-men, also came under scrutiny, having possibly conspired with banks, or groups of banks, to influence the LIBOR submissions. Namely, if the money market were to be volatile or illiquid, banks might have the incentive to try to influence what the voice broker signals to the rest of the market. This scenario was discussed by Mackenzie (2012), when describing the dilemma a voice broker can face in favouring one particular bank ahead of others. The relationship-based trader-broker model can be seen as system where both stand to benefit mutually: the broker by following the instructions from his or her largest and most profitable account, and the bank by gaining from the more ‘independent’ status the broker holds in the market by often being better informed and ‘required’ to adhere to anonymity rules.

Although the investigation covers a large number of banks, at the time of writing three (Citibank, UBS and Barclays) have been penalised by financial regulators for attempting to manipulate the LIBOR. As stated by the FSA regarding the financial penalty imposed upon Barclays, the bank had made ‘submissions which formed part of the LIBOR and EURIBOR setting process that took into account requests from Barclays’ interest rate derivatives traders. These trades were motivated by profit and sought to benefit Barclays’ trading positions’. The regulator also stated that the bank had ‘seek to influence the EURIBOR submissions of other banks contributing to the rate setting process’ and ‘reduced its LIBOR submissions during the financial crisis as a result of senior management’s concerns over the negative media comment’. (Financial Services Agency (2011abc); Financial Services Authority (2012); U.S. Commodity Futures Trading Commission (2012))

This paper illustrates how the LIBOR rate setting process, or fixing mechanism, can be analysed from a game-theoretical perspective. It is shown how collusive behaviour between LIBOR panel

[3] COMCO (2012)

banks, or between banks and brokers, can lead to LIBOR fixings that deviate from what could be regarded as the 'true' funding costs of the banks – more widely referred to as a 'manipulated LIBOR'. However, collusive behaviour is not a prerequisite for such outcomes. Instead, LIBOR-indexed derivatives portfolios, or the stigma attached by signalling a relatively high funding cost, can provide LIBOR panel banks with sufficient incentives to submit quotes deviating from their actual funding cost. Hereby, the 'LIBOR games' highlight a fundamental flaw in the LIBOR rate setting process. It can be seen as a structure where players (LIBOR banks) have the means, opportunity and incentive to submit deceptive quotes, resulting in outcomes (LIBOR fixings) deviating from the 'true' bank funding cost. Constraints put in place to hinder such outcomes are shown to be ineffective.

The paper proceeds as follows. In Section 2, three different cooperative and non-cooperative 'LIBOR games', where players have incentives in terms of endowments, are modelled and solved using a standard Bayes Nash solution concept. Section 3 introduces a purely non-cooperative game, studying the effect of the stigma attached with submitting a relatively high LIBOR, as well as considering the impact of potential reputational constraints or requirements to trade at submitted quotes. Section 4 concludes.

2. Three Single-Period LIBOR Games

2.1. Assumptions and Rules of the Games

i) Players

Consider 3 different single-period games - henceforth called the 'LIBOR Base Game', the 'LIBOR Collusion Game' and the 'LIBOR Bribe Game' respectively. In each game, there are 4 players (i.e. LIBOR panel banks), the smallest number of players in order to account for the so-called trimming mechanism:

$$P = \{P_i, P_j, P_k, P_l\} \tag{1}$$

ii) Endowments

Players start with an endowment (denoted 'E'):

$$E_i \in \{E^+, E^0, E^-\}, \tag{2}$$

where $E^+>0$, $E^0=0$ and $E^-<0$. The endowment is a derivatives portfolio benchmarked against the LIBOR. For the sake of argument, let us simply assume that a player with a positive endowment (E^+) benefits from a high LIBOR, players with E^- from a low LIBOR and players with no endowment (E^0) are indifferent (see Appendix A for a more thorough financial interpretation of the endowment).

iii) The Money Market

All players face the same bank funding cost, denoted ‘M’ (where M is a unique number > 0). At t_0, the interbank money market trades at M, and M is equivalent to the previous day’s LIBOR fixing ($L_{F(t0)}$).

In the LIBOR Base Game and the LIBOR Collusion Game, M is common knowledge. In the LIBOR Bribe Game, however, M is uncertain and can be any number within a range $[M^L, M^H]$, where $M^L \leq M \leq M^H$. Let it also be that $M^L = M - \alpha$, and $M^H = M + \alpha$.

iv) The LIBOR Fixing

Most importantly though, the LIBOR is not a market per se, but an average of where the selected panel banks argue the market is. For the LIBOR, banks are asked ‘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?’ The EURIBOR should be ‘the rate at which Euro interbank term deposits are offered by one prime bank to another prime bank within the EMU zone’. (British Bankers Association, 2012; European Banking Federation, 2012ab)

The LIBOR fixing rule states that all players are supposed to submit their true funding cost to the LIBOR fixing mechanism. However, assume all players are able to submit quotes within a range $[M^L, M^H]$, where $M^L \leq M \leq M^H$. Thus, any individual LIBOR quote, L_i (where $L_i \neq M$) can be regarded as a ‘deceptive quote’. Let it also be that $L^M = M$, $L^H = L + \alpha$, and $L^L = M - \alpha$, where $0 < \alpha < M$.

The actual LIBOR fixing mechanism is straight-forward. Players submit their quotes at t_1 without being able to see each others’ quotes. Thereafter, a third party (a designated independent calculation agent) audits and checks the quotes for obvious errors and then conducts the trimming process – the omission of the highest and lowest quotes. Thereafter, the arithmetic mean is calculated and published. The LIBOR fixing (L_F) at t_2 is thus:

$$L_F = \frac{\sum_{i=1}^{4} L_i - max\{Li\} - min\{Li\}}{2} \quad (3)$$

Henceforth, L_F will denote the *expected* LIBOR fixing at t_1.

v) Payoffs

Let us assume that players act out of self-interest and are rational, and that this is common knowledge. In each game, players try to maximize the payoffs from their respective endowments, with the expected payoff function[4] for player P_i at t_1:

$$\pi_i = E_i(L_F - M) \quad (4)$$

vi) Strategy in the LIBOR Base Game

As the endowment is private knowledge, players set equal probabilities for the other players to have either E^+, E^0 or E^- so that:

$$p(E^+_{n \neq i}) = p(E^0_{n \neq i}) = p(E^-_{n \neq i}) = 1/3 \quad (5)$$

Further, players can choose to submit a 'high' LIBOR quote (L^H), a 'fair' LIBOR quote (L^M) or a 'low' LIBOR quote (L^L):

$$S_i = \{L^H, L^M, L^L\} \quad (6)$$

Let it also be that player P_i *only* submits a quote ≠ M if there is a marginal benefit in doing so, with the optimal strategy being:

$$s_i^* = \begin{cases} L^H, \ \pi_i(L^H) > \pi_i(L^L) \cap \ \pi_i(L^H) > \pi_i(L^M) \\ L^M, \ \pi_i(L^M) \geq \pi_i(L^H) \cap \ \pi_i(L^M) \geq \pi_i(L^L) \\ L^L, \ \pi_i(L^L) > \pi_i(L^H) \cap \ \pi_i(L^L) > \pi_i(L^M) \end{cases} \quad (7)$$

Thus, player P_i sets the probability z_j^H of player P_j playing high if $s_j^* = L^H$, z_j^M if $s_j^* = L^M$ and z_j^L if $s_j^* = L^L$:

[4] See Appendix A

$$
\begin{aligned}
z_{n\neq i}^{H} &= Prob\{s_{n\neq i}^{*}, L_{n\neq i}^{H}\}\\
z_{n\neq i}^{M} &= Prob\{s_{n\neq i}^{*}, L_{n\neq i}^{M}\}\\
z_{n\neq i}^{L} &= Prob\{s_{n\neq i}^{*}, L_{n\neq i}^{L}\}
\end{aligned} \tag{8}
$$

Figure 1: Time Line of Event (LIBOR Base Game)

t_0	t_1	t_2
The endowment of each player is known. The knowledge is private.	*Each player chooses a strategy and submits a LIBOR quote to maximize his expected payoff.*	*The LIBOR fixing is calculated and revealed, as are the individual quotes. The payoffs are calculated.*

vii) Strategy in the LIBOR Collusion Game

In the LIBOR Collusion Game, let us assume that the endowment is no longer private, but 'semi-private' information. To be precise, player P_i (with $E^{\neq 0}$) knows that the endowment of player P_j is $E_j = E_i \neq 0$, and they decide to collude by submitting identical quotes. Hence:

$$
p(E_{n\neq i,j}^{+}) = p\left(E_{n\neq i,j}^{0}\right) = p\left(E_{n\neq i,j}^{-}\right) = 1/3 \tag{9}
$$

Player P_i (with E^0) has nothing to gain by colluding, giving the following strategy options for the players:

$$
S_i^C = \{L^{H(C)}, L^M, L^{L(C)}\} \tag{10}
$$

Like in the LIBOR Base Game, let it also be that player P_i only submits a quote ≠ M if there is a marginal benefit in doing so, with the optimal strategy being:

$$
s(C)_i^* = \begin{cases} L_C^H, & \pi_i\left(L^{H(C)}\right) > \pi_i\left(L^{L(C)}\right) \cap \ \pi_i\left(L^{H(C)}\right) > \pi_i(L^M) \\ L^M, & \pi_i(L^M) \geq \pi_i\left(L^{H(C)}\right) \cap \ \pi_i(L^M) \geq \pi_i\left(L^{L(C)}\right) \\ L_C^L, & \pi_i\left(L^{L(C)}\right) > \pi_i\left(L^{H(C)}\right) \cap \ \pi_i\left(L^{L(C)}\right) > \pi_i(L^M) \end{cases} \tag{11}
$$

Also, player P_i sets the probability z_j^H of player P_j playing high if $s_j^* = L^H$, z_j^M if $s_j^* = L^M$ and z_j^L if $s_j^* = L^L$:

$$
\begin{aligned}
z_{n\neq i}^{H} &= Prob\{s_{n\neq i}^{*}, L_{n\neq i}^{H}\}\\
z_{n\neq i}^{M} &= Prob\{s_{n\neq i}^{*}, L_{n\neq i}^{M}\}\\
z_{n\neq i}^{L} &= Prob\{s_{n\neq i}^{*}, L_{n\neq i}^{L}\}
\end{aligned} \tag{12}
$$

Figure 2: Time Line of Events (LIBOR Collusion Game)

t_0	t_1	t_2
The endowment of each player is known, and semi-private. Players Pi and Pj (with $E_j = E_i \neq 0$) know each others' endowment, but not that of the others.	*Each player chooses a strategy (with possible collusion) and submits a LIBOR quote to the calculation agent to maximize his expected payoff.*	*The LIBOR fixing is calculated and revealed, as are the individual quotes. Payoffs are calculated.*

viii) Strategy in the LIBOR Bribe Game

In the LIBOR Bribe Game, the endowment is private knowledge and collusion with another player is not possible. Let us assume that players sets equal probabilities for the other players to have either E^+, E^0 or E^- so that:

$$p(E^+_{n\neq i}) = p(E^0_{n\neq i}) = p(E^-_{n\neq i}) = 1/3 \tag{13}$$

However, in this game, all players know that M can be any number within a range [M^L, M^H], where $M^L \leq M \leq M^H$. Further, let us assume that there is a third party (money market) broker that is better informed, from whom the precise level of M can be obtained. This third party can be bribed by player P_i to signal a deceptive level of M. In practice, the bribe by a bank could also simply be a threat to cease doing business with the broker and go to a competitor. As such, a bribe, or treat, might put the broker in an awkward position as his revenue depends not only on his long-term reputation of being fair and objective, but also on the trading volume of often just a few trading accounts. Therefore, a bribe or treat can work to cements a strong relationship. From the broker's perspective, the best source of information normally comes from the most active banks, which normally also are the most active trading banks in LIBOR-related instruments. The strategy options when bribes are allowed become:

$$S_i^B = \{L^{H(B)}, L^H, L^M, L^{L(B)}, L^L\} \tag{14}$$

Let it also be that player P_i *only* submits a quote ≠ M if there is a marginal benefit in doing so, with the optimal strategy being:

$$
s(B)_i^* = \begin{cases} L^{H(B)},\ \pi_i\left(L^{H(B)}\right) > \pi_i(L^H) \cap\ \pi_i\left(L^{H(B)}\right) > \pi_i(L^M) \cap \\ \quad \pi_i\left(L^{H(B)}\right) > \pi_i\left(L^{L(B)}\right) \cap\ \pi_i\left(L^{H(B)}\right) > \pi_i(L^L) \\ L^H,\ \pi_i(L^H) > \pi_i\left(L^{H(B)}\right) \cap\ \pi_i(L^H) > \pi_i(L^M) \cap \\ \quad \pi_i(L^H) > \pi_i\left(L^{L(B)}\right) \cap\ \pi_i(L^H) > \pi_i(L^L) \\ L^M,\ \pi_i(L^M) \geq \pi_i\left(L^{H(B)}\right) \cap\ \pi_i(L^M) \geq \pi_i(L^H) \cap \\ \quad \pi_i(L^M) \geq \pi_i\left(L^{L(B)}\right) \cap\ \pi_i(L^M) \geq \pi_i(L^L) \\ L^{L(B)},\ \pi_i\left(L^{L(B)}\right) > \pi_i\left(L^{H(B)}\right) \cap\ \pi_i\left(L^{L(B)}\right) > \pi_i(L^H) \cap \\ \quad \pi_i\left(L^{L(B)}\right) > \pi_i(L^M) \cap\ \pi_i\left(L^{L(B)}\right) > \pi_i(L^L) \\ L^L,\ \pi_i(L^L) > \pi_i\left(L^{H(B)}\right) \cap\ \pi_i(L^L) > \pi_i(L^H) \cap \\ \quad \pi_i(L^L) > \pi_i(L^M) \cap\ \pi_i(L^L) > \pi_i\left(L^{L(B)}\right) \end{cases} \tag{15}
$$

Further, player P_i sets the probability z_j^H of player P_j playing high if $s_j^* = L^H$, z_j^M if $s_j^* = L^M$ and z_j^L if $s_j^* = L^L$:

$$
\begin{aligned}
z_{n\neq i}^H &= Prob\{s(B)_{n\neq i}^*, L_{n\neq i}^{H(B)}\} \\
z_{n\neq i}^M &= Prob\{s(B)_{n\neq i}^*, L_{n\neq i}^{H}\} \\
z_{n\neq i}^L &= Prob\{s(B)_{n\neq i}^*, L_{n\neq i}^{M}\} \\
z_{n\neq i}^L &= Prob\{s(B)_{n\neq i}^*, L_{n\neq i}^{L(B)}\} \\
z_{n\neq i}^L &= Prob\{s(B)_{n\neq i}^*, L_{n\neq i}^{L}\}
\end{aligned} \tag{16}
$$

Figure 3: Time Line of Events (LIBOR Bribe Game)

t_0	t_1	t_2
The endowment of each player is known. The knowledge is private.	*Each player chooses a strategy (with a possible bribe) and submits a LIBOR quote to the calculation agent to maximize his expected payoff.*	*The LIBOR fixing is calculated and revealed, as are the individual quotes. The payoffs are calculated.*

2.2. Outcomes of the Single-Period LIBOR Games

If player P_i assumes all other players will submit quotes equal to M, the trimming process is effective, as any quote ≠ M will be omitted and the expected LIBOR fixing will be equal to M. If, on the other hand, player P_i believes that players might have underlying incentives to deceive, the expected LIBOR fixing depends on the probabilities he sees for each possible outcome. Assuming that all players act out of self-interest and are rational, and that this is common knowledge, we can work out the best strategy given each endowment. By using a Bayes Nash solution concept for these games, we can see how the LIBOR fixings can differ from M, as it depends on the expected strategy of each of the four players (see Appendix B for more thorough explanation).

i) Outcome of the LIBOR Base Game

In all three LIBOR games, each player has the means and opportunity to submit a deceptive LIBOR quote, as a result of the fixing mechanism and by having the exclusively privilege of being allowed to play the game.

However, a deceptive quote (i.e. where $L_i \neq M$) will only be submitted if a player has the *incentive* to do so, i.e. if $E_i \neq 0$. This is intuitive, as players expect that not only themselves, but also the others, are rational and will act out of self-interest. As each player knows that, on average, one other player will choose the same strategy as himself, the trimming process does not act as a hindrance to submit a deceptive quote. It is irrelevant which one of the two players will be omitted through the trimming process, as one of them will still have an impact.

As a result, the optimal strategy for players with $E \neq 0$ is submitting deceptive quotes with the aim to skew the LIBOR fixing in their favour:

$$
\begin{aligned}
s_i^*(E_i^+) &= L^H \\
s_i^*(E_i^0) &= L^M \qquad (17) \\
s_i^*(E_i^-) &= L^L
\end{aligned}
$$

The expected payoffs are:

$$
\begin{aligned}
\pi_i^*(E_i^+, L_i^H) &= \frac{1}{3}\alpha E \\
\pi_i^*(E_i^0, L_i^M) &= 0 \qquad (18) \\
\pi_i^*(E_i^-, L_i^L) &= \frac{1}{3}\alpha E
\end{aligned}
$$

The expected LIBOR fixing for players with $E \neq 0$ hence deviates from M:

$$
\begin{aligned}
\overline{L}_F(E_i^+, L_i^H) &= M + \frac{1}{3}\alpha \\
\overline{L}_F(E_i^0, L_i^M) &= M \qquad (19) \\
\overline{L}_F(E_i^-, L_i^L) &= M - \frac{1}{3}\alpha
\end{aligned}
$$

ii) Outcome of the LIBOR Collusion Game

In the LIBOR Collusion Game, player P_i (with $E^{\neq 0}$) knows that the endowment of player P_j is $E_j = E_i \neq 0$. Both players know that they are better off colluding by agreeing to play the same strategy at t_1. This alters the probability set as Player P_i now knows the strategy of player P_j with certainty.

The expected payoff increases for players with $E^{\neq 0}$. Player P_i (with E^0) has nothing to gain by colluding, and his strategy remains to submit L_i=M:

$$\begin{aligned} s_i^*(E_i^+, C) &= L^{H(C)} \\ s_i^*(E_i^0, C) &= L^M \\ s_i^*(E_i^-, C) &= L^{L(C)} \end{aligned} \tag{20}$$

The expected payoff increases for players involved in collusion:

$$\begin{aligned} \pi_i^*(E_i^+, C) &= \frac{13}{18}\alpha E \\ \pi_i^*(E_i^0, C) &= 0 \\ \pi_i^*(E_i^-, C) &= \frac{13}{18}\alpha E \end{aligned} \tag{21}$$

Likewise, the expected LIBOR fixing for players with $E^{\neq 0}$ deviates more from M as the likelihood of deceptive LIBOR quotes has increased:

$$\begin{aligned} \overline{L}_F(E_i^+, C) &= M + \frac{13}{18}\alpha \\ \overline{L}_F(E_i^0, C) &= M \\ \overline{L}_F(E_i^-, C) &= M - \frac{13}{18}\alpha \end{aligned} \tag{22}$$

iii) Outcome of the LIBOR Bribe Game

From the LIBOR Base Game, we know that player P_i knows that players with E^+ will always play high, players with E^- will always play low and players with E^0 will always play fair. However, from the assumptions we know that player P_i *only* submits a quote ≠ M if there is a marginal benefit in doing so. If the level of M is *uncertain*, players with E^0 will therefore have an incentive to get the opinion from the better informed third party broker (who in this case can be bribed).

However, player P_i thus knows that one player – on average – can be influenced by the signal sent from the broker, as players with E^0 will always play fair (M) unless he believes the rate might be at another level. This can be achieved by paying a bribe (B) to the broker for him to signal that M, in fact, is at the higher or lower end of the scale $M^L \leq M \leq M^H$. Thus, for players with $E^{\neq 0}$, bribing the broker will be rational if the cost of the bribe is sufficiently low ($B < 19\alpha E/27$), thereby ensuring that neutral players, unintentionally, will submit deceptive quotes. Thus, the optimal strategies are:

$$s_i^*(E_i^+, B) = \begin{cases} L^{H(B)}, & B < \frac{19}{27}\alpha E \\ L^H, & B \geq \frac{19}{27}\alpha E \end{cases}$$

$$s_i^*(E_i^0, B) = L^M \tag{23}$$

$$s_i^*(E_i^-, B) = \begin{cases} L^{L(B)}, & B < \frac{19}{27}\alpha E \\ L^L, & B \geq \frac{19}{27}\alpha E \end{cases}$$

The expected payoffs:

$$\pi_i^*(E_i^+, B) = \begin{cases} \frac{19}{27}\alpha E - B, & B < \frac{19}{27}\alpha E \\ \frac{1}{3}\alpha E, & B \geq \frac{19}{27}\alpha E \end{cases}$$

$$\pi_i^*(E_i^0, B) = 0 \tag{24}$$

$$\pi_i^*(E_i^-, B) = \begin{cases} \frac{19}{27}\alpha E - B, & B < \frac{19}{27}\alpha E \\ \frac{1}{3}\alpha E, & B \geq \frac{19}{27}\alpha E \end{cases}$$

As a result, the expected LIBOR fixing for players with $E^{\neq 0}$ deviates *more* from M compared to the LIBOR Base Game if the cost of the bribe is low:

$$\bar{L}_F(E_i^+, B) = \begin{cases} M + \frac{19}{27}\alpha, & B < \frac{19}{27}\alpha E \\ M + \frac{1}{3}\alpha, & B \geq \frac{19}{27}\alpha E \end{cases}$$

$$\bar{L}_F(E_i^0, B) = M \tag{25}$$

$$\bar{L}_F(E_i^-, B) = \begin{cases} M - \frac{19}{27}\alpha, & B < \frac{19}{27}\alpha E \\ M - \frac{1}{3}\alpha, & B \geq \frac{19}{27}\alpha E \end{cases}$$

3. A LIBOR Game with Reputational Constraint and Stigma Incentive

Let us now disregard the possibility of collusion and bribes, and return to a situation where the endowments are private knowledge and M both public knowledge and certain. However, here we introduce a new constraint and incentive involving reputation and stigma.

3.1. Assumptions and Rules of the Game

i) Assumptions

At the outset, the assumptions are identical to the LIBOR Base Game, where the 4 players start the game with an endowment that is private knowledge. The payoff from this endowment is:

$$\pi_i(E) = E_i(L_F - M) \tag{26}$$

ii) Reputational Constraint

However, in this game, there is a reputational constraint facing all players. This mechanism is put in place to prevent players from submitting deceptive LIBOR quotes, and thus giving them an incentive to adhere to 'fair play'. The payoff from the reputational constraint (ρ) is written as:

$$\pi_i(\rho) = \left(\sum_{j \neq i} |L_j - M| - 3|L_i - M|\right)\rho \tag{27}$$

Hence, under this arrangement, a player submitting a LIBOR quote $L_i \neq M$ is subject to a payoff consisting of two parts and equalling the sum of profits from others' deception and the loss from their own deception. From a bank's perspective, the constraint could be interpreted as follows:

submitting a deceptive quote might, if discovered, result in less client business, legal costs of being under regulatory investigation or even the risk of being excluded from the panel altogether and being replaced by another bank. Likewise, if only other panel banks decide to deceive, the bank playing fair will receive a reputational boost at the expense of the others.

The constraint could also be interpreted as affecting only the trading desk or treasury, if they were required to commit to their quotes in 'reasonable market size', where a deceptive quote would be exploited monetarily by all other LIBOR panel banks (i.e. similar to a reputational loss). Likewise, there would an immediate trading gain should others decide to submit deceptive LIBOR quotes.

iii) Stigma Incentive

The second new variable is the 'stigma' (denoted as 'σ'):

$$\pi_i(\sigma) = \left(\frac{\sum_{j=1}^{4} L_j}{4} - L_i\right)\sigma, \qquad (28)$$

According to the British Bankers Association (2012), LIBOR quotes are supposed to reflect 'where the bank can fund itself in the interbank market'. Therefore, an individual quote above the average of the panel quotes might be interpreted as a signal that the bank has funding problems relative to the others. Likewise, a lower than average quote would signal that the bank is in relatively good shape – as individually submitted LIBOR quotes are visible to the whole market, not only to the other LIBOR panel banks, after the fixing. The stigma incentive, thus, rewards players submitting a below-average quote – regardless of the actual LIBOR fixing.

iv) Payoff function

This LIBOR game involves a trade-off between the endowment and the different constraints, and the conflicting incentives this can result in. The payoff function facing each player is:

$$\pi_i(E, \rho, \sigma) = \pi_i(E) + \pi_i(\rho) + \pi_i(\sigma) \qquad (29)$$

v) Strategy of the Game

Let us assume that players sets equal probabilities for the other players to have either E^+, E^0 or E^- so that:

$$p(E^+_{n\neq i}) = p(E^0_{n\neq i}) = p(E^-_{n\neq i}) = 1/3 \qquad (30)$$

Further, players can choose to submit a 'high' LIBOR quote (L^H), a 'fair' LIBOR quote (L^M) or a 'low' LIBOR quote (L^L):

$$S_i = \{L^H, L^M, L^L\} \tag{31}$$

Let it also be that player P_i *only* submits a quote ≠ M if there is a marginal benefit in doing so, with the optimal strategy being:

$$s_i^*(E,\rho,\sigma) = \begin{cases} L^H, \ \pi_i(L^H) > \pi_i(L^L) \cap \ \pi_i(L^H) > \pi_i(L^M) \\ L^M, \ \pi_i(L^M) \geq \pi_i(L^H) \cap \ \pi_i(L^M) \geq \pi_i(L^L) \\ L^L, \ \pi_i(L^L) > \pi_i(L^H) \cap \ \pi_i(L^L) > \pi_i(L^M) \end{cases} \tag{32}$$

Thus, player P_i sets the probability z_j^H of player P_j playing high if $s_j^* = L^H$, z_j^M if $s_j^* = L^M$ and z_j^L if $s_j^* = L^L$:

$$\begin{aligned} z_{n\neq i}^H &= Prob\{s_{n\neq i}^*, L_{n\neq i}^H\} \\ z_{n\neq i}^M &= Prob\{s_{n\neq i}^*, L_{n\neq i}^M\} \\ z_{n\neq i}^L &= Prob\{s_{n\neq i}^*, L_{n\neq i}^L\} \end{aligned} \tag{33}$$

Figure 4: Time Line of Events (LIBOR Game with Reputation/Stigma)

t_0	t_1	t_2
The endowment of each player is known (but not those of the others) Constraints and incentives are announced.	*Each player chooses a strategy and submits a LIBOR quote to the calculation agent to maximize his expected payoff subject to constraints and incentives.*	*The LIBOR fixing is calculated and revealed, as are the individual quotes. The payoffs are calculated.*

3.2. Outcomes of the LIBOR Reputation/Stigma Game

Let us consider the two new variables in turn. At the outset, we know that the optimal strategy of players with E^0 is to play 'fair'. However, if the reputational constraint is large enough ($\rho \geq E/9$), players with $E^{\neq 0}$ will also choose to play 'fair'. Thus, the expected outcomes of the game will depend on the ratio between ρ and E.

The stigma incentive has an impact if $\sigma > 0$, as players with E^0 now also will have the incentive to submit deceptive quotes, namely low quotes. The expected payoff matrix changes, as players take into account that the optimal strategy of players with E^0 is now to play low. Under this scenario, fair play is not an optimal strategy, and the expected LIBOR decreases. However, above a certain σ-ratio, even players with E^+ will opt to play 'low' as the benefit of submitting a high quote to maximize the profit of the endowment is outweighed by the stigma of being perceived as a player with funding difficulties.

For {ρ =0 ∩ σ =0}, the outcomes are identical to that of the LIBOR Base Game. However, for {ρ >0 ∩ σ > 0} and again using the Bayes Nash solution concept as in the previous 3 games, we get 6 different equilibria, as the different thresholds where players would choose to change strategy yield different 'scenarios' with altered probability distribution. Each equilibrium has a different set of optimal strategies, expected payoffs and expected LIBOR fixings:

$$s_i^*(E_i^+,\rho,\sigma) = \begin{cases} L^H, & \left(0<\rho<\frac{1}{9}E\right)\cap(\sigma<4\rho) \\ L^H, & \left(4\rho\le\sigma<4\rho+\frac{4}{9}E\right)\cap\left(0<\rho<\frac{1}{9}E\right) \\ L^M, & \left(4\rho-\frac{4}{9}E\le\sigma<4\rho\right) \\ L^M, & \left(4\rho\le\sigma<4\rho+\frac{4}{9}E\right) \\ L^L, & \left(\sigma\ge 4\rho+\frac{4}{9}E\right) \\ L^M, & \left(\sigma<4\rho-\frac{4}{9}E\right) \end{cases}$$

$$s_i^*(E_i^0,\rho,\sigma) = \begin{cases} L^M, & \left(0<\rho<\frac{1}{9}E\right)\cap(\sigma<4\rho) \\ L^L, & \left(4\rho\le\sigma<4\rho+\frac{4}{9}E\right)\cap\left(0<\rho<\frac{1}{9}E\right) \\ L^M, & \left(4\rho-\frac{4}{9}E\le\sigma<4\rho\right) \\ L^L, & \left(4\rho\le\sigma<4\rho+\frac{4}{9}E\right) \\ L^L, & \left(\sigma\ge 4\rho+\frac{4}{9}E\right) \\ L^M, & \left(\sigma<4\rho-\frac{4}{9}E\right) \end{cases} \qquad (34)$$

$$s_i^*(E_i^-,\rho,\sigma) = \begin{cases} L^L, & \left(0<\rho<\frac{1}{9}E\right)\cap(\sigma<4\rho) \\ L^L, & \left(4\rho\le\sigma<4\rho+\frac{4}{9}E\right)\cap\left(0<\rho<\frac{1}{9}E\right) \\ L^L, & \left(4\rho-\frac{4}{9}E\le\sigma<4\rho\right) \\ L^L, & \left(4\rho\le\sigma<4\rho+\frac{4}{9}E\right) \\ L^L, & \left(\sigma\ge 4\rho+\frac{4}{9}E\right) \\ L^M, & \left(\sigma<4\rho-\frac{4}{9}E\right) \end{cases}$$

$$
\pi_i^*(E_i^+,\rho,\sigma) = \begin{cases} \alpha(\frac{1}{3}E - \rho - \frac{3}{4}\sigma)\,, & \left(0 < \rho < \frac{1}{9}E\right) \cap (\sigma < 4\rho) \\ \alpha(-\frac{1}{27}E - \sigma)\,, & \left(4\rho \le \sigma < 4\rho + \frac{4}{9}E\right) \cap (0 < \rho < \frac{1}{9}E) \\ \alpha\left(-\frac{4}{27}E + \rho - \frac{1}{4}\sigma\right), & \left(4\rho - \frac{4}{9}E \le \sigma < 4\rho\right) \\ \alpha\left(-\frac{14}{27}E + 2\rho - \frac{1}{2}\sigma\right), & \left(4\rho \le \sigma < 4\rho + \frac{4}{9}E\right) \\ \alpha(-E), & \left(\sigma \ge 4\rho + \frac{4}{9}E\right) \\ 0, & \left(\sigma < 4\rho - \frac{4}{9}E\right) \end{cases}
$$

$$
\pi_i^*(E_i^0,\rho,\sigma) = \begin{cases} 2\alpha\rho, & \left(0 < \rho < \frac{1}{9}E\right) \cap (\sigma < 4\rho) \\ \alpha(\frac{1}{2}\sigma)\,, & \left(4\rho \le \sigma < 4\rho + \frac{4}{9}E\right) \cap (0 < \rho < \frac{1}{9}E) \\ \alpha(\rho - \frac{1}{4}\sigma), & \left(4\rho - \frac{4}{9}E \le \sigma < 4\rho\right) \\ \alpha(-\rho + \frac{1}{4}\sigma), & \left(4\rho \le \sigma < 4\rho + \frac{4}{9}E\right) \\ 0, & \left(\sigma \ge 4\rho + \frac{4}{9}E\right) \\ 0, & \left(\sigma < 4\rho - \frac{4}{9}E\right) \end{cases} \qquad (35)
$$

$$
\pi_i^*(E_i^-,\rho,\sigma) = \begin{cases} \alpha(\frac{1}{3}E - \rho + \frac{3}{4}\sigma)\,, & \left(0 < \rho < \frac{1}{9}E\right) \cap (\sigma < 4\rho) \\ \alpha(\frac{19}{27}E + \frac{1}{2}\sigma)\,, & \left(4\rho \le \sigma < 4\rho + \frac{4}{9}E\right) \cap (0 < \rho < \frac{1}{9}E) \\ \alpha(\frac{13}{27}E - 2\rho + \frac{1}{2}\sigma), & \left(4\rho - \frac{4}{9}E \le \sigma < 4\rho\right) \\ \alpha(\frac{23}{27}E - \rho + \frac{1}{24}\sigma), & \left(4\rho \le \sigma < 4\rho + \frac{4}{9}E\right) \\ \alpha(E), & \left(\sigma \ge 4\rho + \frac{4}{9}E\right) \\ 0, & \left(\sigma < 4\rho - \frac{4}{9}E\right) \end{cases}
$$

$$\overline{L}_F(E_i^+,\rho,\sigma)=\begin{cases} M+\frac{1}{3}\alpha, & \left(0<\rho<\frac{1}{9}E\right)\cap(\sigma<4\rho) \\ M-\frac{1}{27}\alpha, & \left(4\rho\leq\sigma<4\rho+\frac{4}{9}E\right)\cap(0<\rho<\frac{1}{9}E) \\ M-\frac{4}{27}\alpha, & \left(4\rho-\frac{4}{9}E\leq\sigma<4\rho\right) \\ M-\frac{14}{27}\alpha, & \left(4\rho\leq\sigma<4\rho+\frac{4}{9}E\right) \\ M-\alpha, & \left(\sigma\geq4\rho+\frac{4}{9}E\right) \\ M, & \left(\sigma<4\rho-\frac{4}{9}E\right) \end{cases}$$

$$\overline{L}_F(E_i^0,\rho,\sigma)=\begin{cases} M, & \left(0<\rho<\frac{1}{9}E\right)\cap(\sigma<4\rho) \\ M-\frac{19}{27}\alpha, & \left(4\rho\leq\sigma<4\rho+\frac{4}{9}E\right)\cap(0<\rho<\frac{1}{9}E) \\ M-\frac{4}{27}\alpha, & \left(4\rho-\frac{4}{9}E\leq\sigma<4\rho\right) \\ M-\frac{23}{27}\alpha, & \left(4\rho\leq\sigma<4\rho+\frac{4}{9}E\right) \\ M-\alpha, & \left(\sigma\geq4\rho+\frac{4}{9}E\right) \\ M, & \left(\sigma<4\rho-\frac{4}{9}E\right) \end{cases} \tag{36}$$

$$\overline{L}_F(E_i^-,\rho,\sigma)=\begin{cases} M-\frac{1}{3}\alpha, & \left(0<\rho<\frac{1}{9}E\right)\cap(\sigma<4\rho) \\ M-\frac{19}{27}\alpha, & \left(4\rho\leq\sigma<4\rho+\frac{4}{9}E\right)\cap(0<\rho<\frac{1}{9}E) \\ M-\frac{13}{27}\alpha, & \left(4\rho-\frac{4}{9}E\leq\sigma<4\rho\right) \\ M-\frac{23}{27}\alpha, & \left(4\rho\leq\sigma<4\rho+\frac{4}{9}E\right) \\ M-\alpha, & \left(\sigma\geq4\rho+\frac{4}{9}E\right) \\ M, & \left(\sigma<4\rho-\frac{4}{9}E\right) \end{cases}$$

Interpreting each outcome in turn, we can see that under Scenario I, where:

$$\left(0<\rho<\tfrac{1}{9}E\right)\cap(\sigma<4\rho), \tag{37}$$

the reputational constraint is not large enough to prevent players from submitting deceptive LIBOR quotes. Likewise, the stigma constraint does not tempt players with $E^{\neq 0}$ to submit ‘low’ quotes. The expected LIBOR is identical to that of the outcome of the LIBOR Base game.

Under Scenario II, where:

$$\left(4\rho \leq \sigma < 4\rho + \tfrac{4}{9}E\right) \cap \left(0 < \rho < \tfrac{1}{9}E\right), \tag{38}$$

the reputational constraint is still fairly small, but the stigma constraint has increased – prompting players with E^0 to switch strategy, namely to play 'low' instead of 'fair'. The expected LIBOR falls as the probability of low submissions increases.

Scenario III, where:

$$\left(4\rho - \tfrac{4}{9}E \leq \sigma < 4\rho\right), \tag{39}$$

implies that the reputational constraint is significant. In fact, it is large enough for all players to 'initially consider playing fair'. However, the stigma constraint is also significant enough for players with E^- to play low (boosted by the payoff from the endowment), but for not enough for others to deviate from their fair quotes. The expected LIBOR equilibrium is slightly below M.

Scenario IV, where:

$$\left(4\rho \leq \sigma < 4\rho + \tfrac{4}{9}E\right), \tag{40}$$

also implies that the reputational constraint is large enough for players to initially consider playing fair. However, the stigma constraint is now large enough for players with $E^{\leq 0}$ to play low, whereas players with E^+ stick to their fair quotes. The expected LIBOR equilibrium is lower than under Scenario III.

Under Scenario V, where:

$$\left(\sigma \geq 4\rho + \tfrac{4}{9}E\right), \tag{41}$$

the stigma incentive is considerable – inducing all players to submit low LIBOR quotes regardless of their endowments or the reputational constraint. The expected LIBOR fixing reaches its minimum, i.e. M-α.

Thus, Scenario VI where:

$$\left(\sigma < 4\rho - \tfrac{4}{9}E\right), \tag{42}$$

is the only situation where no deceptive quotes can be expected to be submitted. This is when the reputational constraint is large, whereas the stigma constraint is small enough not to give incentive for any players to deviate from the fair quotes. Here, the expected LIBOR always equals M. This could be regarded as the only scenario where the LIBOR fixing process works as intended, namely to reflect the banks' true funding costs.

4. Concluding Discussion

The LIBOR games presented in this paper illustrate that if panel banks have LIBOR-based derivatives portfolios, are rational and act out of self-interest, they not only have the means and opportunity, but also the *incentive* to submit deceptive LIBOR quotes – resulting in a LIBOR fixing no longer reflecting the 'true' funding cost of the panel banks. Should two or more banks collude, or have the opportunity to collude with a money-market voice broker, the likelihood of what we could regard as off-market LIBOR equilibria increases. However, whereas collusion of this kind makes this more likely, and the impact greater, it is by no means a pre-requisite. Because, at the core of the LIBOR games lies the importance of the *belief* each player has about what others will do and how this will affect the optimal strategy. The LIBOR games are not zero-sum games. Instead, LIBOR panel banks, by having the exclusive privilege to play these 'games', are able to influence the LIBOR that is beneficial to them. The trimming process can act as a hindrance for banks to submit deceptive quotes, but is no guarantee in itself as banks should expect others also to act out of self-interest. Deception can thus become the norm, rather than the exception, depending on the various constraints and incentives banks are presented with.

Banks, being profit-maximising and the most frequent users of instruments indexed to the LIBOR, naturally have an interest in the outcome of the LIBOR fixing. LIBOR-indexed derivatives portfolios (called 'endowments' in these games) serve as an incentive to submit deceptive quotes, and these incentives can be seen as having strengthened in tandem with the growth in the derivatives markets linked to the benchmark. The notional amount of outstanding LIBOR-based derivative contracts has now reached astonishing levels; with the BBA estimating that USD 10 trillion of loans and USD 350 trillion of interest rate swaps alone are indexed by the LIBOR (U.S. Commodity Futures Trading Commission, 2012). According to statistics compiled by the Bank for International Settlements (2011), the notional amount of outstanding OTC interest rate derivatives contracts amounted to USD 554 trillion in the first half of 2011. The LIBOR, and its equivalents, are thus the by far most frequently used benchmarks for IRS, FRAs and OTC interest rate options. The annual turnover in the LIBOR-equivalent futures contracts is equally impressive.[5]

Snider & Youle (2009, 2010) base a theory of misreporting incentives upon the individual banks' portfolio exposure to the LIBOR that gives them an incentive to push the benchmark in a particular direction. They study three LIBOR panel banks that are American bank holding companies and thereby required to provide interest rate derivatives and net interest revenue figures in the quarterly Reports on Conditions and Income (Call Reports) to the FDIC. By using the exposure to outstanding interest rate swaps as an approximation, the authors find that during the period there was a clear incentive for the banks to keep a low LIBOR, thereby supplying evidence that panel banks may have acted strategically when submitting their LIBOR quotes. The outcomes of the LIBOR games lend support to this argument.

The 'stigma' of submitting a relatively high funding costs poises another problem with the LIBOR fixing mechanism, as banks inherently have an interest in appearing sound and solid. In theory, the LIBOR should not only reflect current and future interest rate expectations, but also credit and liquidity risk. Should banks face credit and liquidity constrains, these ought to be reflected in the LIBOR submissions and *ceteris paribus* result in a higher LIBOR fixing, as the banks' funding costs increase. As the individual LIBOR submissions are made public, they serve as a snap-snot of the *perceived creditworthiness* of the banks. This signal to the market is important as the funding cost of the bank and its capital and reputation are closely linked.[6] Downgrades by rating agencies are rare events, as are financial statements. The LIBOR, in contrast, is submitted and published daily and can reduce the uncertainty of whether a particular bank faces immediate funding problems or not. The stigma constraint therefore results from the individual LIBOR submissions being common knowledge at the same time as the actual funding cost is private knowledge. This lack of transparency, coupled with the natural desire of banks to appear sound at all times thus works as an incentive to conceal potential funding problems publicly through the LIBOR signalling process. In other words, it works as an incentive to 'low-ball' the LIBOR in similar fashion to the stigma of having to borrow at the discount window from central banks during the early days of the crisis.[7] Submitting a LIBOR quote could signal that the bank is in trouble and thereby having a direct negative impact on the CDS price, bond price, share price and so on, which would yet again affect the short-term funding cost faced by the bank.

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[5] In 2011, the value of Eurodollar futures contracts traded on the CME reached USD 564 trillion. In addition, the turnover in options on Eurodollar futures was USD 193 trillion. The corresponding figures for the EURIBOR futures and options contracts traded on LIFFE were not far off: EUR 241 trillion and EUR 126 trillion respectively. With regards to short sterling futures (the GBP LIBOR futures), the turnover was GBP 58 trillion (Futures Industry Association, 2011).

[6] See for instance Ederington, Yawitz & Roberts (1987).

[7] As this kind of borrowing was openly disclosed, it proved to be a hurdle for banks in the fear that it could have a direct impact on the perceived creditworthiness of an institution.

The outcomes of the LIBOR Games also highlight the conflict of interest that might exist *within* a LIBOR panel bank. Trading desks, for instance, could be more concerned about the payoff resulting from the LIBOR-indexed derivatives portfolios, whereas the Management might put greater emphasis on the 'stigma constraint'. This issue of loose 'Chinese Walls' between departments, where one department might increase the pressure put on the LIBOR submitting entity, has to some degree been confirmed recently in the case between the Japanese FSA against Citigroup and UBS in December 2011, and the UK and US regulators' against Barclays in July 2012.

Individually submitted LIBOR rates are not binding and LIBOR panel banks do not have to commit to their quotes in any way. Instead, the BBA LIBOR rule states that the submitted rate must be formed from that bank's perception of its cost of unsecured funds in the interbank market, i.e. the London Money Market (British Bankers Association, 2012). Likewise, the rules for the Tokyo Interbank Offered Rate (TIBOR) and the Euro Interbank Offered Rate (EURIBOR) do not mention any requirement to act as a market maker at the submitted rate (Japanese Bankers Association, 2012; European Banking Federation, 2012ab). However, regardless if a binding rule exists or not, the reputational damage of some kind of manipulation should not be totally disregarded. Being seen as unfair and putting an own bank's interests ahead of those of the clients can be equally damaging. Moreover, possibly an even more important factor is the informal gentleman agreements about 'fair play' that exist in financial markets, and it would be unreasonable to assume that even traders are not bound by such. Problematically though, agreements such as these tend to break down in a crisis situation.

However, some kind of reputational constraint could, both in theory and in practise, be imposed in order to prevent banks from submitting rates that deviate from their true funding cost. In this paper, the reputational constraint has been modelled similarly to a 'binding rule', making it clear that LIBOR panel banks not only get penalized by submitting deceptive quotes, but also reap the reward in case another bank decides to do so. As such, it resembles a realistic market making scenario where a market maker is eager to avoid quoting a misprice that will be exploited by a market taker, but at the same time hoping for another market maker to do so and thereby exploiting the market making obligation of the latter. It could also be seen as mechanism whereby individual LIBOR quotes are checked against real transaction data. This paper, however, shows that the constraint mechanism might need to be prohibitively high to have the desired effect, namely to prevent LIBOR panel banks from only looking after their own interests.

Appendix A - The Endowment in LIBOR Games

In this paper, the endowment refers to the net portfolio exposure to the LIBOR. In simple terms we are dealing with how much the net present value (NPV) of the portfolio would change given a certain change in the LIBOR (everything else being constant). This could, in other words, relate both to the realised profit and loss for a floating rate settlement today, as well as the change in the market valuation of future floating payments (benchmarked to the LIBOR) stemming from the change in the LIBOR. The easiest way to understand 'E', would be to regard it as the 'delta' or NPV of a LIBOR forward rate agreement (or a Eurodollar futures contract) done in the past. Consider an example where:

$M = L_{F(t0)} =$	1.00%
$\alpha =$	0.10%
$E =$	$10,000

Here, E^+ corresponds to having *sold* 400 Eurodollar futures contracts (having a tick value of USD 25), and E^- to having bought the equivalent amount. In FRA-terms, E^+ would be equivalent of having bought (or paid fixed) approximately USD 400 million worth of 3M LIBOR FRAs – and E^- of having sold (or received fixed) a similar amount.[8]

$L_{F(t0)}$ corresponds to the LIBOR fixing the previous day, which equals M. This rate is used to mark-to-market the outstanding FRA contracts (i.e. at 1.00%) or the Eurodollar futures contracts (i.e. at 99.00).

Assume L_F is not only the LIBOR fixing, but also that the fixing of the outstanding contracts takes place at t_2 (with settlement 2 business days later). The profit or loss stemming from the contracts will not only depend on the contract rate (in other words at what level they were done in the past), but where they will fix. Thus, the payoff from the single-period game will depend on the movement in the LIBOR fixing from t_0 to t_2:

$$\pi_i = E_i\left(L_{F(t2)} - L_{F(t0)}\right) = E_i(L_F - M)$$

As $\alpha = 0.10\%$, LIBOR panel banks can submit 0.90% ($M - \alpha$ = 1.00% - 0.10% = 0.90%), 1.00% or 1.10%. Matrix A2.1 and A2.2 show the expected LIBOR fixings and payoffs from the endowments under these assumptions:

[8] Whereas these amounts might appear large, they are fairly conventional in these particular markets.

Matrix A.1: Expected LIBOR Fixings

LIBOR Base Game	
E^+	1.0333%
E^0	1.0000%
E^-	0.9667%
LIBOR Collusion Game	
E^+	1.0722%
E^0	1.0000%
E^-	0.9278%
LIBOR Bribe Game (B<$704)	
E^+	1.0704%
E^0	1.0000%
E^-	0.9296%

As can be seen, for players with $E^{\neq 0}$, the expected LIBOR fixing always deviates from M in the first three types of games. Under scenarios with collusion or bribes, this deviation is larger.

Matrix A.2: Expected Payoffs from Endowment

LIBOR Base Game	
E^+	$333.00
E^0	$0.00
E^-	$333.00
LIBOR Collusion Game	
E^+	$722.00
E^0	$0.00
E^-	$722.00
LIBOR Bribe Game (B<$704)	
E^+	$704.00
E^0	$0.00
E^-	$704.00

With regards to the expected payoffs from endowments – they are always > 0 for players with $E^{\neq 0}$. This can be seen as a monetary reward for players with portfolios benchmarked against the LIBOR being allowed to play the LIBOR game.

When it comes to the fourth type of game, with reputation and stigma, we get 6 different scenarios. The LBOR always deviates from M, with the exception of Scenario VI, and Scenario I for players with E^0:

Matrix A.3: Expected LIBOR Fixings (Scenarios I-VI)

LIBOR Game with Constraints	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V	Scenario VI
E^+	1.0333%	0.9963%	0.9852%	0.9481%	0.9000%	1.0000%
E^0	1.0000%	0.9296%	0.9852%	0.9148%	0.9000%	1.0000%
E^-	0.9667%	0.9296%	0.9519%	0.9148%	0.9000%	1.0000%

The stigma has a significant impact on the expected payoff structure. Except for under Scenarios I and VI, players with E^+ can always expect a negative payoff from the endowment. Players with E^-, on the other hand, benefit greatly under the same circumstances:

Matrix A.4: Expected Payoffs from Endowment (Scenarios I-VI)

LIBOR Game with Constraints	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V	Scenario VI
E^+	$333.00	-$37.00	-$148.00	-$519.00	-$1,000.00	$0.00
E^0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
E^-	$333.00	$704.00	$481.00	$852.00	$1,000.00	$0.00

Appendix B - Probabilities and Expected LIBOR Outcomes

In the single period LIBOR games, the outcome (both the LIBOR fixing (L_F) and the LIBOR average (L_A)) depend on the strategies of each of the four players. The total number of possible outcomes is K^{N_0}, where K is the number of strategy choices, and N_0 is the total number of players. As the number of players is 4, and the strategy choices 3 (L^H, L^M and L^L), the total number of possible outcomes is $K^{N0} = 3^4 = 81$. Next, we use formula for the number of permutations (P) for a certain outcome:

$$\binom{N_0}{N_1} * \binom{N_1}{N_2} * \binom{N_2}{N_3},$$

where $N_1 = N_0 - U_1$, $N_2 = N_1 - U_2$ and $N_3 = N_2 - U_3$. Let U_1 be the number of the first type of strategy choice (L^H), U_2 the second type (L^M) and U_3 the third type (L^L). We can thus begin to work out the different possible outcomes, and the probabilities for these to occur.

Example 1: Let us work out the probability of precisely one player submitting L^H, two players submitting L^M and one L^L. The number of players is 4 => N_0=4, and the number of different quotes to choose from is 3 => K=3. If we call the number of 'L^H' for U_1, number of 'L^H' for U_2 and number of 'L^L' for U_3, we get probability $p(L^H, 2L^M, L^L) = \binom{4}{3} * \binom{3}{1} * \binom{1}{0}$ / 81 = 4 * 3 * 1 / 81 = 12/81 ≈ 0.1481.

The different LIBOR outcomes and probabilities (p) are summarised in Matrix B.1 (with Example 1 as outcome number 8). The LIBOR average (L_A) and the expected LIBOR fixing (L_F) are in bold, having taken into account the probabilities of each possible outcome and the trimming process omitting the highest and lowest quote:

Matrix B.1: LIBOR Outcomes and Probabilities

Outcome	L^H	L^M	L^L	**P**	***p***	**Max**	**Min**	L_A	L_F
1	4	0	0	1	0.0123	M+α	M+α	M+α	M+α
2	3	1	0	4	0.0494	M+α	M	M+3α/4	M+α
3	3	0	1	4	0.0494	M+α	M-α	M+α/2	M+α
4	2	2	0	6	0.0741	M+α	M	M+α/2	M+α/2
5	2	1	1	12	0.1481	M+α	M-α	M+α/4	M+α/2
6	2	0	2	6	0.0741	M+α	M-α	M	M
7	1	3	0	4	0.0494	M+α	M	M+α/4	M
8	1	2	1	12	0.1481	M+α	M-α	M	M
9	1	1	2	12	0.1481	M+α	M-α	M-α/4	M-α/2
10	1	0	4	4	0.0494	M+α	M-α	M-α/2	M-α
11	0	4	1	1	0.0123	M	M	M	M
12	0	3	4	4	0.0494	M	M-α	M-α/4	M
13	0	2	6	6	0.0741	M	M-α	M-α/2	M-α/2
14	0	1	4	4	0.0494	M	M-α	M-3α/4	M-α
15	0	0	1	1	0.0123	M-α	M-α	M-α	M-α
Sum				81	1.0000			**M**	**M**

Example 2: Consider outcome number 9 in Matrix B.1, where one player submits L^H, one player L^M and two players L^L. The probability of this to happen is $p(L^H,L^M,2L^L))\approx 0.1481$. The trimming process ensures that the highest and the lowest quotes will be omitted, i.e. M+α and M-α, yielding a LIBOR fixing of:

$$L_F=\frac{\sum_{i=1}^{4}L_i-max\{L_i\}-min\{L_i\}}{2}$$
$$=\frac{\big((M+\alpha)+M+(M-\alpha)+(M-\alpha)\big)-(M+\alpha)-(M-\alpha)}{2}=M-\frac{\alpha}{4}$$

The LIBOR average is the simple arithmetic mean of the 4 quotes:

$$L_A=\frac{\sum_{i=1}^{4}L_i}{4}=\frac{\big((M+\alpha)+M+(M-\alpha)+(M-\alpha)\big)}{4}=M-\frac{\alpha}{2}$$

Next, at the outset, we know that $p(E^+)=p(E^0)=p(E^-)=1/3$, and hence $z_i^H=z_i^M=z_i^L=1/3$. However, as player P_i *knows* his own E, he can work out the probabilities and outcomes given each of his own strategy choice, where $z_{n\neq i}^H=z_{n\neq i}^M=z_{n\neq i}^L=1/3$, as shown in Matrix B.2, B.3 and B.4. In other words, if P_i submits L^H, L_A=M+α/4 and L_F= M+α/3; if P_i submits L^M, L_A=M and L_F= M; and if P_i submits L^L, L_A=M-α/4 and L_F= M-α/3. Given his incentives and constraints as expressed in his payoff function, he chooses which strategy gives the best possible expected payoff.

Matrix B.2: P_i submits L^H

Outcome	L^H	L^M	L^L	Permutations	*p*	Max	Min	L_A	L_F
1	3	0	0	1	0.0123	M+α	M+α	M+α	M+α
2	2	1	0	3	0.0494	M+α	M	M+3α/4	M+α
3	2	0	1	3	0.0494	M+α	M-α	M+α/2	M+α
4	1	2	0	3	0.0741	M+α	M	M+α/2	M+α/2
5	1	1	1	6	0.1481	M+α	M-α	M+α/4	M+α/2
6	1	0	2	3	0.0741	M+α	M-α	M	M
7	0	3	0	1	0.0494	M+α	M	M+α/4	M
8	0	2	1	3	0.1481	M+α	M-α	M	M
9	0	1	2	3	0.1481	M+α	M-α	M-α/4	M-α/2
10	0	0	3	1	0.0494	M+α	M-α	M-α/2	M-α
Sum				27	1.0000			**M+α/4**	**M+α/3**

Matrix B.3: P_i submits L^M

Outcome	L^H	L^M	L^L	Permutations	*p*	Max	Min	L_A	L_F
1	3	0	0	1	0.0123	M+α	M	M+3α/4	M+α
2	2	1	0	3	0.0494	M+α	M	M+α/2	M+α/2
3	2	0	1	3	0.0494	M+α	M-α	M+α/4	M+α/2
4	1	2	0	3	0.0741	M+α	M	M+α/4	M
5	1	1	1	6	0.1481	M+α	M-α	M	M
6	1	0	2	3	0.0741	M+α	M-α	M-α/4	M-α/2
7	0	3	0	1	0.0494	M+α	M	M	M
8	0	2	1	3	0.1481	M+α	M-α	M-α/4	M
9	0	1	2	3	0.1481	M+α	M-α	M-α/4	M-α/2
10	0	0	3	1	0.0494	M+α	M-α	M-α/2	M-α
Sum				27	1.0000			**M**	**M**

Matrix B.4: P_i submits L^L

Outcome	L^H	L^M	L^L	Permutations	*p*	Max	Min	L_A	L_F
1	3	0	0	1	0.0123	M+α	M-α	M+α/2	M+α
2	2	1	0	3	0.0494	M+α	M-α	M+α/4	M+α/2
3	2	0	1	3	0.0494	M+α	M-α	M	M
4	1	2	0	3	0.0741	M+α	M-α	M	M
5	1	1	1	6	0.1481	M+α	M-α	M-α/4	M-α/2
6	1	0	2	3	0.0741	M+α	M-α	M-α/2	M-α
7	0	3	0	1	0.0494	M	M-α	M-α/4	M
8	0	2	1	3	0.1481	M	M-α	M-α/2	M-α/2
9	0	1	2	3	0.1481	M	M-α	M-3α/4	M-α
10	0	0	3	1	0.0494	M-α	M-α	M-α	M-α
Sum				27	1.0000			**M-α/4**	**M-α/3**

Assuming that all players act out of self-interest and are rational, and that this is common knowledge, we can work out the best strategy given each endowment – and systematically the different Bayes Nash equilibria under the different constraints and incentives. The different thresholds where players would choose to change strategy yield different 'scenarios', as the probability distribution is altered.

Example 3: Consider the situation in Table C.9a in Appendix C, with the constraint:

$$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right) \cap (0 < \rho < \frac{1}{9}E).$$

This scenario involves a fairly small reputational constraint, but the stigma incentive is large enough for players with E^0 to choose to play low, whereas players $E^{\neq 0}$ stick to original strategies (as shown in Table C.9b). Thus, using the probabilities below gives us the expected LIBOR outcomes respectively in Matrix B.5, B.6 and B.7:

$$z^H_{n\neq i} = Prob\{s^*_{n\neq i}, L^H_{n\neq i}\} = 1/3$$
$$z^M_{n\neq i} = Prob\{s^*_{n\neq i}, L^M_{n\neq i}\} = 0$$
$$z^L_{n\neq i} = Prob\{s^*_{n\neq i}, L^L_{n\neq i}\} = 2/3$$

Matrix B.5: P_i submits L^H (Scenario II)

Outcome	L^H	L^M	L^L	Permutations	*p*	Max	Min	L_A	L_F
1	3	0	0	1	0.0370	M+α	M+α	M+α	M+α
2	2	0	1	6	0.2222	M+α	M-α	M+α/2	M+α
3	1	0	2	12	0.4444	M+α	M-α	M	M
4	0	0	3	8	0.2963	M+α	M-α	M-α/2	M-α
Sum				27	0.1481	M+α	M-α	**M**	**M-α/27**

Matrix B.6: P_i submits L^M (Scenario II)

Outcome	L^H	L^M	L^L	Permutations	*p*	Max	Min	L_A	L_F
1	3	0	0	1	0.0370	M+α	M	M+3α/4	M+α
2	2	0	1	6	0.2222	M+α	M-α	M+α/4	M+α/2
3	1	0	2	12	0.4444	M+α	M-α	M-α/4	M-α/2
4	0	0	3	8	0.2963	M	M-α	M-3α/4	M-α
Sum				27	0.1481			**M-α/4**	**M-10α/27**

Matrix B.7: P_i submits L^L (Scenario II)

Outcome	L^H	L^M	L^L	Permutations	*p*	Max	Min	L_A	L_F
1	3	0	0	1	0.0370	M+α	M	M+α/2	M+α/2
2	2	0	1	6	0.2222	M+α	M-α	M	M
3	1	0	2	12	0.4444	M+α	M-α	M-α/2	M-α
4	0	0	3	8	0.2963	M-α	M-α	M	M-α
Sum				27	0.1481			**M-α/2**	**M-19α/27**

Appendix C - Beliefs, Expected Payoffs and Expected LIBOR Equilibria

Table C.1a: Beliefs (LIBOR Base Game)

LIBOR Base Game	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^+	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
E_i^0	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
E_i^-	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$

Table C.1b: Expected Payoffs (LIBOR Base Game).Optimal Strategies in Bold.

LIBOR Base Game	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{\frac{1}{3}\alpha E}$	0	$-\frac{1}{3}\alpha E$
E_i^0	0	$\mathbf{0}$	0
E_i^-	$-\frac{1}{3}\alpha E$	0	$\boldsymbol{\frac{1}{3}\alpha E}$

Table C.1c: Expected LIBOR Equilibria (LIBOR Base Game).Under Optimal Strategies in Bold.

LIBOR Base Game	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{M+\frac{1}{3}\alpha}$	M	$M-\frac{1}{3}\alpha$
E_i^0	$M+\frac{1}{3}\alpha$	$\boldsymbol{M}$	$M-\frac{1}{3}\alpha$
E_i^-	$M+\frac{1}{3}\alpha$	M	$\boldsymbol{M-\frac{1}{3}\alpha}$

Table C.2a: Beliefs (LIBOR Collusion game)

LIBOR Collusion Game	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^+	$\frac{15}{27}$	$\frac{6}{27}$	$\frac{6}{27}$
E_i^0	$\frac{6}{27}$	$\frac{15}{27}$	$\frac{6}{27}$
E_i^-	$\frac{6}{27}$	$\frac{6}{27}$	$\frac{15}{27}$

Table C.2b: Expected Payoffs (LIBOR Collusion game).Optimal Strategies in Bold.

LIBOR Collusion Game	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{\frac{13}{18}\alpha E}$	0	$-\frac{13}{18}\alpha E$
E_i^0	0	0	0
E_i^-	$-\frac{13}{18}\alpha E$	$\mathbf{0}$	$\boldsymbol{\frac{13}{18}\alpha E}$

Table C.2c: Expected LIBOR Equilibria (LIBOR Collusion game).Under Optimal Strategies in Bold.

LIBOR Collusion Game	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{M + \frac{13}{18}\alpha}$	M	$M - \frac{13}{18}\alpha$
E_i^0	$M + \frac{13}{18}\alpha$	$\boldsymbol{M}$	$M - \frac{13}{18}\alpha$
E_i^-	$M + \frac{13}{18}\alpha$	M	$\boldsymbol{M - \frac{13}{18}\alpha}$

Table C.3a: Beliefs (LIBOR Bribe Game)

$B < \frac{19}{27}\alpha E$	$z^H_{n\neq i}$	$z^M_{n\neq i}$	$z^L_{n\neq i}$
E_i^+	$\frac{2}{3}$	0	$\frac{1}{3}$
E_i^0	0	0	0
E_i^-	$\frac{1}{3}$	0	$\frac{2}{3}$

Table C.3b: Expected Payoffs (LIBOR Bribe Game).Optimal Strategies in Bold.

$B < \frac{19}{27}\alpha E$	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{\frac{19}{27}\alpha E - B}$	0	$-\frac{19}{27}\alpha E - B$
E_i^0	0	**0**	0
E_i^-	$-\frac{19}{27}\alpha E - B$	0	$\boldsymbol{\frac{19}{27}\alpha E - B}$

Table C.3c: Expected LIBOR Equilibria (LIBOR Bribe Game).Under optimal Strategies in Bold.

$B < \frac{19}{27}\alpha E$	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{M + \frac{19}{27}\alpha}$	M	$M - \frac{19}{27}\alpha$
E_i^0	$M + \frac{19}{27}\alpha$	$\boldsymbol{M}$	$M - \frac{19}{27}\alpha$
E_i^-	$M + \frac{19}{27}\alpha$	M	$\boldsymbol{M - \frac{19}{27}\alpha}$

Table C.4a: Beliefs (Low Reputational Constraint)

$\rho < \frac{1}{9}E$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^{+}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
E_i^{0}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
E_i^{-}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$

Table C.4b: Expected Payoffs (Low Reputational Constraint).Optimal Strategies in Bold.

$\rho < \frac{1}{9}E$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\boldsymbol{\alpha(\frac{1}{3}E-\rho)}$	$2\alpha\rho$	$\alpha(-\frac{1}{3}E-\rho)$
E_i^{0}	$-\alpha\rho$	$\boldsymbol{2\alpha\rho}$	$-\alpha\rho$
E_i^{-}	$\alpha(-\frac{1}{3}E-\rho)$	$2\alpha\rho$	$\boldsymbol{\alpha(\frac{1}{3}E-\rho)}$

Table C.4c: Expected LIBOR Equilibria (Low Reputational Constraint).Under Optimal Strategies in Bold.

$\rho < \frac{1}{9}E$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\boldsymbol{M+\frac{1}{3}\alpha}$	M	$M-\frac{1}{3}\alpha$
E_i^{0}	$M+\frac{1}{3}\alpha$	$\boldsymbol{M}$	$M-\frac{1}{3}\alpha$
E_i^{-}	$M+\frac{1}{3}\alpha$	M	$\boldsymbol{M-\frac{1}{3}\alpha}$

Table C.5a: Beliefs (High Reputational Constraint)

$\rho \geq \frac{1}{9}E$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^+	0	1	0
E_i^0	0	1	0
E_i^-	0	1	0

Table C.5b: Expected Payoffs (High Reputational Constraint).Optimal Strategies in Bold.

$\rho \geq \frac{1}{9}E$	L_i^H	L_i^M	L_i^L
E_i^+	$\alpha(\frac{1}{3}E - 3\rho)$	**0**	$-\alpha(\frac{1}{3}E + 3\rho)$
E_i^0	$-3\alpha\rho$	**0**	$-3\alpha\rho$
E_i^-	$-\alpha(\frac{1}{3}E + 3\rho)$	**0**	$\alpha(\frac{1}{3}E - 3\rho)$

Table C.5c: Expected LIBOR Equilibria (High Reputational Constraint).Under Optimal Strategies in Bold.

$\rho \geq \frac{1}{9}E$	L_i^H	L_i^M	L_i^L
E_i^+	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$
E_i^0	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$
E_i^-	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$

Table C.6a: Beliefs (Low Stigma Incentive)

$0 < \sigma < \frac{12}{27}E$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^{+}	$\frac{1}{3}$	0	$\frac{2}{3}$
E_i^{0}	$\frac{1}{3}$	0	$\frac{2}{3}$
E_i^{-}	$\frac{1}{3}$	0	$\frac{2}{3}$

Table C.6b: Expected Payoffs (Low Stigma Incentive).Optimal Strategies in Bold.

$0 < \sigma < \frac{12}{27}E$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\boldsymbol{\alpha(-\frac{1}{27}E - \sigma)}$	$\alpha(-\frac{10}{27}E - \frac{1}{4}\sigma)$	$\alpha(-\frac{19}{27}E + \frac{1}{2}\sigma)$
E_i^{0}	$\alpha(\sigma)$	$\alpha(-\frac{1}{4}\sigma)$	$\boldsymbol{\alpha(\frac{1}{2}\sigma)}$
E_i^{-}	$\alpha(\frac{1}{27}E - \sigma)$	$\alpha(\frac{10}{27}E - \frac{1}{4}\sigma)$	$\boldsymbol{\alpha(\frac{19}{27}E + \frac{1}{2}\sigma)}$

Table C.6c: Expected LIBOR Equilibria (Low Stigma Incentive).Under Optimal Strategies in Bold.

$0 < \sigma < \frac{12}{27}E$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\boldsymbol{M - \frac{1}{27}\alpha}$	$M - \frac{10}{27}\alpha$	$M - \frac{19}{27}\alpha$
E_i^{0}	$M - \frac{1}{27}\alpha$	$M - \frac{10}{27}\alpha$	$\boldsymbol{M - \frac{19}{27}\alpha}$
E_i^{-}	$M - \frac{1}{27}\alpha$	$M - \frac{10}{27}\alpha$	$\boldsymbol{M - \frac{19}{27}\alpha}$

Table C.7a: Beliefs (High Stigma Incentive)

$\sigma \geq \frac{12}{27}E$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^{+}	0	0	1
E_i^{0}	0	0	1
E_i^{-}	0	0	1

Table C.7b: Expected Payoffs (High Stigma Incentive).Optimal Strategies in Bold.

$\sigma \geq \frac{12}{27}E$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\alpha(-E-\frac{3}{2}\sigma)$	$\alpha(-E-\frac{3}{4}\sigma)$	$\boldsymbol{\alpha(-E)}$
E_i^{0}	$\alpha(-\frac{3}{2}\sigma)$	$\alpha(-\frac{3}{4}\sigma)$	$\mathbf{0}$
E_i^{-}	$\alpha(E-\frac{3}{2}\sigma)$	$\alpha(E-\frac{3}{4}\sigma)$	$\boldsymbol{\alpha(E)}$

Table C.7c: Expected LIBOR Equilibria (High Stigma Incentive).Under Optimal Strategies in Bold.

$\sigma \geq \frac{12}{27}E$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$M-\sigma$	$M-\sigma$	$\boldsymbol{M-\sigma}$
E_i^{0}	$M-\sigma$	$M-\sigma$	$\boldsymbol{M-\sigma}$
E_i^{-}	$M-\sigma$	$M-\sigma$	$\boldsymbol{M-\sigma}$

Table C.8a: Beliefs (Scenario I)

$\left(0 < \rho < \frac{1}{9}E\right) \cap (\sigma < 4\rho)$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^{+}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
E_i^{0}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
E_i^{-}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$

Table C.8b: Expected Payoffs (Scenario I).Optimal Strategies in Bold.

$\left(0 < \rho < \frac{1}{9}E\right) \cap (\sigma < 4\rho)$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\boldsymbol{\alpha(\frac{1}{3}E - \rho - \frac{3}{4}\sigma)}$	$2\alpha\rho$	$-\alpha(\frac{1}{3}E + \rho - \frac{3}{4}\sigma)$
E_i^{0}	$-\alpha(\frac{3}{4}\sigma + R)$	$\boldsymbol{2\alpha\rho}$	$\alpha(\frac{3}{4}\sigma - \rho)$
E_i^{-}	$-\alpha(\frac{1}{3}E + \rho + \frac{3}{4}\sigma)$	$2\alpha\rho$	$\boldsymbol{\alpha(\frac{1}{3}E - \rho + \frac{3}{4}\sigma)}$

Table C.8c: Expected LIBOR Equilibria (Scenario I).Under Optimal Strategies in Bold.

$\left(0 < \rho < \frac{1}{9}E\right) \cap (\sigma < 4\rho)$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\boldsymbol{M + \frac{1}{3}\alpha}$	M	$M - \frac{1}{3}\alpha$
E_i^{0}	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$
E_i^{-}	$M + \frac{1}{3}\alpha$	M	$\boldsymbol{M - \frac{1}{3}\alpha}$

Table C.9a: Beliefs (Scenario II)

$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right) \cap$ $(0 < \rho < \frac{1}{9}E)$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^+	$\frac{1}{3}$	0	$\frac{2}{3}$
E_i^0	$\frac{1}{3}$	0	$\frac{2}{3}$
E_i^-	$\frac{1}{3}$	0	$\frac{2}{3}$

Table C.9b: Expected Payoffs (Scenario II).Optimal Strategies in Bold.

$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right) \cap$ $(0 < \rho < \frac{1}{9}E)$	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{\alpha(-\frac{1}{27}E - \sigma)}$	$\alpha(-\frac{10}{27}E + 3\rho - \frac{1}{4}\sigma)$	$\alpha(-\frac{19}{27}E + \frac{1}{2}\sigma)$
E_i^0	$\alpha(-\sigma)$	$\alpha(3\rho - \frac{1}{4}\sigma)$	$\boldsymbol{\alpha(\frac{1}{2}\sigma)}$
E_i^-	$\alpha(\frac{1}{27}E - \sigma)$	$\alpha(\frac{10}{27}E + 3\rho - \frac{1}{4}\sigma)$	$\boldsymbol{\alpha(\frac{19}{27}E + \frac{1}{2}\sigma)}$

Table C.9c: Expected LIBOR Equilibria (Scenario II).Under Optimal Strategies in Bold.

$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right) \cap$ $(0 < \rho < \frac{1}{9}E)$	L_i^H	L_i^M	L_i^L
E_i^+	$\boldsymbol{M - \frac{1}{27}\alpha}$	$M - \frac{10}{27}\alpha$	$M - \frac{19}{27}\alpha$
E_i^0	$M - \frac{1}{27}\alpha$	$M - \frac{10}{27}\alpha$	$\boldsymbol{M - \frac{19}{27}\alpha}$
E_i^-	$M - \frac{1}{27}\alpha$	$M - \frac{10}{27}\alpha$	$\boldsymbol{M - \frac{19}{27}\alpha}$

Table C.10a: Beliefs (Scenario III)

$\left(4\rho-\frac{4}{9}E\leq\sigma<4\rho\right)$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^+	0	$\frac{2}{3}$	$\frac{1}{3}$
E_i^0	0	$\frac{2}{3}$	$\frac{1}{3}$
E_i^-	0	$\frac{2}{3}$	$\frac{1}{3}$

Table C.10b: Expected Payoffs (Scenario III).Optimal Strategies in Bold.

$\left(4\rho-\frac{4}{9}E\leq\sigma<4\rho\right)$	L_i^H	L_i^M	L_i^L
E_i^+	$\alpha(-\frac{4}{27}E-2\rho-\sigma)$	$\boldsymbol{\alpha\left(-\frac{4}{27}E+\rho-\frac{1}{4}\sigma\right)}$	$\alpha\left(-\frac{13}{27}E-2\rho+\frac{1}{2}\sigma\right)$
E_i^0	$\alpha(-2\rho-\sigma)$	$\boldsymbol{\alpha(\rho-\frac{1}{4}\sigma)}$	$\alpha(-2\rho+\frac{1}{2}\sigma)$
E_i^-	$\alpha(\frac{4}{27}E-2\rho-\sigma)$	$\alpha(\frac{4}{27}E+\rho-\frac{1}{4}\sigma)$	$\boldsymbol{\alpha(\frac{13}{27}E-2\rho+\frac{1}{2}\sigma)}$

Table C.10c: Expected LIBOR Equilibria (Scenario III).Under Optimal Strategies in Bold.

$\left(4\rho-\frac{4}{9}E\leq\sigma<4\rho\right)$	L_i^H	L_i^M	L_i^L
E_i^+	$M-\frac{4}{27}\alpha$	$\boldsymbol{M-\frac{4}{27}\alpha}$	$M-\frac{13}{27}\alpha$
E_i^0	$M-\frac{4}{27}\alpha$	$\boldsymbol{M-\frac{4}{27}\alpha}$	$M-\frac{13}{27}\alpha$
E_i^-	$M-\frac{4}{27}\alpha$	$M-\frac{4}{27}\alpha$	$\boldsymbol{M-\frac{13}{27}\alpha}$

Table C.11a: Beliefs (Scenario IV)

$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right)$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^{+}	0	$\frac{1}{3}$	$\frac{2}{3}$
E_i^{0}	0	$\frac{1}{3}$	$\frac{2}{3}$
E_i^{-}	0	$\frac{1}{3}$	$\frac{2}{3}$

Table C.11b: Expected Payoffs (Scenario IV).Optimal Strategies in Bold.

$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right)$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\alpha(-\frac{14}{27}E - \rho - \frac{5}{4}\sigma)$	$\boldsymbol{\alpha\left(-\frac{14}{27}E + 2\rho - \frac{1}{2}\sigma\right)}$	$\alpha\left(-\frac{23}{27}E - \rho + \frac{1}{24}\sigma\right)$
E_i^{0}	$\alpha(-\rho - \frac{5}{4}\sigma)$	$\alpha(2\rho - \frac{1}{2}\sigma)$	$\boldsymbol{\alpha(-\rho + \frac{1}{4}\sigma)}$
E_i^{-}	$\alpha(\frac{14}{27}E - \rho - \frac{5}{4}\sigma)$	$\alpha(\frac{14}{27}E + 2\rho - \frac{1}{2}\sigma)$	$\boldsymbol{\alpha(\frac{23}{27}E - \rho + \frac{1}{24}\sigma)}$

Table C.11c: Expected LIBOR Equilibria (Scenario IV).Under Optimal Strategies in Bold.

$\left(4\rho \leq \sigma < 4\rho + \frac{4}{9}E\right)$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$M - \frac{14}{27}\alpha$	$\boldsymbol{M - \frac{14}{27}\alpha}$	$M - \frac{23}{27}\alpha$
E_i^{0}	$M - \frac{14}{27}\alpha$	$M - \frac{14}{27}\alpha$	$\boldsymbol{M - \frac{23}{27}\alpha}$
E_i^{-}	$M - \frac{14}{27}\alpha$	$M - \frac{14}{27}\alpha$	$\boldsymbol{M - \frac{23}{27}\alpha}$

Table C.12a: Beliefs (Scenario V)

$\left(\sigma \geq 4\rho + \frac{4}{9}E\right)$	$z_{n\neq i}^{H}$	$z_{n\neq i}^{M}$	$z_{n\neq i}^{L}$
E_i^{+}	0	0	1
E_i^{0}	0	0	1
E_i^{-}	0	0	1

Table C.12b: Expected Payoffs (Scenario V).Optimal Strategies in Bold.

$\left(\sigma \geq 4\rho + \frac{4}{9}E\right)$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$\alpha(-E - \frac{3}{2}\sigma)$	$\alpha\left(-E + 3\rho - \frac{3}{4}\sigma\right)$	$\boldsymbol{\alpha}(-\boldsymbol{E})$
E_i^{0}	$\alpha(-\frac{3}{2}\sigma)$	$\alpha(3\rho - \frac{3}{4}\sigma)$	$\mathbf{0}$
E_i^{-}	$\alpha(E - \frac{3}{2}\sigma)$	$\alpha(E + 3\rho - \frac{3}{4}\sigma)$	$\boldsymbol{\alpha}(\boldsymbol{E})$

Table C.12c: Expected LIBOR Equilibria (Scenario V).Under Optimal Strategies in Bold.

$\left(\sigma \geq 4\rho + \frac{4}{9}E\right)$	L_i^{H}	L_i^{M}	L_i^{L}
E_i^{+}	$M - \alpha$	$M - \alpha$	$\boldsymbol{M - \alpha}$
E_i^{0}	$M - \alpha$	$M - \alpha$	$\boldsymbol{M - \alpha}$
E_i^{-}	$M - \alpha$	$M - \alpha$	$\boldsymbol{M - \alpha}$

Table C.13a: Beliefs (Scenario VI)

$\left(\sigma < 4\rho - \frac{4}{9}E\right)$	$z^H_{n\neq i}$	$z^M_{n\neq i}$	$z^L_{n\neq i}$
E_i^+	0	1	0
E_i^0	0	1	0
E_i^-	0	1	0

Table C.13b: Expected Payoffs (Scenario VI).Optimal Strategies in Bold.

$\left(\sigma < 4\rho - \frac{4}{9}E\right)$	L_i^H	L_i^M	L_i^L
E_i^+	$\alpha(\frac{1}{3}E - 3\rho - \frac{3}{4}\sigma)$	$\mathbf{0}$	$\alpha(-\frac{1}{3}E - 3\rho + \frac{3}{4}\sigma)$
E_i^0	$\alpha(-\frac{3}{4}\sigma - 3R)$	$\mathbf{0}$	$\alpha(\frac{3}{4}\sigma - 3\rho)$
E_i^-	$\alpha(-\frac{1}{3}E - 3\rho - \frac{3}{4}\sigma)$	$\mathbf{0}$	$\alpha(\frac{1}{3}E - 3\rho + \frac{3}{4}\sigma)$

Table C.13c: Expected LIBOR Equilibria (Scenario VI).Under Optimal Strategies in Bold.

$\left(\sigma < 4\rho - \frac{4}{9}E\right)$	L_i^H	L_i^M	L_i^L
E_i^+	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$
E_i^0	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$
E_i^-	$M + \frac{1}{3}\alpha$	$\boldsymbol{M}$	$M - \frac{1}{3}\alpha$

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