Online Appendix

This document provides supplementary material to the paper "A New Indicator of Bank Funding Cost." It provides details on the evolution of interbank spreads (Section A) and on the data and methodology used for computing the forward funding spread (Section B). It also reports the spot and forward funding spreads and the total assets of the central bank for Japan and the United Kingdom (Section C).

A Temporal Evolution of Interbank Spreads

Figure A1. Spread Between IBOR and OIS Rates

Note: The table displays the spread between the 3-month (6-month) deposit rate and the 3-month (6-month) OIS rate. Panel A corresponds to the United States and Panel B to the euro area. The sample periods are January 2005 to March 2020.

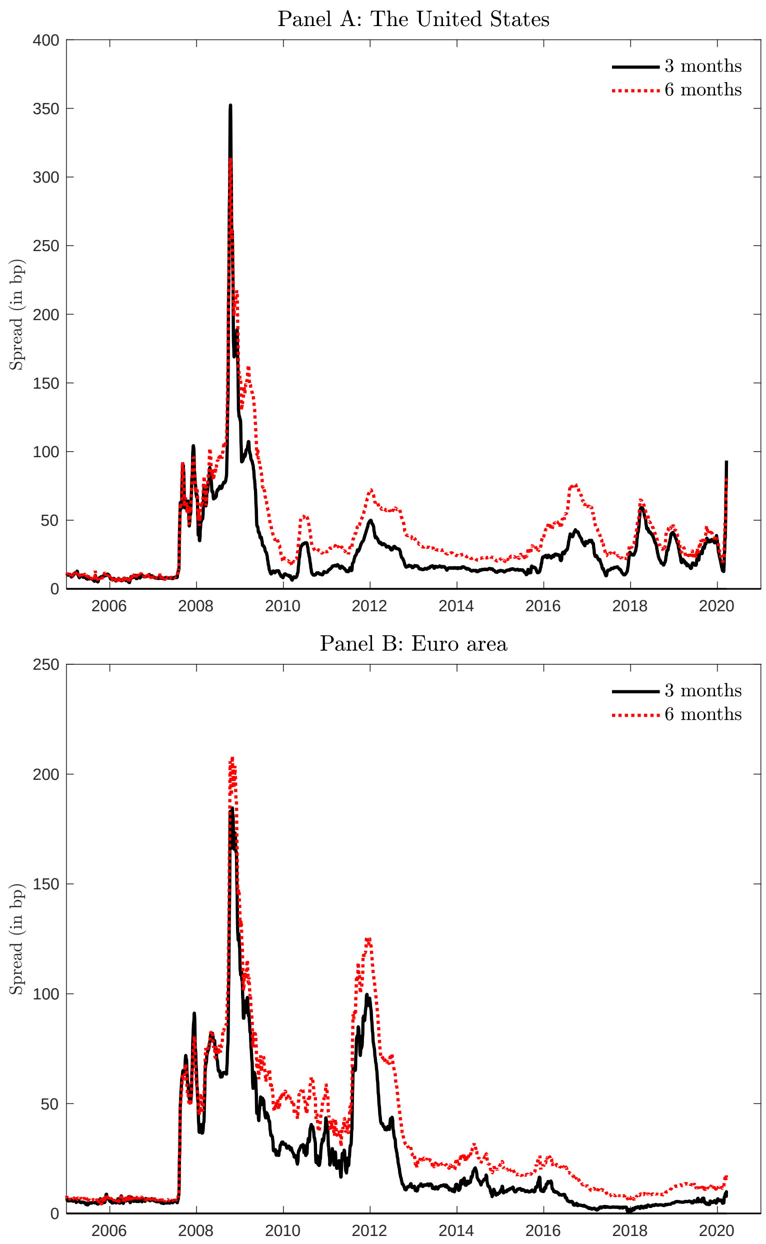
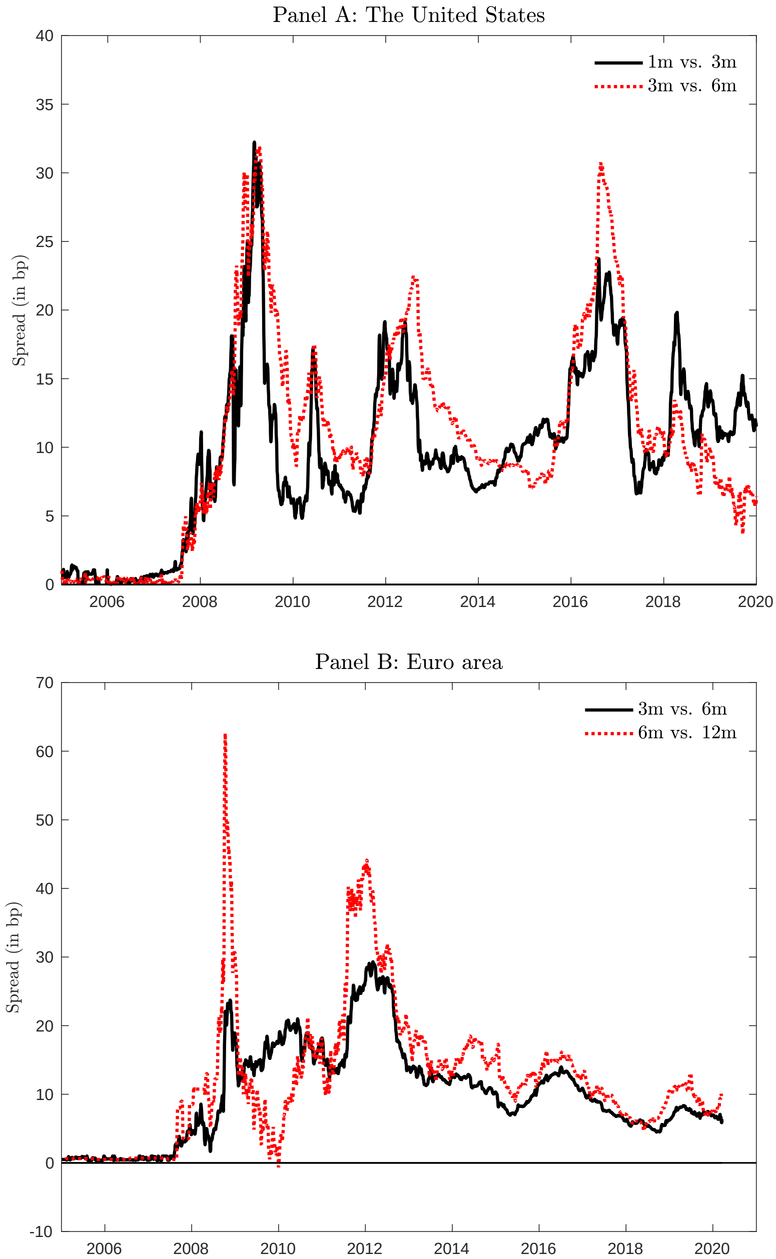


Figure A2. Basis Swap Rates Between 2-Year Swaps of Different Tenors

Note: The table displays the spread between the two-year swap rate with tenor 6 months and the two-year swap rate with tenor 3 months. Panel A corresponds to the United States and Panel B to the euro area. The sample periods are January 2005 to March 2020.



B Methodology

We define two types of yield curves. The discounting curve corresponds to the OIS curve with overnight rates. The forwarding curves correspond to yield curves with tenors 1 month, 3 months, 6 months, and 12 months. We denote by x the tenor of a given curve.

B.1 Notations

We define $P_x(t,T)$, $t \leq T$, the discount factor, i.e., the price of a zero-coupon bond at time t for maturity T, for underlying rate tenor x, with $P_x(t,t) = 1$ and t is reference date. The simply compounded zero-coupon rate at date t for maturity T, denoted by $Z_x(t,T)$, is defined from:

$$P_x(t,T) = \frac{1}{[1 + Z_x(t,T)]^{\tau_x(t,T)}},$$

where $\tau_x(t,T)$ is the year fraction for interval $[t,T]$ under the convention of curve x. For zero-coupon rates, the time interval is computed as $\tau_x(t,T) = (T-t)/365$.

We define the simply compounded forward rate at date t for the future time interval $[T_{k-1}, T_k]$, with tenor x, as:

$$\tilde{F}_{x,k}(t) \equiv \tilde{F}_x(t, T_{k-1}, T_k) = \frac{1}{\tau_{x,k}} \left[\frac{P_x(t,T_k)}{P_x(t,T_{k-1})} - 1 \right],$$

where $\tau_{x,k}$ is the year fraction for interval $[T_{k-1}, T_k]$ under the convention of curve x. For forward rates, the time interval is computed as $\tau_{x,k} = (T_k - T_{k-1})/360$ (actual/360). For example, $\tilde{F}_{3\text{m},6\text{m}}(t)$ denotes the forward rate with tenor 3 months between $t+3$m and $t+6$m.

In the multicurve environment, the following no arbitrage relation holds:

$$P_x(t,T_k) = P_x(t,T_{k-1}) P_x(t, T_{k-1}, T_k), \quad t \leq T_{k-1} \leq T_k$$

where $P_x(t,T_{k-1},T_k)$ is the forward discount factor at date t and corresponding to the future time interval $[T_{k-1}, T_k]$, with

$$P_x(t, T_{k-1}, T_k) = \frac{P_x(t,T_k)}{P_x(t,T_{k-1})} = \frac{1}{1 + \tilde{F}_{x,k}(t)\tau_{x,k}}.$$

We typically consider constant time intervals such as $T_k - T_{k-1} = \delta$. The yield curve of the δ-month forward rates is denoted by: $\mathcal{C}_x^{(F)} = \left\{ T \to \tilde{F}_x(t, T, T+\delta), t \geq T \right\}$.

B.2 Market Instruments

B.2.1 Overnight Index Swap (OIS)

The reference rate for overnight over-the-counter (OTC) transactions is the federal funds rate in the United States and the Eonia (European OverNight Index Average) rate in the euro area. An OIS is an interest rate agreement that involves the exchange of the overnight rate and a fixed interest rate. The floating rate is determined by the geometric average of the overnight index rate over the time interval of the contract period. The fixed leg is quoted in the market as a yield that is applied over the duration of the swap. The two counterparties of an OIS contract agree to exchange at maturity the difference between interest accrued at the agreed fixed rate and the floating rate on the notional amount of the contract. No principal is exchanged at the beginning of the contract. For maturities up to 1 year, there are no intermediate interest payments. Then the broken period is at the beginning.

The floating rate is given by the formula:

$$R_d(t, T_k) = \frac{360}{N_k} \left[\prod_{i=1}^{d_k} \left(1 + \frac{r_i n_i}{360} \right) - 1 \right] \times 100$$

where r_i is the overnight rate at date i, $N_k = T_k - t$ is the total number of days, d_k is the number of working days, and n_i is the number of days with rate r_i, with $N_k = \sum_{i=1}^{d_k} n_i$.

B.2.2 Deposit

Interbank deposits are OTC zero-coupon contracts that start at reference date t and cover the period $[t, T]$ with maturities T ranging from one day to one year. The Libor rate is the reference rate in the United States and the Euribor rate is the reference rate in the euro area (IBOR, in short). They correspond to the rate at which interbank deposits are offered by a prime bank to another prime bank. Fixing rates are constructed as the trimmed average of the rates submitted by a panel of banks. The IBOR reflects the average cost of funding of banks on the interbank market for a given maturity. The deposit with duration x is selected for the construction of the curve with tenor x.

We denote by $R_x^D(t, T_k)$ the quoted rate (annual, simply compounded) associated to the deposit of maturity T_k, with tenor $x = T_k - t$ months. The implied discount factor at time t for time T_k is given by:

$$P_x(t, T_k) = \frac{1}{1 + R_x^D(t, T_k)\tau_{x,x}}, \quad t \leq T_k.$$

B.2.3 Forward Rate Agreement (FRA)

FRA contracts are forward starting deposits. They are defined for forward start dates calculated with the same convention used for the deposits. Therefore, FRAs concatenate exactly with deposits. Market FRAs on x-tenor IBOR contracts can be selected for the construction of the short-term of the yield curve with tenor x.

We denote by $\tilde{F}_{x,k}(t)$ the forward rate reset at time T_{k-1}, with tenor $x = T_k - T_{k-1}$ months. Then the implied discount factor at time T_k is given by:

$$P_x(t, T_k) = \frac{P_x(t, T_{k-1})}{1 + \tilde{F}_{x,k}(t)\tau_{x,k}}, \quad t \leq T_{k-1} \leq T_k.$$

B.2.4 Swap

Interest rate swaps are OTC contracts by which two counterparties exchange fixed against floating rate cash flows. On the U.S. market, the floating leg is usually indexed to the 3-month Libor rate payed with 3-month frequency. On the euro market, the floating leg is indexed to the 6-month Euribor rate payed with 6-month frequency. The day count convention (τ_S) is 30/360 (bond basis). Swaps on x-tenor IBOR contracts are selected for the construction of the medium and long-term of the yield curve with tenor x.

A swap is defined by two date vectors $T = \{t, T_1, \cdots, T_n\}$ and $S = \{t, S_1, \cdots, S_m\}$ with $t < T_1 < S_1 < \cdots < T_n = S_m$ and $n < m$. The fixed leg pays a fixed rate at times S_j. The floating leg pays the IBOR with tenor $x = T_k - T_{k-1}$ fixed at time T_{k-1}. We denote by $S_x(t, T, S)$ the swap rate with floating leg payment dates T and fixed leg payment dates S, with tenor $x = T_k - T_{k-1}$ months. The price of a swap with payment times T and S is given by the no arbitrage relation:

$$S_x(t, T, S) \sum_{j=1}^{n} P_d(t, S_j)\tau_j = \sum_{k=1}^{m} P_d(t, T_k)\tilde{F}_{x,k}(t)\tau_{x,k}.$$

Once the curve points at $\{t, T_1, \cdots, T_{k-1}\}$ and $\{t, S_1, \cdots, S_{j-1}\}$ are known, it is possible to bootstrap the yield curve at point $T_i = S_j$. In practice, the fixed leg frequency is annual, whereas the floating leg frequency is given by the IBOR tenor. Some points of the curve are unknown and have to be interpolated.

B.2.5 Basis swap

Basis swaps are floating versus floating swaps, admitting underlying rates with different tenors. On the U.S. market, the typical basis swaps are 1-month vs 3-month, 3-month vs 6-month, and 3-month vs 12-month. On the euro market, the typical basis swaps are 1-month vs 3-month, 3-month vs 6-month, and 6-month vs 12-month. The quotation convention is to provide the difference (in basis points) between the fixed rate of the higher frequency swap and the fixed rate of the lower frequency swap. Basis swaps are used for the construction of the yield curve with non-quoted swaps (for instance, the 6-month curve in the United States and the 3-month curve in the euro area).

We define by $BS_{x,y}(t, T_x, T_y)$ the quoted basis spread for a basis swap receiving the long y-month rate and paying the short x-month rate plus the basis spread for maturity T_{m_x}.

The price of a basis swap is given by the no arbitrage relation:

$$\sum_{k=1}^{m_y} P_d(t, T_{y,k})\tilde{F}_{y,k}(t)\tau_{y,k} = \sum_{j=1}^{m_x} P_d(t, T_{x,j})(\tilde{F}_{x,j}(t) + BS_{x,y}(t, T_x, T_y))\tau_{x,j}.$$

B.3 Construction of the Curves

We now briefly explain how we construct the yield curve of a given tenor and compute tenor spreads. We consider a curve with a tenor x corresponding to overnight (the discounting curve), 1 month, 3 months, 6 months, and 12 months (the forwarding curves).

All the curves are constructed using instruments with the tenor of the curve. The forwarding curves also depend on the OIS curve used for discounting future cash flows. Several techniques can be used for interpolating a yield curve. Usual techniques are the linear or cubic interpolations. These techniques can be applied to the discount factor, the log of the discount factor, or the zero-coupon rate. A feature of the multicurve environment is the scarcity of the data for a given curve (except for the discounting curve). This implies that a large amount of maturities must be interpolated. The selection of the interpolation technique is therefore critical.

Ideally, all the available discount factors should be exactly given by the interpolation, yielding an arbitrage-free curve. However, it would lead to a very erratic yield curve. To cope with this problem, we allow for some arbitrage opportunity to obtain a smooth curve. We minimize a weighted sum of the squared changes in the forward rates under the arbitrage-free restrictions and the squared difference between the market and theoretical prices. The criterion is based on the 3-month forward rate. This maturity appears as a reasonable trade-off between the number of parameters to estimate and the ability to generate all the curves with similar data. For a given curve $\mathcal{C}_x^{(F)}$, we solve (imposing $T_k - T_{k-1} = 3\text{m}$ and $T_0 = t$):

$$\begin{aligned}\min_{\left\{\tilde{F}_x(t,T_{k-1},T_k)\right\}_{k=1}^{N}} \quad & w\sum_{k=1}^{N-1}\left(\tilde{F}_x(t, T_k, T_{k+1}) - \tilde{F}_x(t, T_{k-1}, T_k)\right)^2 \\ & +(1-w)\sum_{j=1}^{n}\left(P_x^{mkt}(t, T_j) - P_x^{theo}(t, T_j)\right)^2,\end{aligned}$$

where w is weight of the smoothness relative to the fit of the market prices (we use $w = 0.25$); $N = 120$ is the number of 3-month forward rate over the 30 years used for the curve; n is the number of instruments used to construct curve with tenor x; $P_x^{mkt}(t, T_j)$ is the discount factor implied by the market quote, based on the pricing formula presented in Section B.2; $P_x^{theo}(t, T_j)$ is the discount factor implied by the estimated 3-month forward rates:

$$P_x^{theo}(t, T_j) = \frac{P_x^{theo}(t, T_{j-1})}{1 + \tilde{F}_x(t, T_{j-1}, T_j)\tau_{x,j}}, \qquad j = 1, \cdots, n,$$

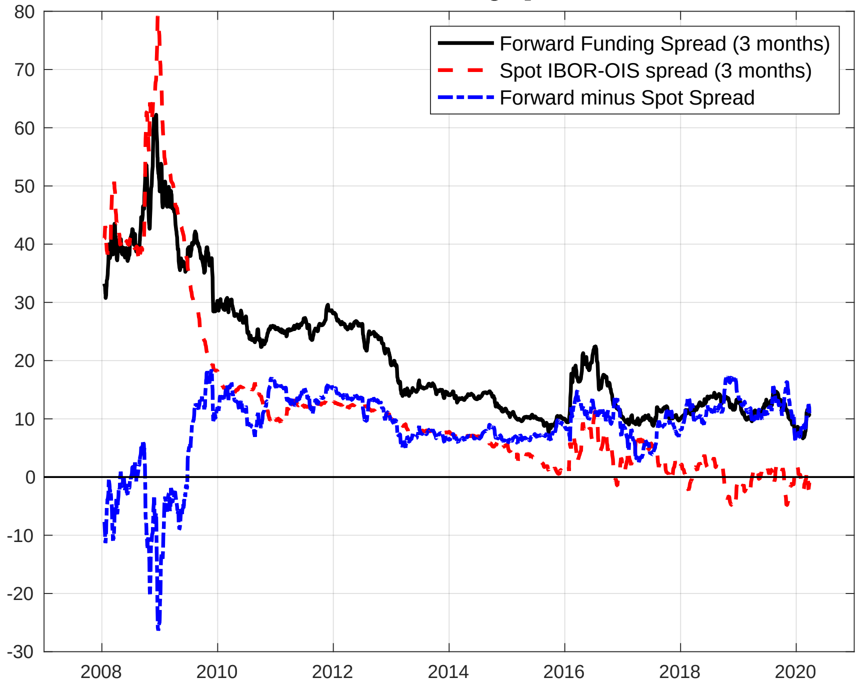
with $P_x^{theo}(t, t) = 1$.

C Data for Japan and the United Kingdom

Figure A3. Funding Spreads in Japan and Bank of Japan Total Assets

Note: Panel A displays the 3-month FFS (3-month tenor), the spot 3-month IBOR-OIS, and the difference between the two spreads. Panel B displays the Bank of Japan total assets (in JPY trillion). The spread series are smoothed using a 5-day moving average. The sample periods are January 2007 to March 2020.

Panel A: Funding Spreads



Panel B: Bank of Japan Total Assets

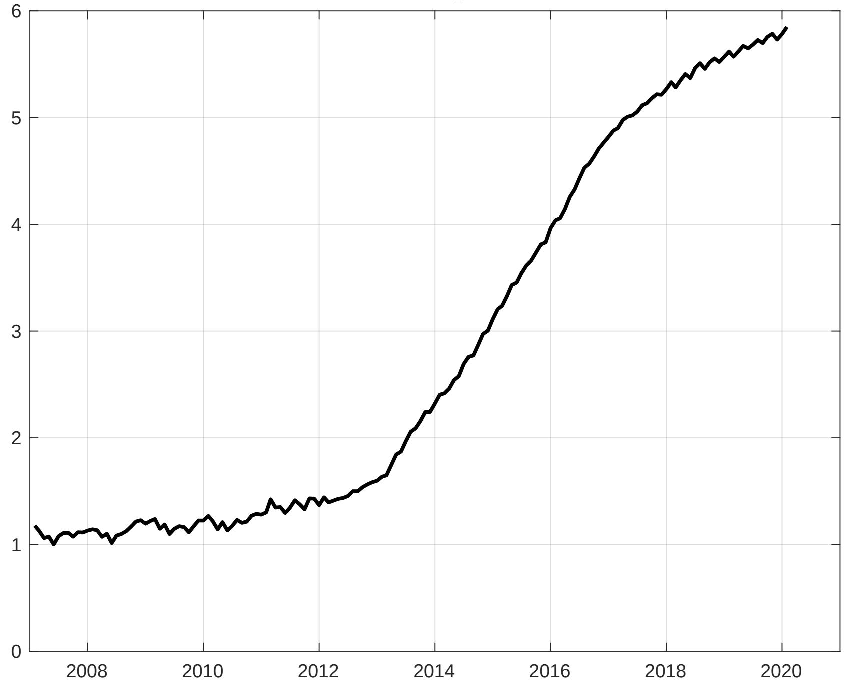


Figure A4. Funding Spreads in the United Kingdom and Bank of England Total Assets

Note: Panel A displays the 3-month FFS (3-month tenor), the spot 3-month IBOR-OIS, and the difference between the two spreads. Panel B displays the Bank of England total assets (in GBP trillion). The spread series are smoothed using a 5-day moving average. The sample periods are January 2007 to March 2020.