An International Examination of the Role of Default and Liquidity Risks in the Interbank Market

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Abstract

We study international interbank spreads and attempt to disentangle credit and liquidity risk premium in the interbank market. We examine the consistency of the spreads' movements across major currencies and assess the effectiveness of monetary policy actions on the deterioration of credit and liquidity risks. We find that at the core of the financial crisis, the interbank spread is clearly driven by liquidity risk. By early 2009, the dominant driver of the spread is credit risk. Our analysis suggests that the establishment of the unconventional policy programs, led to the deterioration of liquidity risk in the interbank market and the policy of major Central banks to substantially cut interest rates, kept credit pressures at low levels. Moreover, we distinguish two components of the spread due to the expectation hypothesis and time-varying risk premium and find that the hypothesis of constant risk premium is rejected.

Keywords: Interbank Market, Credit Risk, Liquidity Risk, LOIS spread, Risk Premium.

JEL classification: E43, E48, G12, G15, C11

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1 Introduction

The recent financial crisis has created, among others, important discrepancies on the valuation of interest rate financial instruments. One of the main reasons is the sudden and steep increase of the credit and liquidity premia, which resulted on the widening of the spread among interbank interest rates with different tenors and across different currencies. Interbank rates represent the cost of funding for banks and, as such, their variation can influence the borrowing conditions of financial institutions and corporations. That is why the interbank money market is at the heart of bank funding issues.

Understanding what moves the Libor-OIS spread is important mainly for monetary policy, forecasting, as well as derivatives pricing and hedging. The current term structure of the spread contains information about the future state of the spread which is of tremendous interest both for policy makers and market practitioners. Central banks, on one side, are particularly interested to identify the effect of the policy measures they have established on market expectations and prices dynamics across currencies, in order to adapt their decisions accordingly. For practitioners, on the other side, the availability of accurate forecasts can provide a basis for successful investment decisions.

Despite this importance, existing studies have focused almost exclusively on the US market. This article is the first to carry out international comparisons of the term structure of interbank spreads. The information coming from the analysis is important due to the different approaches undertaken by those countries regarding the monetary policies and interest and inflation processes. Therefore, the main objectives of this article are, first, to set up a theoretical framework that can explain the observed market data, second, to understand what determines the spreads' movements and whether these drivers are consistent in periods of stability and market turmoil, third, to identify any consistency on the spreads' movements across major currencies, and fourth, to assess the effectiveness of the conventional and unconventional monetary policy decisions in decreasing risk premia in the interbank market.

To do so, we estimate a no-arbitrage affine model of international interbank spreads and attempt to disentangle the credit and liquidity risk premia in the interbank market. Our framework is based on the discrete-time model of Ang and Piazzesi (2003). In particular, we use the 'yield-only' version of the model and separate our analysis into two different, yet related, estimation parts. In the first part the identification of the credit and liquidity components relies on (observable) proxies, while in the second part we treat them as completely unobservable (latent) and estimate our model using a Kalman Filter/MLE technique. Doing so, we avoid applying ex-ante restrictions that could potentially alter our results, while at the same time, we manage to get a more complete picture on the behaviour of the factors explaining the spreads' movements. We concentrate our analysis on six major currencies, the US Dollar (USD), the Euro (EUR), the British Pound (GBP), the Japanese Yen (JPY), the Canadian Dollar (CAD) and the Australian Dollar (AUD), in order to identify any similarities on the spreads' movements.

Our main empirical results are summarized as follows. First, at the peak of the financial crisis, Libor-OIS spread is clearly driven by liquidity risk. This finding, which is evident and consistent across all six markets, is in line with previous studies. For instance, Beber et al. (2009) argue that investors tend to chase liquidity rather than credit quality, during periods of market turmoil, thus increasing liquidity pressures in the market. This phenomenon is more intense in the US market, which seems to suffer greater pressure, mainly due to the exposure of the US financial institutions to subprime related products, and the shortage of US dollar as a funding currency. Second, in the aftermath of Lehman's default, liquidity risk started decreasing, supporting the view that the establishment of the unconventional monetary policy programs (e.g. massive liquidity injections, purchase of government/corporate bonds, etc.) adopted by major central banks, helped the banking system acquire a high level of reserves, which arguably led to the deterioration of liquidity risk in the interbank market, as also documented by Christensen et al. (2014). Third, our analysis suggests that the policy of major central banks to substantially cut interest rates, kept credit pressures at very low levels, during the early phase of the financial crisis, when markets were under severe pressures. However, by mid-2009 and until the end of our sample period, the dominant driver of the spread is credit risk. Fourth, we document that the EUR and UK markets experience much higher credit pressures compared to the rest of the markets, reaching their peak values the period after 2010, mainly reflecting the credit pressures faced in the Eurozone, due to the sovereign debt crisis of the countries in its periphery. This is not the case of the Japanese market though, which experienced remarkably low credit pressures during the core of the crisis, due to the low interest rate environment, the small exposure of its financial institutions to subprime related products and the effectiveness of the policy measures adopted by Bank of Japan.

In the final part of our analysis, we move one step forward and attempt to decompose the spread into an expectation hypothesis component and a time-varying risk premia component. The importance of identifying these components accurately, is mainly twofold; first, it helps us to capture market participants' views about the risk of important instruments of the fixed income market and second, it helps Central banks to assess the expectations of future (mainly conventional) monetary policy actions. To do so, we draw from the traditional term structure literature and attempt to answer the following question; is the assumption of constant risk premia supported by the observed data across maturities and currencies? Our empirical results suggest that the hypothesis of constant risk premia is overwhelmingly rejected, since, allowing for time-varying risk premia makes the model more capable for explaining the behavior of the term structure of the Libor-OIS spread. This is more evident at longer maturities (e.g. 12-month) rather than short ones (e.g. 1-month), which is in line with the term structure literature which suggests that the EH approximately holds in the short run but fails in the long run.

The remainder of this paper is organised as follows. Section 2 reviews the related literature. Section 3 describes the mathematical framework and the model of the Libor-OIS spread. Section 4 presents the market data that have been used in this study. Sections 5 and 6 describe the estimation procedures and present the empirical results for the model using observable and non-observable factors. Finally, section 7 concludes the paper.

2 Related Literature

Our study is mainly related to two segments of the finance literature. First, our modeling approach is related to studies focused on modeling the dynamic behavior of yield spreads [1] associated with different fixed income instruments, such as repos, bonds and swaps. Using a variety of multi-factor affine-type models, these studies typically try to disentangle swap and credit [2] spreads into different components, mainly credit and liquidity. Early research on the determinants of swap spreads includes Duffie and Singleton (1997), Grinblatt (2001) and He (2001), who conclude that both credit and liquidity factors need to explain the behavior of the US swap market. More recently, Liu et al. (2006) and Feldhütter and Lando (2008) attempt to identify the risk premia

[1] There is strong empirical and theoretical evidence that credit and liquidity risks are important determinants of the yield spreads (see, Duffie et al. (2003), Longstaff et al. (2005) and Beber et al. (2009), among others).

[2] A number of contributions are related to affine credit models. Important examples are Duffie and Singleton (1999), Collin-Dufresne and Solnik (2001) and Longstaff et al. (2005), among others, who investigate the determinants of credit spreads between corporate bonds and swap rates of counterparts with high credit quality.

associated with these factors and verify that both factors are significant in explaining the credit spreads in swaps, although according to Feldhütter and Lando (2008), the largest contribution to the swap spread is coming from the liquidity component, a conclusion that also reached by Grinblatt (2001), among others.

Our modeling approach is also related to the literature that uses Gaussian affine term structure models to study a variety of questions about the interactions of asset prices and risk premia [3] (see, Duffee (2002), Cochrane and Piazzesi (2005), Cochrane and Piazzesi (2009)). Related literature includes the use of both the continuous-time (see, Dai and Singleton (2000), Duffee (2002) and Kim and Orphanides (2012)) and the discrete-time versions (see, Ang and Piazzesi (2003), Cochrane and Piazzesi (2009), Duffee (2011), Joslin et al. (2011), Hamilton and Wu (2012) of the model. Previous contributions are also separated to those that use only latent risk factors to reflect information in the yield curve (e.g. yield-only model) and to determine the risk premia (see, Dai and Singleton (2002), Duffee (2002)) and to those that get information by incorporating macroeconomic variables as well (see, Ang and Piazzesi (2003), Rudebusch and Wu (2008), among many others). In this paper we mainly follow Ang and Piazzesi (2003) and work under the discrete-time version of the affine term structure model. However, in our analysis rather than using both latent and macroeconomic variables to reflect information in the spreads, we use the 'yield-only' version of the model.

The empirical part of our paper is also related to a recent and growing strand of research that studies interbank spreads. A wide range of studies has recently tried to decompose interbank spreads into default and liquidity components. As most of them reached different conclusions, their results are still controversial. Earlier contributions (see, McAndrews et al. (2008), Wu (2008), Taylor and Williams (2009), Christensen et al. (2014)) focus their analysis on the effectiveness of Central banks' liquidity facility programs (mainly the term Auction Facility (TAF) adopted by Federal reserve) on interbank rates and conclude (with the exception of Taylor and Williams (2009)) that these measures did help in deteriorating liquidity pressures in the interbank market. Furthermore, previous studies are separated to those arguing that the main driver of the spreads' movements is credit risk rather than liquidity risk (see, Taylor and Williams (2009), Angelini et al. (2011), Smith (2012)), and those concluding that liquidity risk is the dominant component of the

[3] Important contributions also focus on the forecasting performance of the models (see, Duffee (2002), Ang and Piazzesi (2003) and Christensen et al. (2011)) and the interactions between economic variables (see, Ang and Piazzesi (2003) and Rudebusch and Wu (2008)).

interbank spread during the recent global financial crisis (see, McAndrews et al. (2008), Michaud and Upper (2008), Wu (2008), Eisenschmidt and Tapking (2009)).

More recently, a number of important contributions attempt to study interbank risk by developing dynamic term structure models. These studies decompose the term structure into default and liquidity components and arrive at useful conclusions regarding the drivers of the spread at the short and the long end of the term structure of the interbank market. Focusing on the EUR market [4], Schwarz (2010) finds that market liquidity effects explain more than two thirds of the widening of 1-month and 3-month Euro Libor-OIS spreads. Similarly, using latent factors for the credit and liquidity components, Gefang et al. (2011) concludes that the short term (1-month, 3-month) spread is mainly driven by the liquidity risk, while for the long-term (12-month) spread both credit and liquidity risks play an important role. A similar conclusion is reached by Filipović and Trolle (2013) who find that the credit component is important at longer maturities, while at shorter maturities the non-default component is the main driver of the spread.

Finally, to the best of our knowledge, there are only two recent empirical works that attempt to study the dynamics of the Libor-OIS spread at an international level. Using various econometric tests, Ji and In (2010), study the cross-currency interactions of the spreads at the earlier phase of the financial crisis, while, Olson et al. (2012), accounts for structural breaks and concludes that all international Libor-OIS spreads studied, contain multiple structural breaks.

Our analysis differs from the related literature in a number of ways. First, sample periods employed by previous studies do not extend beyond 2009. Our sample period extends to 2013, and as such, it covers the most interesting phases of the unfolding of the global financial crisis (e.g. Lehman's default, European sovereign debt crisis, etc.). Second, they mostly base their analysis on standard event-study ordinary least squares (OLS) regressions, using proxies for the credit and liquidity factors, which could adversely influence their results. Our approach is based on a dynamic essentially affine model of the term structure of interbank risk, which allows us to delineate the credit and liquidity shocks incorporated into the spread fluctuations, and helps us to identify whether these drivers are consistent in periods of stability and market turmoil. In the third place, existing studies mostly concentrate their analysis on the USD or EUR market and ignore a critical aspect; are these drivers consistent across major currencies? Our analysis, on the

[4] See also Beirne (2012) for an interesting analysis of the EUR interbank market and the factors affecting the EONIA spread.

other hand, is focused on six major currencies and tries to investigate any common factors on the behaviour of the spreads. Furthermore, we attempt to assess whether the different (conventional and unconventional) monetary policy actions established by major central banks, were effective in decreasing credit and liquidity risks in the interbank market. Finally, we distinguish two components of the term structure of the spread due to the expectation hypothesis and time-varying risk premia. Our ultimate target is to give a definite answer on the assumption of constant risk premia and whether this assumption is capable of explaining the behaviour of the spread across currencies and maturities.

3 The Model of the Term Structure

The model of the Libor-OIS spread, as described in our setting, is based on the no-arbitrage affine model of Ang and Piazzesi (2003) [5]. Under this framework, the term structure dynamics are given by a Gaussian term structure model, where the risk premia are assumed to be time-varying. According to Dai and Singleton (2002), Gaussian models do a better job in capturing the dynamic behaviour of risk premia, when an affine framework is used.

Following Ang and Piazzesi (2003), we denote by X_t the (3×1) vector of state variables. The first state represents the interest rate factor, the second one the credit factor and the third one the liquidity factor. In our setting, these state variables are either observable or latent, depending on the case we are investigating. We assume that X_t follows a first-order Gaussian Vector Autoregressive process,

$$X_t = \mu + \Phi X_{t-1} + \Sigma \epsilon_t \tag{1}$$

where, μ is a (3×1) vector, Φ is a (3×3) matrix, ϵ_t is an i.i.d. Gaussian white noise, $\epsilon_t \sim N(0, I_3)$, and Σ is assumed to be a lower triangular matrix. The system is cholesky factorised and $\Sigma'\Sigma$ captures the variance-covariance of ϵ_t.

Under the affine term structure framework that we work, the short rate is assumed to be an affine function of the underlying factors. So, the one-period interest rate r_t is an affine function

[5] This is a discrete-time version of the affine models introduced by Duffie and Kan (1996), and have been extensively studied by Dai and Singleton (2000).

of the three state variables X_t,

$$r_t = \delta_0 + \delta_1' X_t \tag{2}$$

where, δ_0 is a scalar and δ_1 is a three dimensional vector.

Using the assumption of no-arbitrage (see, Harrison and Kreps (1979)), there exists a risk neutral probability measure Q, such that the price of any non-paying dividend asset V_t satisfies,

$$V_t = E_t^Q \left[\exp(-r_t) V_{t+1} \right] \tag{3}$$

Following Ang and Piazzesi (2003), we use the stochastic discount factor M_{t+1} to define the change of probability measure from (risk neutral) Q to (physical) P. The stochastic discount factor is assumed to follow a log-normal process and is defined to be of an exponential form,

$$M_{t+1} = \exp(-r_t - \frac{1}{2}\lambda_t' \lambda_t - \lambda_t' \varepsilon_{t+1}) \tag{4}$$

where λ_t is the time-varying market prices of risk. Following Duffee (2002) and Dai and Singleton (2002), we specify the vector of market prices of risk λ_t to be an affine function of the state variables,

$$\lambda_t = \lambda_0 + \lambda_1 X_t \tag{5}$$

where λ_0 is a three dimensional vector and λ_1 is a (3×3) matrix. This is the essentially-affine specification introduced by Duffee (2002) [6], which provides flexibility to the model and has been proved capable to capture any time-variation in the risk premia [7].

In models of this type, as shown by Duffie and Kan (1996), the time-t price of an n-period zero-coupon bond can be expressed as an exponential affine function of the underlying state variables,

[6] Different specfications for the market price of risk have been proposed in the related literature. See, Dai and Singleton (2000) for the 'completely affine' model, Duarte (2004) for the 'semi-affine' model and Cheridito et al. (2007) for the 'extended affine' model. For a comparison of the specifications, see Feldhütter (2016).

[7] According to Ang and Piazzesi (2003), all time variation in market prices of risk is carried by the state vector X_t. In the essentially-affine specification that we use, time-varying risk premia are captured by λ_1, while λ_0 captures constant risk premia. This is an important part of the analysis in the final part of this study, where we decompose the spread into an Expectations Hypothesis component and a Risk premia component.

$$p_t^n = \exp(\bar{A}_n + \bar{B}_n X_t) \tag{6}$$

where the coefficients $\bar{A}_n$ and $\bar{B}_n$ are captured recursively by solving the system of the following difference equations,

$$\bar{A}_{n+1} = \bar{A}_n + \bar{B}_n'(\mu - \Sigma\lambda_0) + \frac{1}{2}\bar{B}_n'\Sigma\Sigma'\bar{B}_n - \delta_0 \tag{7}$$

$$\bar{B}_{n+1} = \bar{B}_n'(\Phi - \Sigma\lambda_1) - \delta_1 \tag{8}$$

with $\bar{A}_1 = -\delta_0$ and $\bar{B}_1 = -\delta_1$.

The bond's yield y_t^n is also an affine function of the state vector and is given by,

$$y_t^n = -\frac{\log p_t^n}{n} = A_n + B_n' X_t \tag{9}$$

where, $A_n = -\bar{A}_n/n$ and $B_n = -\bar{B}_n/n$.

Looking at the difference equations, we see that the constant risk premia parameter λ_0 only affects coefficients $\bar{A}_n$, whereas parameter λ_1, which captures any time variation in risk premia, only affects the response coefficients $\bar{B}_n$. We will use this observation at the latest stage of our analysis, where we will try to decompose response coefficients into an expectations hypothesis component and a risk premia component.

3.1 The Libor-OIS Spread

Adapting the analysis of the previous section about the term structure model, we follow McAndrews et al. (2008) and Smith (2012) and define the Libor-OIS spread for maturity n as:

$$z_t^{(n)} = R_t^{lib,(n)} - R_t^{ois,(n)} \tag{10}$$

where, $R_t^{lib,(n)}$ denotes the n-period Libor rate and $R_t^{ois,(n)}$ denotes the n-period OIS rate. Furthermore, we assume that the difference (i.e. spread) between the short term Libor, which is an unsecured rate and the short term OIS, which is a secured rate, incorporates the credit and liquidity factors. So, if we consider that $R_t^{ois,(1)} = r_t$, the short risk-free rate, then, $R_t^{lib,(1)} = r_t + k_t$, where $k_t = (k_1, k_2)$, with k_1 being the coefficient for the credit factor and k_2 the coefficient for the liquidity factor. But, from equation (2), we have assumed that the short rate is an affine function of all three state variables, which means that the short-term rate for Libor is given as,

$$R_t^{lib,(1)} = \delta_0 + r_t + k_1 C_t + k_2 L_t = \delta_0 + (1, k_1, k_2) X_t = \delta_0 + \delta_1' X_t \tag{11}$$

where, δ_0 is a constant, $\delta_1 = (1, k_1, k_2)$ and $X_t = (r_t, C_t, L_t)$, with C_t and L_t denoting the credit and liquidity factors respectively. So, according to equations (9) and (10) the Libor-OIS spread is given by,

$$\begin{aligned} z_t^{(n)} &= \left(A_{lib,(n)} + B'_{lib,(n)} X_t\right) - \left(A_{ois,(n)} + B'_{ois,(n)} X_t\right) \\ &= \left(A_{lib,(n)} - A_{ois,(n)}\right) + \left(B'_{lib,(n)} - B'_{ois,(n)}\right) X_t \end{aligned} \tag{12}$$

where,

$$A_{lib,(n)} = -\frac{1}{n}\left[\bar{A}_{lib,(n-1)} + \bar{B}'_{lib,(n-1)}(\mu - \Sigma\lambda_0) + \frac{1}{2}\bar{B}'_{lib,(n-1)}\Sigma\Sigma'\bar{B}_{lib,(n-1)} - \delta_0\right] \tag{13}$$

$$B'_{lib,(n)} = -\frac{1}{n}\left[\bar{B}'_{lib,(n-1)}(\Phi - \Sigma\lambda_1) - \delta_1\right] \tag{14}$$

$$A_{ois,(n)} = -\frac{1}{n}\left[\bar{A}_{ois,(n-1)} + \bar{B}'_{ois,(n-1)}(\mu - \Sigma\lambda_0) + \frac{1}{2}\bar{B}'_{ois,(n-1)}\Sigma\Sigma'\bar{B}_{ois,(n-1)}\right] \tag{15}$$

$$B'_{ois,(n)} = -\frac{1}{n}\left[\bar{B}'_{ois,(n-1)}(\Phi - \Sigma\lambda_1) - (1,0,0)\right] \tag{16}$$

with: $\bar{A}_{lib,(1)} = -\delta_0$, $\bar{A}_{ois,(1)} = 0$, $\bar{B}'_{lib,(1)} = -\delta_1$ and $\bar{B}'_{ois,(1)} = -(1,0,0)'$.

4 Data

We estimate our model using data that cover the period from January 2007 to December 2012. For the estimation we use weekly averages of daily data in order to avoid synchronisation problems. Weekly figures are computed by averaging daily observations within the corresponding week (ending every Friday). This makes a total of 313 observations for each time series. Most data are extracted from Bloomberg [8]. We use three data sets for this study, one data set containing the interest rates, a second one containing proxies for the credit factor and a third one containing proxies for the liquidity factor. Furthermore, our analysis concentrates on six major currencies. So, the first data set contains daily prices for:

- USD, GBP, JPY, CAD, AUD LIBOR and EURIBOR rates with maturities 1-week, 1-month, 3-months, 6-months, 9-months and 12-months.
- OIS rates in USD, EUR, GBP, JPY, CAD and AUD with maturities 1-week, 1-month, 3-months, 6-months, 9-months and 12-months.
- Federal Funds, EONIA [9] , SONIA, TONAR, CORRA and RBACOR rates [10] .

The second data set contains proxies for the credit factor:

- 3-month repo rates for USD, EUR, GBP, JPY [11], CAD and AUD.
- 30-day Asset Backed Commercial Paper and Dealer places Commercial Paper.
- JP Morgan Banking sector CDS Index.

The third data set contains proxies for the liquidity factor:

- On-the-run and off-the-run 10-year treasury securities for USD, EUR and UK.
- 3-month Mortgage Backed Security (MBS) General Collateral (GC) repo rates and 3-month Treasury GC repo rates.
- 3-month T-Bills for USD, EUR, UK, JPY, CAD and AUD.

[8] The Fed Funds rate and the USD three-month T-bill rates were collected from the Federal Reserve, the UK three-month Repo rates were collected from the Bank of England, the JPY TONAR was collected from the Bank of Japan and the CAD three-month T-bill was collected from the Bank of Canada.

[9] The Eonia rate is the euro area overnight interest rate. It is constructed as the weighted average of all overnight lending transactions undertaken by a panel of contributing banks in the euro area's interbank money market.

[10] TONAR is the acronym of Tokyo OverNight Average Rate. It is the weighted average rate of all unsecured overnight cash transactions between financial institutions and is published by the Bank of Japan. CORRA, is the acronym of Canadian Overnight Repo Rate Average. It is the weighted average rate of overnight general (non-specific) collateral repo trades and is regarded as a measure of the average cost of collateralised funding in the market. RBACOR is the Reserve Bank of Australia (RBA) interbank overnight cash rate. It is the weighted average rate of overnight transactions in the domestic interbank market, undertaken by a panel of banks.

[11] One important difference between the repo market in Japan and the other major overseas markets is that more than 90% of bond repos uses Japanese Government bonds.

4.1 Interbank Rates

The London Interbank Offered Rate (LIBOR) and the Euro Interbank Offered Rate (EURIBOR) provide a measure of the average cost of borrowing of unsecured (i.e. no collateral is received by the borrower) funds among financial institutions. The recent financial crisis has, among others, questioned the stability of the whole financial system, which resulted in the steep increase of the credit and liquidity premia among counterparties that participate in the interbank market. The Libor and Euribor rates, referencing cash instruments, were rapidly affected by this increase, and reached their highest values since 2000.

An Overnight Indexed Swap (OIS), is an interest rate swap, whose floating leg is tied to an overnight rate index. In US, the floating leg is linked to the overnight Federal Funds rate, in the euro area it is linked to the EONIA rate and in UK, it is linked to the SONIA rate. Other overnight rates include TONAR in Japan, CORRA in Canada and RBACOR in Australia. OIS is believed to contain very little liquidity risk premia, mainly because the market for OIS is highly liquid, especially for major currencies. Furthermore, credit risk premia are limited in an OIS, due to the fact that in such a contract, there is, initially, no exchange of principal and the only exchange of funds occurs at the maturity of the contract. This means that in case of a default of the counterparty, the loss is only related to the accrued interest. That is why the OIS rate is assumed to be risk-free and the OIS curve is seen as a proxy for the risk-free yield curve.

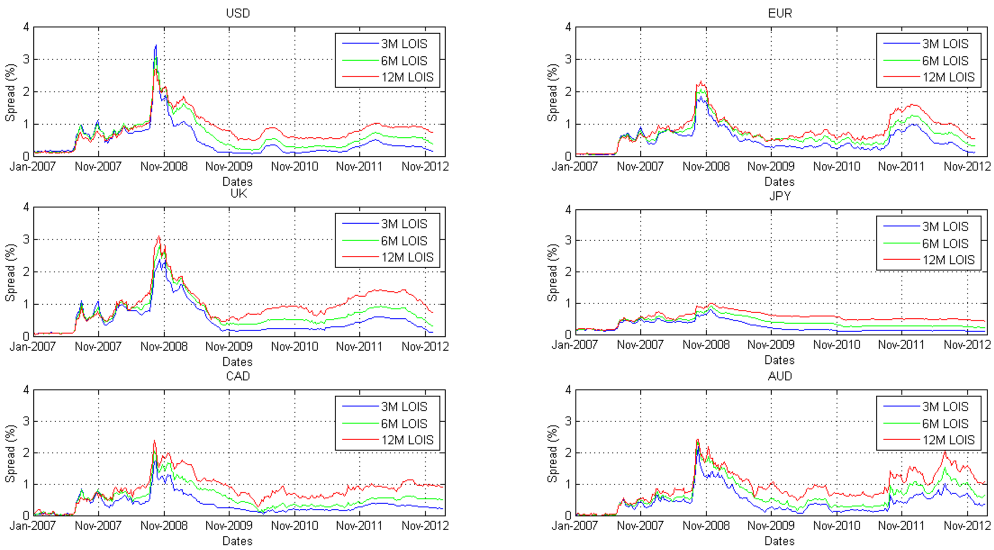

Figure 4.1: The figure plots the 3-month (blue line), 6-month (green line) and 12-month (red line) Libor-OIS spreads observed in the market for the United States, Europe, United Kingdom, Japan, Canada and Australia for the period of January 2007 to December 2012.

Figure 4.1 presents the Libor-OIS spread for the 3-month, 6-month and 12-month maturities for all six currencies. In short, the period 2007-2012, the spread between the two rates has undergone substantial variations. Following the sharp increase in October 2008 [12], the spread started progressively decreasing. This was followed by a two year period where the spread was stabilised at relatively low levels, until November 2011 when a sharp increase observed again. Another interesting observation is that spreads tend to increase more for longer term interest rates. This is the case for all six markets, providing that they all reset in tandem to global economic conditions.

Table 4.1 reports summary statistics for the interest rates and spreads data of each country. Not surprisingly, data of different countries share similar features. In all countries, average spreads are increasing with respect to maturity; for example, the average spread for the USD increases from 31 basis points for the 1-month spread to 80 basis points for the 12-month spread. The slope of the term structure is mainly upward and time-varying. This is also depicted in figure 4.1. Overall, the JPY has the lowest average spreads (increasing from 14 bps to 54 bps), whereas the UK and AUD markets have the highest average spreads (increasing from 27 bps to 95 bps and from 23 bps to 90 bps for the UK and AUD respectively).

Standard deviations of spreads are generally increasing with maturity in all countries. This is in contrast with the volatilities of actual interest rates which either decreasing with maturity or present a humped shape. Furthermore, spread volatility tends to be higher in countries such as the UK and the AUD and much lower in the JPY. This could be an initial indication that the JPY money markets have experienced less liquidity and /or credit pressures than other countries.

Table 4.1 also reports higher order moments. For all currencies and across all maturities, both interest rates and spreads are positively skewed (spreads are more positively skewed though). Furthermore, interest rates possess negative kurtosis, which indicates a 'light-tailed' distribution. However, this is not the case for the spreads, where the positive kurtosis indicates a 'heavy-tailed' behavior. This is observed at the end of 2008, where the spreads reached their highest values.

Finally, all spreads seem to be highly persistent. All countries possess a first-order autocorrelation of over 0.94 across maturities. In JPY, autocorrelation for maturities more than 1-month

[12]Historically, the spread was around 10 bps, the period before 07/2007. When the Bank of England announced the rescue of Northern Rock, the spread increased to 62 bps (14/09/2007). The next increase was observed at the time when UBS and Lehman announced huge write downs, where the spread reached at 82 bps (14/12/2007). Finally, the spread rose to 222 bps on 10/10/2008, following Lehman's default.

Table 4.1: Descriptive Statistics.

	LIBOR					OIS					LOIS Spread				
Maturity	1M	3M	6M	9M	12M	1M	3M	6M	9M	12M	1M	3M	6M	9M	12M
USA															
min	0.1854	0.2458	0.3843	0.5580	0.7234	0.0718	0.0719	0.0717	0.0737	0.0751	0.0538	0.0667	0.1085	0.0940	0.0862
max	5.8050	5.7071	5.5685	5.4493	5.4873	5.0758	5.2657	5.2899	5.3318	5.3764	3.2585	3.4439	3.0787	2.8594	2.6823
mean	1.5309	1.7026	1.8881	2.0011	2.1205	1.2175	1.2478	1.2579	1.2785	1.3165	0.3134	0.4548	0.6303	0.7226	0.8040
std	1.9418	1.9020	1.7949	1.6892	1.5940	1.7668	1.8083	1.7966	1.7743	1.7492	0.4150	0.4834	0.5010	0.4742	0.4587
skewness	1.1288	1.0524	0.9946	1.0105	1.0239	1.3310	1.3587	1.3745	1.3743	1.3586	3.8148	2.8893	1.9942	1.7500	1.3219
kurtosis	-0.4039	-0.5163	-0.5725	-0.5036	-0.4414	0.1166	0.2115	0.2828	0.3087	0.2936	18.8265	11.4314	4.9590	4.0138	2.7590
Autocorr	0.9976	0.9983	0.9987	0.9986	0.9983	0.9995	0.9995	0.9995	0.9993	0.9992	0.9532	0.9757	0.9863	0.9873	0.9876
EUR															
min	0.1090	0.1950	0.3738	0.4898	0.5974	0.0852	0.0680	0.0476	0.0462	0.0448	0.0119	0.0459	0.0516	0.0514	0.0518
max	5.1546	5.3778	5.4342	5.4584	5.4992	4.3087	4.3397	4.4185	4.5590	4.6337	1.2785	1.8420	2.0772	2.2247	2.3197
mean	1.9288	2.2002	2.3905	2.5033	2.6068	1.7010	1.7104	1.7381	1.7745	1.8143	0.2278	0.4899	0.6524	0.7287	0.7925
std	1.6774	1.6928	1.6094	1.5661	1.5301	1.6041	1.6168	1.6234	1.6183	1.6069	0.2440	0.3484	0.3822	0.4157	0.4455
skewness	0.5988	0.6140	0.6258	0.6197	0.6179	0.6558	0.6759	0.6854	0.6881	0.6854	2.0023	1.4007	1.1785	1.0501	0.8718
kurtosis	-1.4188	-1.3627	-1.3278	-1.3106	-1.2757	-1.4197	-1.3898	-1.3619	-1.3334	-1.3047	4.5500	2.6145	2.4918	2.0084	1.3199
Autocorr	0.9990	0.9993	0.9993	0.9993	0.9992	0.9993	0.9994	0.9992	0.9990	0.9988	0.9631	0.9857	0.9871	0.9872	0.9883
UK															
min	0.5000	0.5265	0.6968	0.8859	1.0770	0.3730	0.3178	0.3172	0.2871	0.2612	0.0341	0.0512	0.0420	0.0431	0.0511
max	6.7238	6.8813	6.7708	6.6630	6.6243	5.9392	5.9349	6.0803	6.1882	6.2747	1.8136	2.3778	2.7843	2.9913	3.1096
mean	2.3262	2.5701	2.7628	2.9158	3.0524	2.0588	2.0451	2.0457	2.0637	2.0987	0.2674	0.5250	0.7171	0.8521	0.9537
std	2.3600	2.3559	2.2563	2.1611	2.0764	2.2529	2.2586	2.2611	2.2494	2.2274	0.3152	0.4695	0.5050	0.5258	0.5495
skewness	0.7440	0.6986	0.6918	0.6963	0.7059	0.7962	0.8132	0.8327	0.8478	0.8581	2.6557	1.8534	1.8398	1.5229	1.0822
kurtosis	-1.3648	-1.4059	-1.4186	-1.4100	-1.3897	-1.3070	-1.2793	-1.2361	-1.1943	-1.1548	7.9880	3.5163	4.1681	3.6051	2.4276
Autocorr	0.9988	0.9991	0.9991	0.9990	0.9989	0.9994	0.9994	0.9994	0.9993	0.9992	0.9617	0.9870	0.9887	0.9887	0.9883
JPY															
min	0.1193	0.1771	0.2823	0.4054	0.4871	0.0629	0.0590	0.0555	0.0530	0.0482	0.0259	0.0902	0.1255	0.1346	0.1293
max	1.0440	1.0818	1.1775	1.2428	1.3245	0.5998	0.6686	0.7208	0.7952	0.8590	0.7377	0.7796	0.9003	0.9666	1.0072
mean	0.3548	0.4684	0.6054	0.7132	0.7839	0.2174	0.2224	0.2292	0.2368	0.2467	0.1374	0.2460	0.3763	0.4764	0.5372
std	0.2718	0.3076	0.2753	0.2399	0.2297	0.1912	0.2015	0.2155	0.2294	0.2452	0.1299	0.1645	0.1645	0.1651	0.1781
skewness	0.7999	0.5842	0.4865	0.4896	0.4954	0.8382	0.8702	0.9400	1.0029	1.0552	2.3021	1.1004	0.8838	0.2561	-0.1437
kurtosis	-0.9266	-1.3395	-1.3363	-1.2663	-1.2226	-1.2095	-1.0857	-0.8578	-0.6567	-0.4883	5.4370	0.1386	0.2768	0.5697	0.7056
Autocorr	0.9925	0.9982	0.9979	0.9979	0.9978	0.9970	0.9977	0.9978	0.9972	0.9969	0.9730	0.9937	0.9926	0.9921	0.9925
CAD															
min	0.2933	0.3993	0.6963	0.9818	1.2382	0.2365	0.2391	0.2304	0.2537	0.2993	0.0058	0.0003	-0.0007	-0.0072	-0.0358
max	5.2223	5.3040	5.2527	5.1367	5.0787	4.5134	4.6335	4.7393	4.8137	4.8740	1.6185	1.7310	2.0559	2.2732	2.3848
mean	1.8955	2.0383	2.2269	2.3889	2.5785	1.7119	1.6923	1.6892	1.7164	1.7637	0.1836	0.3460	0.5377	0.6725	0.8147
std	1.5436	1.4963	1.3896	1.2952	1.1924	1.4744	1.4593	1.4372	1.4164	1.3952	0.2254	0.2889	0.3632	0.4006	0.4332
skewness	0.8039	0.8004	0.8290	0.8396	0.8433	0.8693	0.9207	0.9772	1.0079	1.0342	2.8868	1.9823	1.4081	1.1400	0.6101
kurtosis	-0.9267	-0.9386	-0.9093	-0.9082	-0.8831	-0.8443	-0.7289	-0.5819	-0.4974	-0.4330	10.2702	4.8278	2.6476	2.0762	1.1168
Autocorr	0.9987	0.9988	0.9985	0.9980	0.9975	0.9994	0.9994	0.9989	0.9984	0.9979	0.9437	0.9758	0.9827	0.9827	0.9837
AUD															
min	3.1420	3.2380	3.3720	3.5253	3.6867	2.9091	2.5290	2.3360	2.2800	2.2840	-0.1469	-0.0808	-0.0730	-0.0569	-0.0551
max	8.0200	7.9793	8.1560	8.3760	8.6285	7.2950	7.3926	7.5424	7.6656	7.7624	1.6529	2.1910	2.3845	2.4650	2.4190
mean	5.0473	5.1978	5.3729	5.5408	5.7115	4.8178	4.7719	4.7471	4.7635	4.8059	0.2295	0.4259	0.6258	0.7773	0.9056
std	1.3527	1.3735	1.3344	1.3019	1.2757	1.3853	1.4467	1.5275	1.5788	1.6068	0.2487	0.3604	0.4516	0.4873	0.5081
skewness	0.5118	0.6110	0.6795	0.6718	0.6091	0.4417	0.4348	0.4006	0.3545	0.3125	2.4369	1.4916	1.0662	0.6796	0.3022
kurtosis	-0.9709	-0.8586	-0.7572	-0.6647	-0.6045	-1.0836	-1.0838	-1.0996	-1.1204	-1.1334	8.4148	2.9223	1.1204	0.3166	-0.1665
Autocorr	0.9978	0.9980	0.9977	0.9972	0.9965	0.9986	0.9980	0.9973	0.9971	0.9968	0.9589	0.9770	0.9830	0.9828	0.9822

The table reports descriptive statistics for the 1-month, 3-month, 6-month, 9-month and 12-month Libor rates, OIS rates and Libor-OIS spreads for the United States, Europe, United Kingdom, Japan, Canada and Australia. All numbers (other than autocorrelation) are in % per year. The sample is from January 2007 to December 2012.

is above 0.99. The picture is quite similar for cross-correlations as well. Correlations between distant maturities (1-month and 12-month) are on the range of 0.6 (for USD, JPY and CAD) to 0.8 (for EUR, UK and AUD), while, correlations between nearby maturities are above 0.98. This cross-correlation feature indicates that in order to explain the behavior of spreads across maturities, only a small number of factors is needed.

4.2 The Credit Risk Factor

Different proxies for the credit risk component have been proposed in the related literature [13]. In this paper we follow Liu et al. (2006), Feldhütter and Lando (2008), Michaud and Upper (2008) and Smith (2012) to proxy the credit risk component with the spread between the 3-month Libor rate and the 3-month GC repo rate [14]. This spread represents the difference between secured (i.e. repo) and unsecured (i.e. Libor) lending between financial institutions, at the same maturity. In the repo market, financial players can borrow short-term (usually overnight) funds on a fully collateralised basis, by providing collateral to their counterparties in the form of liquid government securities, mainly Treasury bills. According to Longstaff (2000) and Liu et al. (2006), the collateralized nature of the repo market makes these contracts virtually free of default risk. This means that any difference between the two rates can be regarded as coming due to credit risk.

The use of Libor-repo spread as a proxy for the credit risk factor, has been criticised by recent studies. Filipović and Trolle (2013) and Feldhütter and Lando (2008) argue that this spread incorporates liquidity premia as well, and as such is not suitable in capturing the credit risk premium, especially at the longer end of the swap curve.

However, the reason we have decided to use this specific spread as a credit risk proxy, is that we would like to be consistent across the six currencies, which means, that we would like to build an appropriate measure, using data that are widely available across the set of currencies used in our analysis.

In addition, for robustness checks we use different measures of the credit factor, mainly for the US market, including, first, the spread between asset-backed commercial paper and dealer-placed commercial paper, since according to Taylor and Williams (2009) this spread is a good measure of default risk. The second measure, discussed in McAndrews et al. (2008) and Michaud and Upper (2008) is the daily time series of the JP Morgan banking sector CDS Index, since CDS prices of the banks can be a natural proxy of the credit risk of the interbank loans.

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[13]See, Duffie and Singleton (1997), Liu et al. (2006) and Feldhütter and Lando (2008) for the analysis of swap spreads, or Taylor and Williams (2009), Smith (2012) and Filipović and Trolle (2013) for the analysis of the interbank market.

[14]A similar measure has been used by He (2001), who use the 1-month Libor-repo spread as a proxy for credit risk.

4.3 The Liquidity Risk Factor

Regarding the liquidity risk component, a number of different measures of liquidity risk [15] have been proposed in the fixed-income literature (see, Longstaff (2004), Brunnermeier (2008), Beber et al. (2009), Schwarz (2010) and Filipović and Trolle (2013), among others). In this study, we mainly follow Brunnermeier (2008) and Krishnamurthy (2010) to proxy the liquidity risk component with the spread between the 3-month OIS rate and the 3-month Treasury bill rate. T-bills are assumed to be the most liquid short-term debt instruments in the fixed income market. Since both rates are regarded as default free, their spread is assumed to be driven by liquidity premia.

For robustness, we have used two different measures that have been proposed, recently, to study the US and EUR markets. The first one is the spread between the just issued (on-the-run) 10-year US Treasury security and the 10-year US Treasury bond issued three months ago (off-the-run). [16] The two bonds have identical characteristics, since they are issued by the same government, and similar future cash-flows, but the on-the-run bond is significantly more liquid than the off-the-run. The second one, which is studied in Brunnermeier (2008) and is used in Filipović and Trolle (2013), is the spread between the 3-month Mortgage Backed Security (MBS) General Collateral (GC) repo rate and the 3-month Treasury GC repo rate. It is denoted as a funding liquidity measure, since it reflects the difference in the cost of funding between securities.

5 Estimation and Empirical Results - Observed Factors

5.1 Estimation

We define the difference between the market and the model Libor-OIS spread as,

$$n_t^{(n)} = z_t^{(n)} - \hat{z}_t^{(n)} = z_t^{(n)} - \left(\hat{A}_{lib,(n)} - \hat{A}_{ois,(n)}\right) - \left(\hat{B}'_{lib,(n)} - \hat{B}'_{ois,(n)}\right) X_t \tag{17}$$

[15] In this study liquidity risk incorporates both market and funding liquidity. Assessing them separately (see, Brunnermeier and Pedersen (2009)) is not in the scope of this study.

[16] Longstaff (2004) constructed a similar measure of liquidity risk, by subtracting bonds issued by the Refcorp (US Government Agency), from US Treasury bonds. Furthermore, more recently, Schwarz (2010) built a similar measure in the euro area market by comparing the German Government bonds with the KfW agency bonds. In both cases, bonds are guaranteed by the same entity, and as such, they possess similar credit quality characteristics.

where, $z_t^{(n)}$ denotes the observed spreads and $\hat{z}_t^{(n)}$ are the predicted ones. We proceed by using the two step estimation procedure, described in Ang and Piazzesi (2003).

First, using Ordinary Least Squares (OLS), we estimate the VAR dynamics and the coefficients of the short rate equation, δ_0 and δ_1; in other words, we estimate, $\Theta_1 = (\Phi, \Sigma, \delta_0, \delta_1)$. The short rate coefficients are estimated according to equation (11), with $R_t^{lib,(1)}$ being the one week Libor rate and δ_1' being constrained as, $\delta_1 \equiv (1, k_1, k_2)$. The first element of δ_1 corresponds to OIS rate and is constrained to be one. The lag order of the VAR process was selected by using the Akaike's Information Criterion (AIC). The selected lag order is one, which leads to a three dimensional VAR(1) process.

In the second step, we hold Θ_1 fixed, and we estimate the market price of risk parameters λ_0 and λ_1 using non-linear least squares. The minimisation procedure is given by,

$$\min_{\lambda_0,\lambda_1} \sum_{t=1}^{T} \sum_{n=1}^{N} n_t^{(n)} \tag{18}$$

Achieving convergence in this highly non-linear system is a challenging process. In order to find good starting values, we follow the related literature (see, Ang and Piazzesi (2003) and Hamilton and Wu (2012), among many others) and estimate the model several times.

5.2 Empirical Results

In table 5.1 we report the estimated parameters of the model, for the six different markets. Matrix Σ is Cholesky-factorized and parameters P are given as, $P = chol(\Sigma\Sigma')$. Furthermore, estimates of the market price of risk parameters are reported.

In figure 5.1, we present the short term (one week) rates and the estimated premium, $\hat{k}_t$, for all six currencies. This is the premium described in section 3.1, which has been estimated by regressing the one week Libor-OIS spread to a credit and a liquidity factor. The blue line describes the observed one week OIS rate, the green line is the estimated one week Libor rate and the red line is the estimated premium $\hat{k}_t$, given as, $\hat{k}_t = \hat{R}_t^{lib,(1)} - R_t^{ois,(1)}$.

As we can observe, all markets depict similar characteristics. The short term premium increased the period before mid 2009 and reached its peak value during the panic period of Lehman's default. It is clearly higher in the US market, where, during the peak of the crisis, it reached a level of more than 2%, compared to the rest of the markets, where it did not increase beyond 1%. After mid 2009, the premium seems to have settled down, although, there is a period around

Table 5.1: Parameter estimates - Observed factors.

Parameters	USA	EUR	UK	JPY	CAD	AUD
Φ_{11}	0.9823	0.9983	0.9913	0.9932	0.9892	0.9985
	(0.0312)	(0.0264)	(0.0350)	(0.0410)	(0.0137)	(0.0298)
Φ_{12}	-0.0475	-0.0755	-0.1163	-0.0147	-0.0282	-0.0278
	(0.0419)	(0.0511)	(0.223)	(0.0192)	(0.0199)	(0.0222)
Φ_{13}	-0.0954	-0.0334	0.0871	0.0757	-0.0119	-0.0228
	(0.1721)	(0.0918)	(0.0449)	(0.0289)	(0.3820)	(0.0019)
Φ_{21}	-0.0196	0.0066	0.0069	0.0264	0.0044	-0.0123
	(0.0374)	(0.0823)	(0.0781)	(0.0217)	(0.0041)	(0.0197)
Φ_{22}	0.8643	0.9206	0.9703	0.9644	0.9515	0.9370
	(0.0221)	(0.0721)	(0.0214)	(0.0082)	(0.0361)	(0.0719)
Φ_{23}	0.2617	0.1435	-0.1031	-0.0418	-0.1039	0.0191
	(0.0910)	(0.0185)	(0.0090)	(0.0372)	(0.0657)	(0.0735)
Φ_{31}	0.0118	0.0032	0.0007	0.0029	0.0124	0.0046
	(0.0063)	(0.0972)	(0.0751)	(0.0672)	(0.0285)	(0.0184)
Φ_{32}	-0.0157	-0.0038	-0.0076	-0.0490	0.0096	-0.0177
	(0.0472)	(0.0021)	(0.0037)	(0.0318)	(0.0472)	(0.0923)
Φ_{33}	0.8482	0.9143	0.8421	0.7955	0.8803	0.9837
	(0.0017)	(0.0352)	(0.0910)	(0.0660)	(0.0315)	(0.0404)
P_{11}	0.1131	0.1231	0.0973	0.0206	0.0689	0.0883
P_{21}	0.0116	0.0020	0.0061	0.0022	-0.0154	0.0172
P_{22}	0.1343	0.0523	0.0780	0.0197	0.1969	0.1975
P_{31}	-0.0060	-0.0003	-0.0032	-0.0025	-0.0064	0.0263
P_{32}	0.0279	0.0312	0.0104	-0.0009	0.0193	0.0323
P_{33}	0.0918	0.0872	0.0482	0.0135	0.0882	0.1052
δ_0	-0.0452	-0.0357	-0.0010	-0.0231	-0.0722	0.1687
	(0.0191)	(0.0109)	(0.0096)	(0.0059)	(0.0278)	(0.0445)
$\delta_{1,1}$	1	1	1	1	1	1
$\delta_{1,2}$	0.5918	0.0208	0.3095	0.2060	0.0568	0.2702
	(0.0393)	(0.0205)	(0.0143)	(0.0435)	(0.0139)	(0.0278)
$\delta_{1,3}$	0.3503	0.2730	0.0107	-0.9320	0.3388	0.0163
	(0.0831)	(0.0316)	(0.0621)	(0.1408)	(0.0401)	(0.0158)
$\lambda_0(1)$	-3.326	1.587	1.933	-2.724	1.703	-1.924
	(0.3924)	(0.1118)	(0.2839)	(0.0736)	(0.2931)	(0.6372)
$\lambda_0(2)$	-0.913	-2.503	0.871	1.229	2.027	-1.749
	(0.0843)	(0.2146)	(0.0371)	(0.0319)	(0.1731)	(0.2429)
$\lambda_0(3)$	0.426	-0.792	-0.974	-0.831	0.927	-0.551
	(0.2833)	(0.0184)	(0.0819)	(0.0027)	(0.1937)	(0.3621)
$\lambda_1(1,1)$	1.522	0.843	-1.116	1.291	1.793	0.996
	(0.07314)	(0.0134)	(0.7389)	(0.0028)	(0.0842)	(0.3722)
$\lambda_1(1,2)$	-0.401	0.27	1.167	-0.832	0.717	1.118
	(0.3332)	(0.1838)	(0.0872)	(0.0319)	(0.0823)	(0.0642)
$\lambda_1(1,3)$	-0.158	0.37	0.454	0.271	-0.512	0.449
	(0.0735)	(0.0213)	(0.3742)	(0.0183)	(0.3418)	(0.0432)
$\lambda_1(2,1)$	0.339	-0.297	0.667	-0.616	0.331	0.492
	(0.0459)	(0.0239)	(0.0328)	(0.0947)	(0.0463)	(0.2938)
$\lambda_1(2,2)$	-0.231	-0.14	-0.333	-0.193	-0.431	-0.319
	(0.1821)	(0.0642)	(0.0397)	(0.0485)	(0.0047)	(0.0748)
$\lambda_1(2,3)$	-0.929	-1.016	0.473	-0.941	-1.416	0.729
	(0.8274)	(0.0284)	(0.2939)	(0.5832)	(0.0377)	(0.0858)
$\lambda_1(3,1)$	-0.029	-0.619	-0.192	1-0.172	-0.394	-0.518
	(0.0467)	(0.8573)	(0.0982)	(0.0831)	(0.3727)	(0.1354)
$\lambda_1(3,2)$	0.293	-0.018	0.726	-0.931	-0.331	0.182
	(0.0112)	(0.3728)	(0.0273)	(0.0916)	(0.0474)	(0.1916)
$\lambda_1(3,3)$	0.697	0.193	-0.731	0.281	0.793	-0.821
	(0.0028)	(0.0273)	(0.0848)	(0.0037)	(0.0736)	(0.0645)

This table reports parameter estimates and standard errors of the VAR dynamics, the short rate and the price of risk, for the United States, Europe, United Kingdom, Japan, Canada and Australia.

November 2011, where it has an increased behavior. This is more clear in the EUR market, mainly due to the solvency issues that some member states faced during this specific period.

To assess the effect and the relative importance of each one of the factors for the dynamics of the spreads, we perform an impulse response analysis in the VAR model. More specifically, we

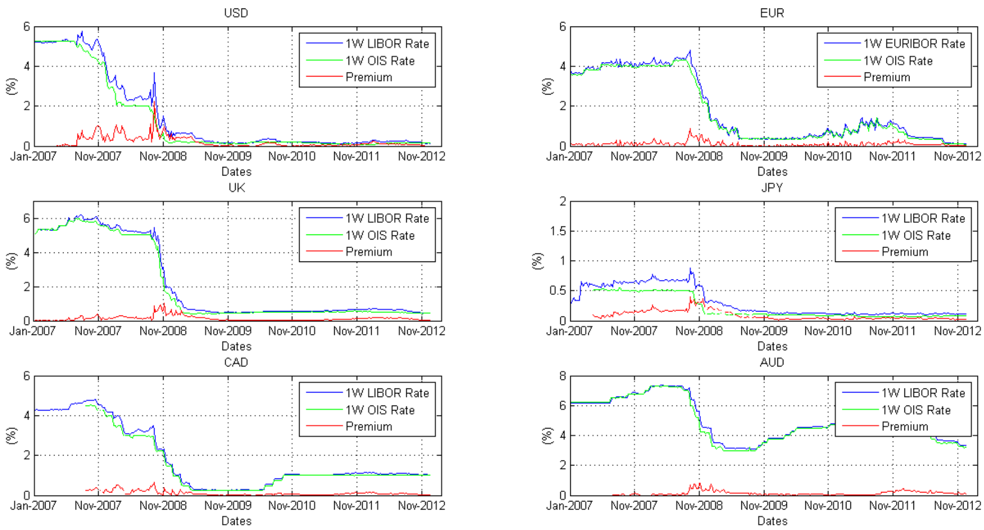
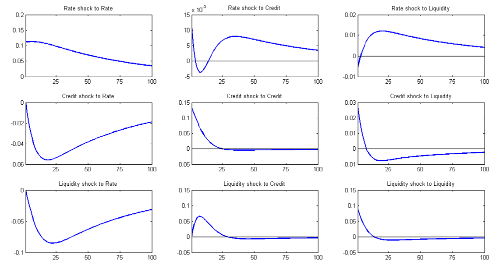


Figure 5.1: The figure plots the observed 1-week OIS rate (blue line), the 1-week estimated LIBOR rate (green line) and the estimated short-term premium (red line) for the United States, Europe, United Kingdom, Japan, Canada and Australia. The premium is estimated by regressing the 1-week Libor-OIS spread to the credit and liquidity proxies.

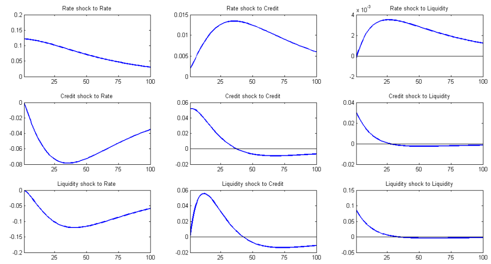
attempt to investigate what is the impact of a one standard deviation shock of each one of the three factors to the rest of the factors. Figures 5.2a to 5.2f present the impulse response functions of the VAR for the six currencies used in our analysis. Each figure contains three panels, each one depicting the dynamic responses of the interest rate, the credit and the liquidity factors when a shock is given to a particular factor. This means that the second panel of the first row presents how the credit factor responds to a shock in the interest rate factor.

During the sample period, a shock in the interest rate factor positively affects the credit factor for all currencies. The only exception is the Canadian Dollar, where the shock has a negative impact on its credit factor. Furthermore, in the case of the US market, the impact on the credit factor was initially negative, but then, very quickly it becomes positive. This implies that the standard policy of Central banks to lower the interest rates, decreased the credit pressures in most countries, with the exception of the Canadian market. However, in the case of the Australian Dollar, this positive effect is not that persistent as it appears to be in the other currencies, since it only lasts for a small period of time (around 10 days) and dies out quickly. The reason is that the Australian Central bank, although followed the other central banks at lowering their interest rates, however this decrease was not that deep, as the interest rates did not fall at their lowest possible levels, which was the case of the other Central banks.

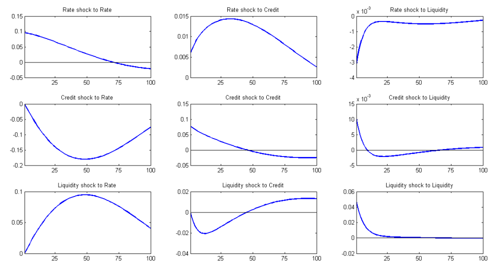
On the other hand, the liquidity factors are not significantly affected by the shock in the



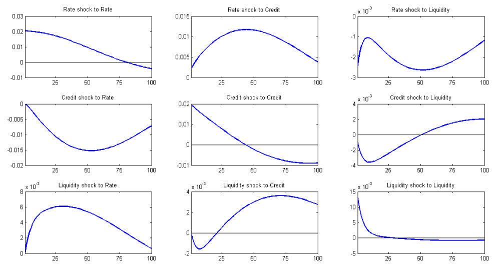
(a) USA



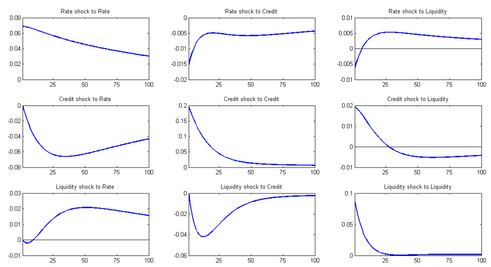
(b) EUR



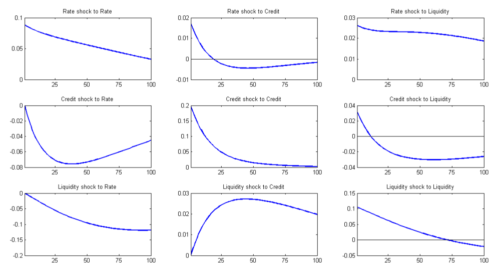
(c) UK



(d) JPY



(e) CAD



(f) AUD

Figure 5.2: The figure plots the impulse response functions of the VAR model for the United States (a), the Europe (b), the United Kingdom (c), Japan (d), Canada (e) and Australia (f). Each panel depicts the dynamic responses of the interest rate, the credit and the liquidity factors.

interest rate factor, since most of the effects are non-zero (positive) but smaller than one basis point. However, in the JPY market the effect has a negative impact on its liquidity factor, with this impact being quite persistent.

Now let's examine what is the impact of a shock in the credit factor to the other two factors. Neither the interest rate factor nor the liquidity factor showed any significant responses, since most effects seem to be smaller than five basis points in all currencies. The only exception is the impulse response of the AUD market, where the impact is significantly larger (about ten times) than the other currencies. This means that credit pressures in the interbank market created liquidity problems as well. Since the interest rates of the Australian Central bank remained higher than the other markets, the credit pressures were significantly higher.

Furthermore, an interesting conclusion comes from the Japanese market, where the impact of the credit shock is initially negative (and it remained negative for a long period of time) and then becomes positive. This indicates that the Japanese market experienced less liquidity pressure than other currencies. This could mean that the Japanese financial institutions were less exposed to sub-prime related products, which means lower credit issues.

Finally, let's examine the effect that a liquidity shock would have on the credit factor. Most currencies (USD, EUR, AUD) seem to have similar reactions to shocks, although the response on the Australian Dollar seems to be more persistent than the other two currencies. Furthermore, in the UK and JPY markets, the shock has an initially negative effect, which after a period of time (much shorter in the JPY case) becomes positive. This implies that as the liquidity in the market deteriorates, which is what happened during the crisis, the credit pressures start increasing. But we can also look on the other side of the coin and argue that if the liquidity in the market increases (through Central banks' liquidity facilities), then the impact is positive and credit pressures deteriorate.

At this point, it is important to mention that for robustness we have also investigated other modelling assumptions, by using different proxies for the credit and liquidity risks, as explained in sections 4.2 and 4.3. Since our empirical results are found to be qualitatively similar and do not particularly alter our conclusions, they are not presented here [17].

6 Estimation and Empirical Results - Latent Factors

6.1 Estimation

In this section we undertake an alternative estimation procedure by assuming that all three state variables (factors) are completely non-observable (latent). In other words, we treat the short interest rate, the liquidity risk factor and the credit risk factor as latent variables, avoiding the use of common proxies that adversely influence the results. The advantage of estimating the model using non-observable variables is that, this way, we avoid applying ex-ante restrictions on the behaviour of the factors determining the spreads.

Since the factors that determine the dynamics of the Libor-OIS spread are treated as non-observable and the parameters are unknown, a Kalman Filter and a maximum likelihood procedure are chosen for the estimation of the model. This econometric technique allows for a wide range of

[17] Results are available upon request from author.

model specifications which compute the optimal estimate for the state variables at a given moment using all past information available.

Going back to our baseline model, since the three-dimensional vector of state variables X_t is assumed to follow a Gaussian VAR process [18], as in equation (1), and since the spread $Z_t^{(n)}$ falls within the affine class of functions, as in equation (12), a simple linear Kalman Filter is used for the estimation procedure. [19] In a nutshell, the Kalman Filter is an algorithm that computes the optimal estimate for the state variables at a moment in time (t) using the information available up to $(t-1)$.

6.1.1 The State Space Model

The starting point for the derivation of the Kalman Filter is to write the model in state space form, which consists of a measurement (observation) equation and a transition (state) equation. The measurement equation describes the relation between the (unobserved) state variables and the Libor-OIS spread of different maturities, while the transition equation describes the discrete time dynamics of the state variables. The state space representation of the model is written as:

$$X_t = H + AX_{t-1} + u_t \tag{19}$$

$$Z_t = B + DX_t + v_t \tag{20}$$

where, in the transition equation, X_t is a $(k \times 1)$ vector representing the state variables, with k being the number of non-observable exogenous variables (i.e. the factors), and H and A are $((k \times 1)$ and $(k \times k)$ respectively) coefficient matrices that follow from the mean of the transition density. Furthermore, u_t is a $(k \times 1)$ vector of i.i.d. shocks (residuals), distributed as $u_t \sim N(0, Q_t)$, where Q_t is a $(k \times k)$ diagonal matrix with its elements representing the variances of the transition densities of the factors.

In the measurement equation, Z_t is a $(r \times 1)$ vector of observables (i.e. spreads of different maturities), with r being the number of variables (maturities) to estimate, and B and D are

[18] In case of a non-linear (i.e. non-Gaussian) state process, the state equation is approximated by the conditional mean and conditional variance of X_t as in De Jong (2000) and Duffee (2002). In this case, the extended Kalman Filter or the Unscented Kalman Filter is used to infer the latent state variables (see, Christoffersen et al. (2014)).

[19] Duffee and Stanton (2012) suggest that for the Gaussian case the Kalman Filter combined with a Maximum Likelihood Estimator is tractable, consistent and unbiased.

($(r \times 1)$ and $(r \times k)$ respectively) selector matrices that combine elements of the state X_t into observable variables and are constructed from the spread (bond alike) formula discussed in section 3.1. Finally, every Libor-OIS spread is observed with error which is indicated by v_t [20], a $(r \times 1)$ vector of measurement errors distributed as $v_t \sim N(0, R_t)$, where R_t is a $(r \times r)$ diagonal matrix with as many diagonal elements as spread maturities. Assuming R_t to be diagonal, we have followed the usual practice in the empirical term structure literature, where the pricing errors are uncorrelated [21] (see, Hamilton and Wu (2012), Christensen et al. (2014), among others) across different maturities. Furthermore, to reduce the number of parameters in R_t, we apply the same variance σ^2_{error} applies to all pricing errors (see, Feldhütter (2016)). This later assumption, has the advantage of leaving one single parameter to be estimated, without, at the same time, giving materially different estimates, than having one variance for each maturity, as reported by Duffee (2011).

These elements are part of the set of parameters that are estimated with the Kalman Filter and the maximum likelihood method. The values of the errors are an indication of the goodness of fit of the model. If the model gives a perfect fit with the observed spreads, then these errors should be zero.

6.1.2 The Kalman Filter

Given the system of equations (19), (20), the Kalman Filter recursively computes estimates of the unobserved state variables X_t conditional on the history of observations Z_t and an initial estimate $X_{0|0}$ with variance $P_{0|0}$. The estimation of the Kalman Filter is performed as a two-step process, first prediction then update. In the prediction step, the Kalman Filter produces estimates of the current state variables along with their uncertainties. Therefore, the optimal estimator of X_t, the

[20] v_t is added to reflect the possibility of model misspecification and measurement errors in the spreads' data. When v_t is assumed to be zero, the k unobservable factors can be inverted from the spreads (see, Dai and Singleton (2002), Cheridito et al. (2007), Aït-Sahalia and Kimmel (2010), Joslin et al. (2011), Hamilton and Wu (2012)).

[21] Kim and Orphanides (2012) show that allowing for correlated errors in surveys does not affect their results, while being more cumbersome to estimate.

forecast of Z_t and their variance-covariance matrices, $P_{t|t}$ and F_t respectively are given as:

$$\widehat{X}_{t|t-1} = H + A\widehat{X}_{t-1|t-1} \tag{21}$$

$$P_{t|t-1} = AP_{t-1|t-1}A' + Q_t \tag{22}$$

$$\widehat{Z}_{t|t-1} = B + D\widehat{X}_{t|t-1} \tag{23}$$

$$F_t = DP_{t|t-1}D' + R_t \tag{24}$$

As new information becomes available, the mean and the variance-covariance matrices of the Kalman filter may be updated as follows,

$$X_{t|t} = X_{t|t-1} + K_t \left[Z_t - (B + DX_{t|t-1}) \right] \tag{25}$$

$$P_{t|t} = P_{t|t-1} - P_{t|t-1}D'F_t^{-1}DP'_{t|t-1} \tag{26}$$

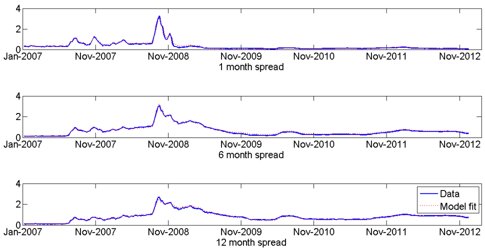
where, K_t is the Kalman gain calculated as, $K_t = P_{t|t-1}D' \left[DP_{t|t-1}D' + R_t \right]^{-1}$. After the updates are carried out, the parameters of the model are recursively estimated by maximizing the log-likelihood function defined by,

$$\log(\theta) = -\frac{nT}{2}\log(2\pi) - \frac{T}{2}\log|F_t| - \frac{1}{2}\sum_{t=1}^{T}\left[\widetilde{Z}_t' F_t^{-1}\widetilde{Z}_t\right] \tag{27}$$

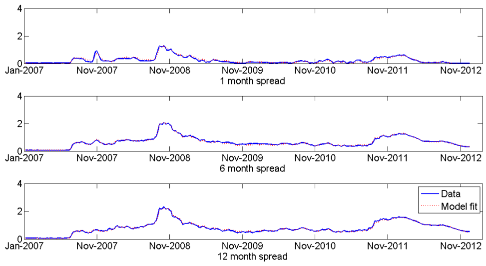
where, $\widetilde{Z}_t = Z_t - Z_{t|t-1}$.

As before, the optimisation procedure will be performed as a minimisation problem. We need to estimate 24 parameters in total, a challenging but not insurmountable numerical task [22]. We initialise the Kalman Filter using the unconditional mean and the unconditional covariance matrix of the state vector. We also use the Kalman smoother to obtain optimal extractions of the latent factors. Finally, to maximise the likelihood, the simulated annealing global optimisation algorithm is used.

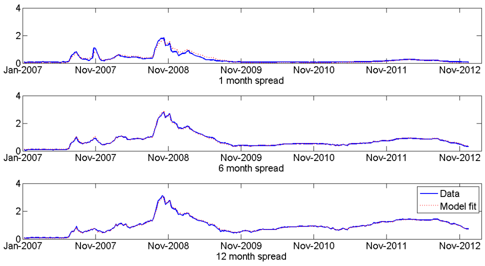
[22] Computational issues associated with the estimated process have been discussed in Ang and Piazzesi (2003), Joslin et al. (2011), Hamilton and Wu (2012) and Duffee and Stanton (2012), among others.



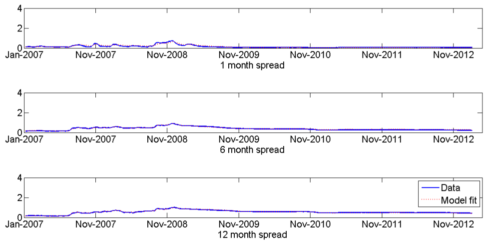
(a) USA



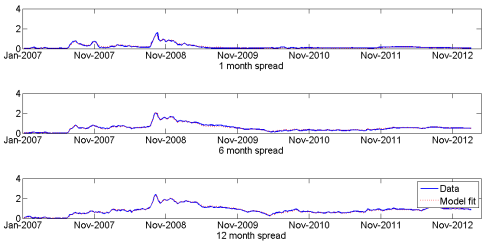
(b) EUR



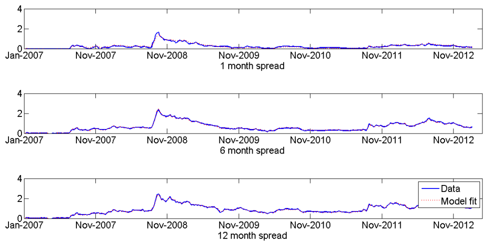
(c) UK



(d) JPY



(e) CAD



(f) AUD

Figure 6.1: The figure plots the 1-month, 6-month and 12-month Libor-OIS spreads predicted by the model for the United States (a), the Europe (b), the United Kingdom (c), Japan (d), Canada (e) and Australia (f) for the period of January 2007 to December 2012. The red dashed line represents the spreads predicted by the model, and the blue solid line represents the observed spreads. Numbers on y-axis are in percentages (%).

6.2 Empirical Results

This section presents the empirical results of the estimation procedure. Figures 6.1a to 6.1f, depict the difference between the estimated time series, produced by the measurement equation, and the observed time series, over the whole sample period and for several maturities. We can observe that the estimates are capable to closely reproduce the data across the maturity spectrum for all six currencies. In table 6.1 we report the estimation results for the parameters of the model. The likelihood functions for all six markets are also reported.

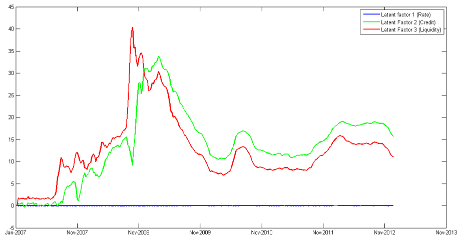
Figures 6.2a to 6.2f, display the latent factors for the credit and liquidity risk components of the Libor-OIS spreads. Similar characteristics are depicted for the first three markets (USA, EUR, UK). This is not a surprising observation though, since, the majority of banks in the Libor panel are considerably overlapped in these markets, as is also mentioned in Taylor and Williams (2009). Furthermore, central banks in the US, EUR, UK and Canada have adopted similar policies in order to increase liquidity risk and decrease credit risk in the market, a practice that is well-documented in Christensen et al. (2014). Early policy actions adopted included liquidity facility programmes (e.g. TAF in US) and foreign exchange swap lines mainly between the Federal reserve and the rest of the central banks, in an attempt to provide US dollar funding in Europe and Canada. This is not the case for JPY and AUD though.

Table 6.1: Parameter estimates - Latent factors.

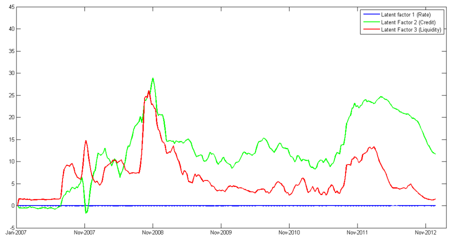
Parameters	USA	EUR	UK	JPY	CAD	AUD
Φ_{11}	-0.6312	-0.6848	0.8504	-0.4104	-0.1307	0.7948
	(0.0371)	(0.0843)	(0.0748)	(0.8243)	(0.0341)	(0.1937)
Φ_{12}	0.0000	0.0000	-0.0000	0.0000	0.0000	0.0000
Φ_{13}	0.0000	-0.0000	0.0000	0.0000	0.0000	0.0000
Φ_{21}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Φ_{22}	0.9928	0.9968	0.9960	0.9287	0.9984	0.9933
	(0.0046)	(0.0928)	(0.0246)	(0.0036)	(0.1737)	(0.0548)
Φ_{23}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Φ_{31}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Φ_{32}	-0.0030	-0.0224	-0.0165	-0.0337	-0.0243	-0.0132
	(0.0017)	(0.0093)	(0.0039)	(0.0758)	(0.0365)	(0.0532)
Φ_{33}	0.9928	0.9516	0.9813	0.9559	0.9414	0.9926
	(0.0058)	(0.0427)	(0.0379)	(0.2836)	(0.7283)	(0.0627)
$\delta_{1,1}$	1	1	1	1	1	1
$\delta_{1,2}$	0.1077	-0.0078	0.0165	0.0116	0.0212	0.0131
	(0.0182)	(0.0793)	(0.0651)	(0.0026)	(0.0743)	(0.1927)
$\delta_{1,3}$	-0.1228	0.0739	0.0642	0.0220	0.0818	0.0481
	(0.1831)	(0.0377)	(0.0589)	(0.0472)	(0.0467)	(0.1937)
$\lambda_0(1)$	-514.0111	458.5216	-497.4512	254.9903	439.1997	-374.8430
	(0.8364)	(0.6451)	(0.8841)	(0.0389)	(0.7393)	(0.9351)
$\lambda_0(2)$	4.5259	-11.6504	-151.2088	33.0057	-69.7690	-154.9321
	(2.3981)	(1.8372)	(13.7367)	(6.9271)	(92.273)	(9.9837)
$\lambda_0(3)$	10.1052	1.4898	35.4187	-1.5194	14.0161	36.5879
	(0.9846)	(4.9234)	(2.3889)	(0.7382)	(3.6183)	(2.8462)
$\lambda_1(1,1)$	-13.1865	-10.3088	11.4008	-7.9923	-10.5901	-8.2284
	(5.2831)	(3.9138)	(1.8421)	(0.0381)	(0.9271)	(1.2873)
$\lambda_1(1,2)$	-0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$\lambda_1(1,3)$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$\lambda_1(2,1)$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$\lambda_1(2,2)$	0.0651	0.0146	-0.0079	2.0612	-0.0027	-0.0143
	(0.0187)	(0.2919)	(0.0927)	(0.1112)	(0.0299)	(0.0562)
$\lambda_1(2,3)$	0.0022	-0.0160	-0.0515	-0.7211	-0.0189	-0.0560
	(0.0012)	(0.0264)	(0.0031)	(0.0932)	(0.0093)	(0.0312)
$\lambda_1(3,1)$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$\lambda_1(3,2)$	-0.0301	0.0204	0.0146	0.0452	0.0159	0.0191
	(0.0018)	(0.0098)	(0.0172)	(0.0481)	(0.0829)	(0.0035)
$\lambda_1(3,3)$	0.0219	-0.0367	-0.0288	-0.0664	-0.0490	-0.0368
	(0.0192)	(0.0054)	(0.0087)	(0.0128)	(0.0382)	(0.0091)
$logL$	-1.702	-2.064	-1.785	-2.738	-2.0577	-2.0186

This table reports parameter estimates and standard errors for the United States, Europe, United Kingdom, Japan, Canada and Australia. The parameters are estimated using a Kalman Filter/MLE.

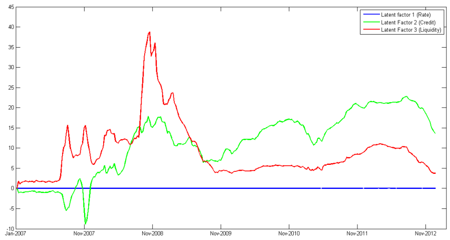
Let us first consider the credit risk component for the six markets. After mid 2007, credit risk started to gradually increasing, reaching each peak level in early 2009. Interestingly, throughout this period, there were a couple of sharp decreases. The first one occurred the period (end 2007),



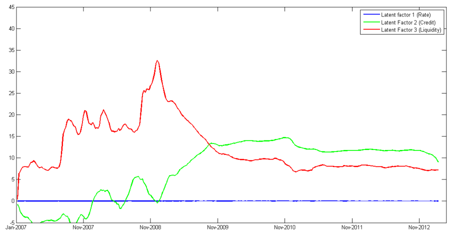
(a) USA



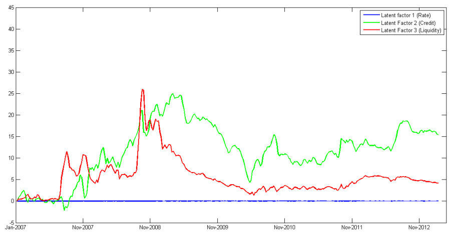
(b) EUR



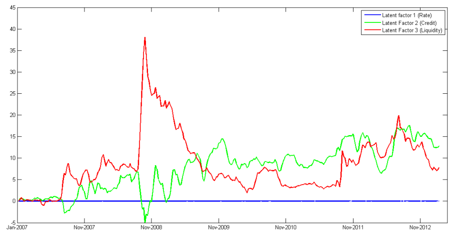
(c) UK



(d) JPY



(e) CAD



(f) AUD

Figure 6.2: The figure plots the latent risk factors for the credit and liquidity risks for the United States (a), the Europe (b), the United Kingdom (c), Japan (d), Canada (e) and Australia (f) for the period of January 2007 to December 2012. The series are filtered out from the observed Libor-OIS spread using the Kalman Filter. All time series are measured in basis points.

when the large financial institutions announced large write downs. The second, smaller, drop occurred in mid 2008. However, by November 2008, the credit risk component started increasing again, reaching its peak level during the first months of 2009. By that time onwards, credit risk started deteriorating, mainly due to the fact that most major Central banks started applying substantial cuts in their policy rates, which had an effect on the credit risk component, pushing it further down. This is evident across all markets other than the JPY. These findings are in line with our preliminary analysis in section 5.2, where we concluded that the policy of the major Central banks to cut their interest rates, resulted in the deterioration of credit risk.

Interestingly though, the Japanese market has experienced a remarkably low credit stress during the first phase of the financial crisis (i.e. until mid 2009), where the markets were under severe pressures. This clear difference in credit risk between the JPY and the rest of the currencies is due to the fact that the Japanese financial institutions were not heavily exposed to subprime related products compared to other markets. Furthermore, the low interest rate environment together with the effectiveness of the different policy measures (e.g. swap scheme, purchase of bonds, etc.) employed by the Bank of Japan, helped in deteriorating credit risk.

Finally, what is interesting to note, is that the credit risk component in the UK, and especially in the EUR market remained to a very high level, almost reaching its peak value, the periods of mid 2010 and end of 2011. The first period represents the escalation of the European sovereign debt crisis, often marked by the downgrade of Greece's debt to non-investment grade status by Standard and Poor's on April 27, 2010. The second one reflects the sovereign debt crisis of countries in the periphery of the Eurozone (e.g. Ireland, Spain, Portugal), which clearly had a positive impact on the increase of credit pressures in the interest rate markets, as also reported in Ang and Longstaff (2011).

Regarding the liquidity risk component, figures 6.2a to 6.2f display that liquidity risk started gradually increasing the period after mid-2007, i.e. around the same period that the increase in the Libor-OIS spread started being evident. In contrast to the credit risk factor, the liquidity risk factor experienced two steep increases on its value prior to October 2008. The first one occurred in August 2007, just before Bank of England announce the rescue of Northern Rock, which is considered as the beginning of the financial crisis. The second one occurred in December 2007, around the time when UBS and Lehman announced large write downs. However, there was a sharp increase in its value, around the time (October 2008) that is characterised as the core of the financial crisis, because of Lehman's default. This sharp increase is evident in all six markets, where the liquidity factor reached its peak value and is clearly the dominant driver of the Libor-OIS spread. This is in line with previous studies (see, Beber et al. (2009)) that attempt to disentangle credit and liquidity risk components in the fixed income market and argue that in periods of market turmoil, investors tend to chase liquidity rather than credit quality. This created huge liquidity pressures that resulted in a remarkably high liquidity risk component compared to the credit risk component.

An interesting observation comes from the US market, where the level of liquidity risk is much higher than in the other currencies. A number of reasons are responsible for this. First, the US market was, arguably, more exposed to subprime related products compared to the other markets. Second, what played an important role was the shortage of US dollar as a funding currency, a factor that influenced liquidity, mainly, in the US and in foreign markets, until new policy measures (e.g. swap schemes) took place by major Central banks. Third, a large number of financial institutions' liabilities were transferred to the government balance sheet through the credit facility programmes (i.e. Capital purchase programme, Troubled asset relief programme, etc.), which raised concerns about the increase of the US deficit and created an extra layer of pressures in the market.

Finally, another interesting observation comes from the Australian market, where the liquidity component did not decrease as much as in the other currencies. In fact during the period of 2012, liquidity risk seems to be the main driver of the spread. The interpretation is mainly twofold; first, the Reserve Bank of Australia did not follow the other Central banks in substantially cutting its policy rates at the lowest possible levels (i.e. zero lower bound). Additionally, it even increased its official cash rate from the level of 3% in mid 2009 to 4.75% at the end of 2010, where it stayed for a year, before decreasing it again in 2012. Secondly, in contrast to the rest of Central banks, Australia mainly relied on conventional policy measures rather than the unconventional ones adapted by the rest.

In short, prior to Lehman's default in October 2008, the Libor-OIS spread was mainly driven by the liquidity component, with the credit component accounting only a small part (in line with Michaud and Upper (2008), Eisenschmidt and Tapking (2009), Gefang et al. (2011) and Christensen et al. (2014)). In the aftermath of Lehman's default however, liquidity risk started decreasing. The reason is that most Central banks started establishing unconventional monetary policy programs (e.g. massive liquidity injections, purchase of government bonds and/or non-traditional assets, such as covered bonds (ECB), agency bonds (Fed) or corporate bonds (BoE)), which resulted in helping the banking system acquiring a high level of excess reserves, which arguably helped liquidity risk to deteriorate. This is in line with previous studies on the analysis of the interbank market which argue that liquidity facility programmes were effective in decreasing liquidity pressures (see, McAndrews et al. (2008), Wu (2008) and Christensen et al. (2014)). By mid 2009, and until the end of our sample period, liquidity risk was less of an issue (with the exception of AUD) and the main driver of the spread was credit risk.

6.3 Decomposing the Risk Premium

What we believe is of great importance for our analysis, is to understand and try to explain the information coming from the Libor-OIS spread and accurately identify the expectation and risk premium components in long-term spreads. This is important for two reasons; first, because it gives us an indication of how market participants assess the risk of different fixed income instruments and second, because it would help Central banks to make important monetary policy decisions by applying specific policy rates. Following our discussion in section 6.2, we come to realise that the later is even more important, if we think of how the Libor-OIS spread has evolved, depending on the different policy decisions adopted by central banks.

In our analysis, we draw, again, from the traditional term structure literature, and decompose the spread into an expectation hypothesis component and a risk premia component. Our ultimate target is, first, to understand whether our model can capture the main stylised facts of the interest rates market, mainly the failure of the expectation hypothesis and the assumption of time-varying risk premia and second, if these facts are also supported by the Libor-OIS spread data. Is the assumption of constant risk premia supported by historical spreads across maturities and currencies?

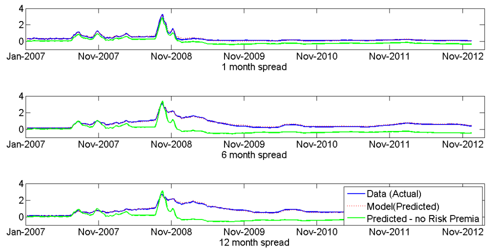
To do so, we derive a simple decomposition method of the model in section 3.1, where we separate the Libor-OIS spreads into a time-varying expectation and a time-varying risk premia components. But, as we explained in section 3, any time variation in risk premia is captured by the market price of risk parameter λ_1, which only affects the response coefficients B_n. This means that any movements in the Libor-OIS spreads over time, are driven by the second part of equation (12), which is given by,

$$B_n = B'_{lib,(n)} - B'_{ois,(n)} \tag{28}$$

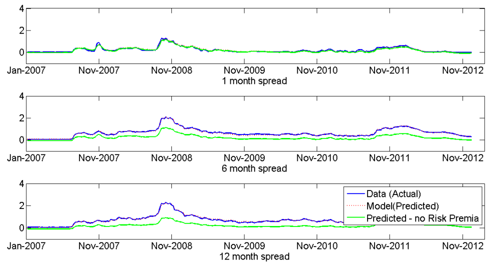
So, instead of decomposing the Libor-OIS spread (z_t^n, in equation (12)) into an expectation hypothesis term and a time-varying risk premia term, we decompose its response coefficient counterpart B_n as,

$$B_n = B_n^{EH} + B_n^{RP} \tag{29}$$

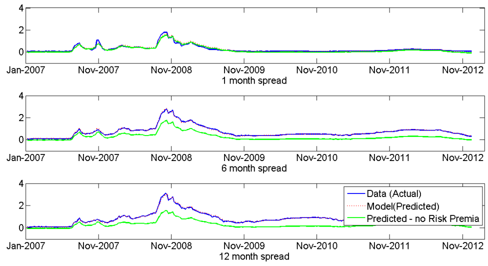
We recall from section 3 that the vector of market prices of risk λ_t, is a linear function of the state variables and is given by $\lambda_t = \lambda_0 + \lambda_1 X_t$, where λ_0 captures the constant risk premia and λ_1 captures any time variation in risk premia. In case the investor is risk neutral though, the physical (P) and the risk neutral (Q) probability measures coincide. But this is the case when



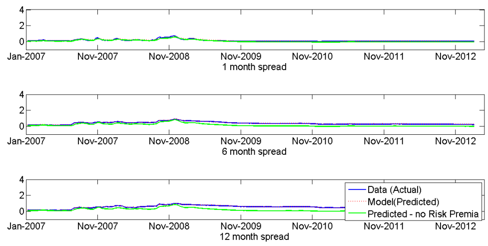
(a) USA



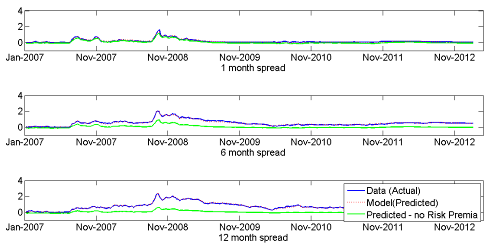
(b) EUR



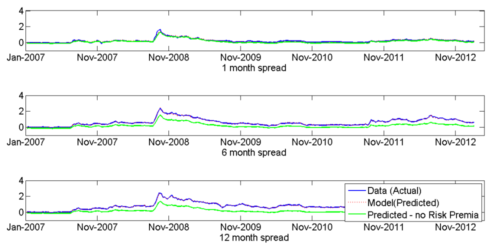
(c) UK



(d) JPY



(e) CAD

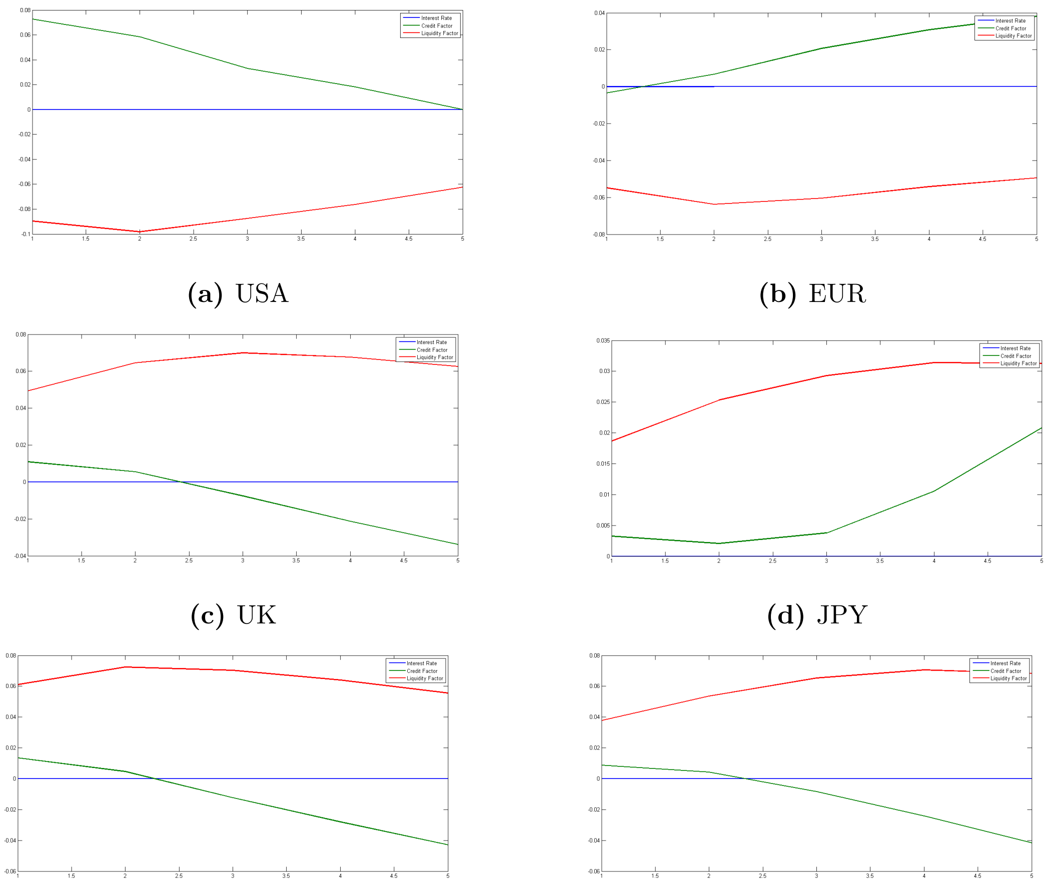


(f) AUD

Figure 6.3: The figure plots the 1-month, 6-month and 12-month Libor-OIS spreads predicted by the model, and predicted under the expectation hypothesis only, for the United States (a), the Europe (b), the United Kingdom (c), Japan (d), Canada (e) and Australia (f) for the period of January 2007 to December 2012. The red dashed line represents the spreads predicted by the model, and the green solid line represents the spreads predicted by the model under the assumption that the time-varying risk premia is zero. Numbers on y-axis are in percentages (%).

the market is free of risk premia (i.e, when $\lambda_t = 0$) and the expectation hypothesis holds (i.e. without adjustment for time-varying risk). In case of a non risk neutral investor, the dynamics of the spreads depend on the market price of risk parameters λ_0, which captures the constant part of the spread and λ_1 that captures the time variation of the risk premia of the spread. So, to capture the expectation hypothesis term, we assume that $\lambda_1 = 0$, which means that the market price of risk is given by its constant part only, i.e. $\lambda_t = \lambda_0$.

Figures 6.3a to 6.3f, plot the actual 1-month, 6-month and 12-month spreads predicted from the model, and predicted under the expectation hypothesis only (no Risk Premium). From our empirical results, we observe that when only the expectation hypothesis is used, the fit of our model is not good, since the deviations of the predicted (model) spreads from the actual spreads



(a) USA **(b)** EUR **(c)** UK **(d)** JPY **(e)** CAD **(f)** AUD

Figure 6.4: The figure plots the estimated response coefficients B_n for the United States (a), Europe (b), United Kingdom (c), Japan (d), Canada (e) and Australia (f). Numbers on y-axis are in percentages (%).

are large. This evidence is more clear in the 6-month and 12-month maturities, especially for the period after mid 2007. This is in line with the term structure literature, where it has been proved that the EH approximately holds in the short run, but fails in the long run. This means that if we assume constant risk premia, the model loses a large part of its predictive strength. So, we can conclude that a model with time-varying risk premia, associated with credit and liquidity components, is more capable at explaining and predicting the behavior of the term structure of Libor-OIS spreads. Looking at figures 6.3a to 6.3f, one can observe that this conclusion can be inferred from all six markets.

In the final part of our analysis, we are aiming at getting information from the response coefficients, by specifying how movements in the state variables affect the spreads. But since, according to our previous analysis, the response coefficients incorporate time-varying risk premia, this makes our aim equivalent on how movements in spreads are driven by these risk premia.

Figures 6.4a to 6.4f, display the estimated response coefficients, B_n, across maturities. Each line depicts the reaction of the Libor-OIS spread to a 1% increase in each one of the state variables.

In the US market, a 1% increase in the credit factor has a positive impact on the spread. However, as the maturity increases the impact starts declining. At short maturities, a 1% increase, increases the spread by 0.075%, while at longer maturities this increase is negligible. On the other hand, the liquidity factor has a negative effect on the spread. This means that a 1% increase in the liquidity factor, decreases the spread by 0.09% at the short end of the term structure, and by around 0.06% at the longer term. The negative effect at the short end is in line with the negative value of the parameter $\delta_{1,3}$ which governs the liquidity factor for the 1-period (short-term) spread.

A similar picture is observed in the EUR market, regarding the liquidity factor. Its relation with the spread is negatively correlated, since an increase in liquidity risk, reduces the spread by about 0.05%. What is different though is the effect of the credit factor. So, a 1% increase in the credit factor has initially a negative impact on the spread. However, as maturity increases, it becomes positive. This negative effect only influences the very short end of the term structure of the spread, as the negative value of the parameter $\delta_{1,2}$ indicates. So, at the 12-month maturity, a one percent increase in the credit factor has almost 0.04 percent increase in the Euribor-OIS spread. This reflects the fact that long maturity assets are associated with higher credit premia.

Similar characteristics can be observed in the UK, CAD and AUD markets, where the liquidity factor has, clearly, a positive effect across the maturity spectrum. So, an increase in liquidity risk increases the spread in all three markets. Furthermore, the higher the maturity, the biggest the impact that the increase has on the spread, which makes sense, since longer maturity assets are associated with higher liquidity premia. Finally, in the JPY market, the impact of both the credit and the liquidity factors is positive. A 1% increase in the state variables results in a positive reaction on the spread. The longer the maturity of the spread the larger the effect of the increase in the underlying factors.

7 Conclusion

We estimate a no-arbitrage model of the term structure of international interbank spreads, from January 2007 to December 2012. Our analysis is concentrated on six major currencies (USD, EUR, UK, JPY, CAD, AUD) and attempts to disentangle credit and liquidity risk premium in the interbank market. Our ultimate targets are, first, to identify any similarities on the spreads movements and, second, to understand the effects of different policy decisions in decreasing risk premia in the interbank market. To do so, we have followed two different estimation procedures. In the first one, the underlying factors that determine the dynamics of the spread are observable (proxies), while in the second one, we let them be latent, and estimate our model using a Kalman filter. In both cases, the model is capable to closely reproduce the movements of the spreads across the maturity spectrum.

Our empirical results suggest that both credit and liquidity risks played an important role in the widening of the spread during the recent financial crisis. However, liquidity risk seems to account more on the spread's level at the early phase of the crisis, while after Lehman's default, the spread is mainly driven by credit risk. The Impulse response function analysis indicates that the policy of most central banks to apply substantial cuts in their policy rates resulted in the deterioration of credit pressures in most countries. Furthermore, the unconventional monetary policy programs adapted, helped the banking system to obtain a high level of excess reserves, which pushed liquidity pressures down.

In the US market, the level of liquidity was higher compared to the other currencies, mainly due to the exposure in the subprime market and the important role that the US dollar played as a funding currency. On the other side, the Japanese market experienced less credit and liquidity pressures, even during the early phase of the turmoil. The reason for that was the low interest rate environment, the light exposure of banks to subprime products and the effectiveness of the policy measures applied by the Japanese Central bank. This was not the case for the Australian market though, where the policy measures adopted and the higher policy rates resulted in high and persistent liquidity pressures throughout the sample period. Another interesting conclusion comes from the EUR and the UK markets, where the credit risk component remained at very high levels the period after mid 2010, mainly due to the escalation of the European sovereign debt crisis.

In the final part of our analysis, we draw from the traditional term structure literature and attempt to decompose the spread into an expectation hypothesis term and a time-varying risk premia term. Our empirical results indicate that the hypothesis of constant risk premia is rejected, since allowing for time-varying risk premia makes the model more capable at explaining the behaviour of the term structure of the spreads, especially at longer maturities.

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