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Determinants of the multiple-term structures from interbank rates

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Keywords: Basis swap, noise measure, credit risk, liquidity risk, capital arbitrage

JEL classification: G01, G12, G15, G32

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The classic relationship between deposit rates and interest rate derivatives has been fractured since August 2007. Uncertainty in the interbank money market has increased the risk premia differentials on unsecured deposits rates of different tenors, such as Euribor, leading to a new pricing framework of interest rate derivatives based on multiple curves. This article analyzes the economic determinants of this new multi-curve framework. We employ basis swap (BS) spreads –floating-to-floating interest rate swaps– as instruments for extracting the interest rate curve differentials. Our results show that the multi-curve framework mirrors the standard single-curve setting in terms of level, slope and curvature factors. The level factor captures 90% of the total variation in the curves, and this factor significantly covaries with a proxy for systemic risk. Moreover, the curve residuals are significantly correlated with interbank liquidity. Our empirical findings also show unidirectional causality running from risk (and liquidity) to level (and noise) factors.

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1. Introduction

The risk of losses resulting from lending in the interbank money market, or interbank risk, is a recent phenomenon in financial markets (Filipovic and Trolle, 2013). The financial distress that began in August 2007 resulted in a preference for cash flows receiving payments with shorter maturities, increasing the spreads on unsecured deposits, such as Libor or Euribor rates, of different tenors. This uncertainty in unsecured deposit rates has been transmitted to derivative markets because many interest rate–linked instruments, such as forward rate agreements (FRAs) and interest rate swaps (IRSs), reference those interbank rates. This new scenario is characterized by the rupture of classic relationships between deposit rates and interest rate derivatives. For example, deposit rates and overnight interest swap (OIS) rates of the same maturities, which historically evolved with negligible spreads, started to diverge. Similarly, the spreads between the forward rates implied by consecutive deposits and those implied by market FRAs have been significantly different from zero since August 2007. Furthermore, basis swap (BS) spreads and floating-to-floating IRS instruments, traditionally close to zero, have increased to unprecedented levels.

These non-negligible discrepancies between the implicit rates of deposit and market instruments have led to a novel multi-curve framework, where the assumption of an unique zero-coupon curve as benchmark for pricing derivative instruments suddenly does not hold. Investors and practitioners now select suitable term structures according to the tenor of the interbank reference. For instance, IRSs indexed to the three-month Euribor must employ a different curve than those indexed to the six-month Euribor. The interest rate derivatives market is one of the largest markets worldwide – in terms of notional outstanding, the market accounts for more than 80% of the total amount outstanding of over-the-counter (OTC) derivatives[1]. However, the academic literature on the multi-curve framework is still sparse; see, for example, recent papers by Mercurio (2009), Henrard (2014) and Filipovic and Trolle (2013).

This paper analyzes the dynamics of the multi-curve framework, searching for economic drivers that could illuminate this new scenario. We exploit the informational content of BS spreads, a type of IRS in which the parties exchange two floating rate inter-

[1] For instance, the notional outstanding of IRS (FRA) contracts was USD 461.3 (82.3) trillion in December 2013, according to the September 2014 BIS Quarterly Review.

ests. BS spreads are suitable instruments to study how investors price liquidity and credit risks in the interbank market, and they are employed to extract the different interest rate curves differentials in the multi-curve framework. Our sample focuses on the BS spreads written on Euribor against OISs linked to Eonia. Because Eonia is commonly accepted as the risk-free reference rate in the interbank market, the BS spread can be considered a direct measure of the liquidity/credit premium embedded in the multiple curves. Not surprisingly, these BS spreads, which were negligible before August 2007, subsequently increased to unprecedented levels.

BS spreads are used as instruments to determine interest rate curve differentials. Along these lines, this paper adopts an orthodox procedure to analyze the term structure following the approach in Diebold and Li (2006). This methodology extracts the curves at different tenors using the spline fitting of Nelson and Siegel (1987). When applied to BS data, we are able to identify the multiple-curve (main) factors, which eases the process of comparing sets of curve dynamics while taking advantage of the goodness of fit properties of this model. Then, the methodology of Diebold and Li (2006) is used to characterize the information contained in each curve into three parameters that evolve dynamically. These parameters are interpreted as the level, slope and curvature factors of the term structure (Nelson and Siegel, 1987), providing an extensive analysis of the determinants of these curve factors and their relationships to various macroeconomic and financial variables. Additionally, our approach considers the information content of the model residuals, similarly to Hu, Pan and Wang (2013) or Berenguer, Gimeno and Nave (2013). The dataset employed here is composed of weekly BS spreads from the Euro interbank market, and it corresponds to different maturities and tenors underlying the Euribor rates. The BS spread market data period ranges from June 2008 to August 2013, including the recent European sovereign debt crisis.

The main contributions of this article to the financial literature are threefold. First, this paper shows that the multi-curve framework mirrors the single-curve framework. We find that information in the multi-curve setting can be divided into three factors explaining the level, slope and curvature, and this information accounts for approximately 97% of the total variation in the spreads. Furthermore, we explore the different sources of commonality among these curves, studying each factor's behavior.

Second, a projection of the time series coefficients onto a set of economic variables shows the role of credit and liquidity risk as determinants of the multi-curve framework.

The time series of the factor levels covaries significantly with a proxy for systemic risk, the spread between AAA EUR Financial sector and German sovereign yields. Analogously, illiquidity in the market, proxied by the ECB liquidity indicator, is statistically significant in explaining the model residuals. Finally, a VAR approach shows not only that the empirical errors that arise from the fitted curves are mainly explained by liquidity in the money market for the euro area but also that systemic risk is the main economic driver of interest rate factors for levels.

This paper belongs to the growing literature on interbank risk. Our work is most closely related to Filipovic and Trolle (2013), who employ a similar dataset but consider a different methodological approach. Additionally, Filipovic and Trolle (2013) focus on understanding the roles of credit and liquidity in explaining interbank spreads in risk premiums, while we seek to characterize the dynamic properties of the multi-curve setting. This strategy permits us to draw important conclusions about the commonalities in the behavior of interest rates in the multi-curve framework beyond examining their sources. A recent series of papers has also analyzed Libor-OIS spreads as measures of interbank risk, emphasizing their credit and liquidity risk components; see, for instance, Michaud and Upper (2008), Schwartz (2010), Eisenschmidt and Tapking (2009) or McAndrews, Sarkar and Wang (2008). Our research also employs interbank spreads but extends its analysis to the entire term structure of these spreads captured by BS quotes. This strategy allows us to explore a more complete set of information regarding interbank risk because BSs contain information concerning market expectations of future Libor-OIS spreads. In addition, we consider several term structures of BS spreads associated with interbank rates of different tenors. To the best of our knowledge, this paper represents the first attempt to model the multiple curves using the methodology in Diebold and Li (2006).

This article is also related to the body of literature devoted to term structure modeling, especially to studies attempting to fit observed yield curves. The academic literature on this topic focuses on two main types of models: Nelson and Siegel (1987) models and affine term structure models. Nelson-Siegel models rely on three latent factors (interpreted as level, slope and curvature) and postulate a particular form of the term structure of interest rates that does not depend on the existence of arbitrage opportunities. Affine term structure models depend on assumptions concerning the absence of arbitrage opportunities and postulate that the unobservable factors underlying the term structure follow a stochastic process. A non-exhaustive review of this literature includes Vasicek (1977), Cox, Ingersoll and Ross (1985), Chan, Karolyi, Longstaff and Sanders (1992), Duffie and Kan (1996), Dai and Singleton (2000), Dai and Singleton (2002), and Piazzesi (2005), among many others.

Thus, this article seeks to characterize the economic determinants of the multi-curve framework using the informational content of BS spreads. The structure of the paper is as follows. Section 2 presents the multi-curve framework and its connection to BSs. Section 3 introduces the structure of the market and the dataset. Section 4 develops the estimation, and Section 5 analyzes the determinants. The forecasting analysis is presented in Section 6, and some conclusions are provided in Section 7.

2. One curve, multiple curves and basis swap spreads.

Next, we review the classic link between forward and implicit rates and its connection to the existence of a unique curve for valuation. As is conventional in the interest rate derivative market, we consider simple compounded interest rates.

2.1. The replicating portfolio

The departures of interest rate derivatives market quotes from the classic single-curve framework can be illustrated using the replicating strategy of an FRA, an interest rate derivative contract that guarantees the interest rate on an obligation that will be lent or borrowed in the future. This agreement starts at future date T_i, finalizing at maturity date T_j, where $\tau(T_i,T_j)$ is the time elapsed. Within an FRA, one party decides to exchange a variable or reference interest rate $L(t,T_x)$ with tenor T_x, usually an interbank market reference such as Euribor. Accordingly, her counterparty interchanges a fixed interest rate $F(t,T_i,T_j)$ that is determined at the beginning of the contract. Because FRAs are liquidated at time T_i, the cash flow of an FRA at maturity is the spread among variable and fixed interest rates. The rate $F(t,T_i,T_j)$ is fixed to equalize the present value of EUR 1 at time T_i and the present value of a deposit of EUR 1 from time T_i until T_j,

$$P(t,T_i) - (1+F(t,T_i,T_j)\tau(T_i,T_j))P(t,T_j) = 0, \quad \text{with } i < j \tag{1}$$

considering as discount factors the prices at time t of zero-coupon bonds with maturity T_x, i.e., $P(t,T_x) = 1/(1+L(t,T_x)\tau(t,T_x))$.

The cash flows of an FRA can be replicated by combining a long position in a bond with maturity T_i and face value EUR 1 and a short position in a bond with maturity T_j and face value $(1+F(t,T_i,T_j)\tau(T_i,T_j))$. Therefore, there exists an equivalence between i) entering into an FRA and ii) obtaining funding at different periods. This previous expression may be restated to represent the well-known non-arbitrage relationship between forward and FRA rates. In other words, ignoring that credit and liquidity issues may affect the funding that can be obtained at different periods, the implicit forward rate from deposits and the FRA rate should be equal. This replicating portfolio argument holds regardless the tenor of the FRA, implying that there should be consistency between the value of a particular tenor FRA rate and the capitalization of shorter tenor forward rates. In this way, the forward curve is *unique* because for a given maturity, financing at any tenor is equivalent.

Equivalence between the rate from FRAs and the implicit rate from deposits changed after August 2007, leading to inconsistent FRA rates at different tenors. As noted by Filipovic and Trolle (2013), the lack of confidence in the balance sheets of many financial institutions moved market makers to assign credit and liquidity risk premiums to different tenor (deposit) financing operations in the interbank market. Then, deposit rates started to reflect credit and liquidity risks.[2] In this situation, borrowing for a given maturity at different tenor floating rates is not equivalent. Consequently, the above-mentioned replication strategy for valuing interest rate derivatives does not yield a unique valuation after August 2007.

To reconcile post-crisis derivative market prices with classic single-curve replicating strategies, market makers have mainly adopted a solution based on a multiple curve, or multi-curve, framework. The existence of a multi-curve framework has been previously noted in the literature in, for instance, Mercurio (2009) and Henrard (2014). In this new setting, agents discriminate among the term structures of interest rates differentiated by the underlying interbank market reference rates according to their tenor. Denoting the Euribor rate associated with tenor x as $L_x(T_{i-1},T_i)$ (note the subscript x), where $x=\{1M,3M,6M,12M\}$, the price of the zero-coupon bond associated with this Euribor

[2] In parallel to the recognition of the credit and liquidity risks, the perception of higher counterparty risk resulted in the establishment of clauses and collateral agreements, such as CSAs, in interbank market contracts to mitigate the consequences associated with counterparty defaults. Although these clauses helped mitigate the counterparty risk concerning the derivative contracts themselves, the credit and liquidity risks embedded in the instrument reference rates still had effects on these derivatives quotes.

rate with tenor x is,

$$P_x(T_{i-1},T_i) = \frac{1}{1+L_x(T_{i-1},T_i)\tau_x(T_{i-1},T_i)} \quad . \tag{2}$$

Because the multi-curve framework arises as a consequence of curves differentiated by tenor, the curve construction uses distinct sets of instruments linked to different tenor rates. For instance, only FRAs and IRSs associated with a 6-month payment frequency are used in deriving the curve associated with the Euribor 6M frequency. To value an interest rate instrument, the curve associated with a particular tenor underlying rate is used to estimate the instrument future rates, and a unique discounting curve is considered in the computation of the present value of these flows. Presently, FRA rates are themselves considered building blocks, and they are valued either directly from market quotes or implicitly as forward rates from the curve associated with its corresponding tenor.

Another aspect to be revisited is the concept of the risk-free rate. The appearance of the multi-curve framework poses some questions about the risk-free instruments employed for discounting derivatives (see Hull and White, 2013). There seems to exist a consensus in the market on using the curve of the overnight tenor Eonia rate as a discounting curve because most interbank derivative contracts are collateralized through CSAs, which implies that the collateral is capitalized at the Eonia rate. To avoid no-arbitrage opportunities, this rate curve must be considered in the discounting process. In the following, the discount factors associated with the OIS curve are denoted as $P_d(t,T)$.

2.2. The basis swap and its relationship with multiple curves

The lack of consistency between the post-crisis market quotes and the single-curve framework was particularly evident for certain instruments such as the BS, which is an interest rate derivative that involves the exchange of two floating rates at different tenors. BSs are OTC instruments, and they are mainly used by counterparties to swap interest rate payments linked to short-term reference rates of different tenor for a given period – the maturity of the contract. Therefore, these BS quotes reflect the premium that exists for term lending compared to rolling funding at shorter intervals in the Euro (Libor) interbank money markets, as longer tenor Euribor rates involve higher risk compared to shorter tenors. The BS spread reflects the difference between lending at compound shorter tenor rates compared to longer tenor rates in the Euro interbank money market. Then, the BS term structure captures the spread between the tenor IRS curves and the differential costs of funding at distinct tenors.[3]

The BS contract may be quoted as a portfolio of two standard floating versus fixed swaps with two different floating rates and coincident fixed leg tenors.[4] The BS spread is the difference between the two equilibrium fix-to-float swap rates, and hence, it has the same payment frequency as the embedded swap's fixed leg. Then, the value of the BS contract is

$$\begin{aligned}\Delta_{x,y} &= IRS\left(t;T_x,T_z\right)-IRS\left(t;T_y,T_z\right)\\ &= \frac{\begin{pmatrix} E_t\left(\sum_{j=1}^{n_x} e^{-\int_t^{T_{x,j}} r(s)ds}\tau_x\left(T_{x,j-1},T_{x,j}\right)L_x\left(T_{x,j-1},T_{x,j}\right)\right)\\ -E_t\left(\sum_{j=1}^{n_y} e^{-\int_t^{T_{y,j}} r(s)ds}\tau_y\left(T_{y,j-1},T_{y,j}\right)L_y\left(T_{y,j-1},T_{y,j}\right)\right)\end{pmatrix}}{\sum_{j=1}^{n_z} P_d\left(t,T_{z,j}\right)\tau_z\left(T_{z,j-1},T_{z,j}\right)}, \qquad (3)\end{aligned}$$

where $IRS\left(t;T_x,T_z\right)$ and $IRS\left(t;T_y,T_z\right)$ link the equilibrium swap rates of fixed versus floating IRS contracts and the floating legs, respectively, to the x- and y-tenor Euribor reference rates.

If the pricing formula (3) is considered under the classic interest rate framework, the existence of a unique riskless curve implies that the IRS floating leg would be replicated by a portfolio of two single zero-coupon bonds irrespective of the floating reference rate tenor. This is because the IRS floating leg represents the sum of discounted expected values of FRA rates. Under the single-curve framework, such a net present value would be equivalent to the sum of implicit forward rates and may be replicated by the value of two

[3]Consider, for example, the 3-month Euribor versus the 6-month Euribor BS. In this contract, one of the counterparties makes payments linked to the 3-month Euribor and, in exchange, receives the 6-month Euribor rate. If the 6-month Euribor rate is expected to be greater than the 3-month Euribor compounded quarterly, then the longer tenor leg of the swap involves a basis spread over the value of the shorter tenor leg that is necessary to be considered for the contract to be in equilibrium at inception.

[4]There exist two types of single-currency BS contracts exchanged in the interbank market. On the one hand, a BS can be constituted by two vanilla swaps, which is called the first type here. On the other hand, single line items, the second type, consist of the interchange of two floating rates, the longer tenor Euribor rate against the shorter tenor rate plus a spread. The choice of the contract type depends on the infrastructure capability of the financial entities. In any case, there are negligible differences between the quotes of both type of swaps, mainly due to the frequency of compounding and day count conventions. This paper employs the first type of BS contract, providing a complete description of the second type in Appendix B.

zero-coupon bonds with the same maturity as the contract start and maturity dates. This would imply that the value of the IRS rate would not depend on the tenor of the underlying FRA rates, and consequently, the BS spreads would be zero, that is, $\Delta_{x,y} = 0$, as occurred before August 2007. This fact is shown in Figure 1, which displays the time series of the Euribor 6M versus 3M BS spread from July 2003 until August 2013. According to the single-curve framework, before August 2007, BSs exhibited a low volatility pattern with quotes that were close to zero. However, since the credit crunch, BS spreads have increased to unprecedented levels and have become extremely volatile.

[FIGURE 1 ABOUT HERE]

3. The structure of the basis swap market

BS contracts are mainly used for hedging and speculative purposes. Entities use a BS as a hedging instrument for basis risk, for instance, in situations where assets and liabilities are tied to rates of different tenor. Similarly, entities are exposed to basis risk when the underlying and hedging instruments are linked to different tenor Euribor rates. Moreover, because BSs reflect short-term expectations about market credit and liquidity conditions, these derivative contracts can also be used to speculate about future levels of basis spreads.

Figure 2, which depicts the evolution of BS aggregated transaction data in terms of outstanding trades gross notional, shows the increment of trading operations with BS contracts during recent years. The BS notional outstanding is the total amount of open interest that the clearing house has in these swaps. The BS trades are disaggregated by the type of counterparty: a) central clearing counterparties (CCP); b) G-14 dealers, and c) non-G-14 dealers. The data are collected from fourteen financial entities' interest rate derivative transactions reports and published by TriOptima and DTCC.[5] As shown in Figure 2, we observe that trading with central clearing counterparties has dramatically contributed to increased BS turnover.[6]

[5] The G-14 financial entities include Bank of America-Merrill Lynch, Barclays Capital, BNP Paribas, Citi, Credit Suisse, Deutsche Bank AG, Goldman Sachs & Co., HSBC Group, JP Morgan, Morgan Stanley, The Royal Bank of Scotland Group, Societe Generale, UBS AG and Wells Fargo Bank. For more details, see http://www.trioptima.com/repository.html.

[6] This pattern is corroborated by our conversations with traders, who highlight that BS contracts exchanged in the interbank market are commonly cleared through central clearing houses of which one of the most important is the London Clearing House (LCH).

[FIGURE 2 ABOUT HERE]

Figure 3 depicts the gross notional evolution of basis swap trades with respect to other interest rate–linked products. Data on IRSs, FRAs, swaptions and caps/floors comprises from July 2010 until July 2013. Data from OIS starts in April 2012. Records before those dates are not available to us. As observed, trading activity with interest rate derivatives is heavily concentrated in IRS. However, its relative size has decreased in the recent years in favor of FRA and BS trading operations. The BS volume accounts for approximately 6% of the total volume, and this percentage remains stable during the period analyzed.

[FIGURE 3 ABOUT HERE]

3.1. Data and descriptive statistics

The dataset comprises BS spread market quotes from June 2nd, 2008 to August 30th, 2013. The data frequency is weekly, and they have been drawn from Bloomberg. We are interested in the BS spreads of different Euribor tenors with respect to Eonia, which is the underlying rate of OISs. We focus on the BS contracts whose payments are associated with Euro interbank deposit rates for tenors of 1, 3, 6 and 12 months. In addition, each BS contract based on Euribor rates is traded for maturities from 1 to 10, 12, 15, 20, 25 and 30 years. Given that market does not provide quotes for these BS spreads for all tenors, we synthetically build those BS spreads by non-arbitrage when they are not available. This procedure requires the use of the BS pricing formulas stated in Section 2. Information and details about the BS contracts are reported in Table 1, which summarizes the available BS market quotes (Panel I) and the synthetically obtained BS spreads (Panel II). As an example of our procedure, consider, for instance, the series of Euribor 6M vs OIS spreads, which are not directly available in the market. We add Euribor 6M vs Euribor 3M to Euribor 3M vs OIS BS quotes, having previously transformed the latter from type 2 into type 1 swap contracts. As a robustness check, we confirm that this methodology matches the quotes for existing data.

[TABLE 1 ABOUT HERE]

Figure 4 shows the evolution of the BS time series used. Some interesting aspects are illustrated in this Figure. First, BS premiums tend to increase in the presence of risk uncertainty. For example, Figure 4 shows that the Lehman Brothers bankruptcy in September

2008 resulted in a sharp increase in BS spreads that lasted several months. Analogously, BS spreads rose significantly during the European sovereign debt crisis, for instance, during the government bailouts of Greece in May 2010, Ireland in November 2010, and Spain in June 2012. Second, the term structure of BS spreads is consistently downward sloping, especially at longer tenors (3, 6 and 12 months). This effect is also observable at 1-month BS spreads during times of financial distress. Finally, BS spreads seem to react to the special measures undertaken by the ECB during the crisis.[7] The implementation of these actions appears to be correlated with a gradual decrease in BS spreads. In sum, BS spreads seem to capture liquidity shortages within the financial sector and perceptions of the default risk associated with lending in the interbank market, as noted by Filipovic and Trolle (2013).

[FIGURE 4 ABOUT HERE]

Table 2 provides some descriptive statistics. We observe that BS curves are, on average, downward sloping and convex. Moreover, the volatility of BS spreads tends to be higher for short term maturities. A cross-sectional inspection of the BS spread shows that i) long-term BS spread tenors are higher than short-term tenors and that ii) long-term tenors are more volatile than shorter ones. In addition, the median is generally lower than the mean, signaling that the distribution is skewed to the right, particularly for shorter maturities. Finally, the autocorrelation coefficients reveal that shorter maturities exhibit more persistence, and this persistence is declining with the time horizon over the long-run.

[TABLE 2 ABOUT HERE]

3.2. Commonality analysis

As an initial exercise to address the nature of comovements in the BS time series, we perform a principal components analysis (PCA) of the entire sample of (standardized)

[7] To enable banks to access funding just after the Lehman collapse, the ECB conducted massive injections of liquidity on October 8th, 2008 and special term refinancing operations on September 29th, 2008. Additionally, the ECB intervened in debt markets to prevent government borrowing costs from increasing to prohibitively high levels and ensure depth and liquidity in certain dysfunctional market segments. The first goal was achieved by the Securities Markets Programme, introduced in May 2010, and its successor, Outright Monetary Transactions, launched in August 2012. The second objective was pursued by the purchase of Euro-denominated covered bonds under two programs introduced on June 30th, 2010 and October 31st, 2012. Through the long-term refinancing operations conducted in fall 2011, the ECB also intended to enable banks to access long-term funding.

Euribor tenor BS spreads. The results show strong commonality in the data, where a first principal component accounts for 73.36% of the total explained variance in the BS series. This percentage increases to 89.41% and 96.84% when incorporating the information from the second and third components, respectively. An inspection of the loading coefficients (not reported here but available upon request) shows that the first principal component can be understood as an equally weighted portfolio of the BS series. The second component loadings clearly disentangle the short-term tenors (1M and 3M) from long-term tenors (6M to 1 year). While the first component represents a level factor, the second component reflects a slope factor. Finally, the third component could be interpreted as a curvature factor embedded in the cross-section of BS spreads. Further inspection of the first principal component loading coefficients reveals that the medium-term tenors are representative of the joint behavior of the level factor, while the 1- and 12-month tenors, particularly the latter, may display slight heterogeneity with respect to the medium-term tenor spreads.

To further be sure of the interpretation of the term structure components, we perform a PCA for each tenor; then, we execute four different PCAs. The results are consistent across tenors, and they are consistent with the standard interest rate term structure assessment. The first component clearly captures most of the variation in BS spreads; for example, the lowest (highest) explained variance for this first component is 87.72% (92.66%). Moreover, the loading coefficients of first principal components are approximately equal, reinforcing the view that first components behave as level factors. We also observe that medium-term maturities (from 5 to 10 years) present slightly higher loading coefficients. This may indicate that medium-term maturities act as level benchmarks.

The second principal component could be interpreted as a slope factor: the loading coefficients are statistically significant for shorter and very long-term maturities, differing in their sign. The explained variance is 7.14%, on average. Finally, the third principal components clearly represent curvature factors, and their explained variance is nearly residual – on average, 2.15%.

From the previous results, we conclude that the different BS spread curves have strong commonalities and that their term structures exhibit similar level, slope and curvature patterns. Heterogeneity in the joint BS behavior may arise across maturities, over the short- and very long-run, and across tenors, at shorter and longer tenors.

4. An analysis of the multiple-term structures

4.1. Curve fitting

There exist several approaches for fitting the term structure in the unique curve setting that are of potential interest in the analysis of the multi-curve framework.[8] This article focuses on the Nelson and Siegel (1987) model, which imposes a parametric structure on the interest rate curve at different maturities that is flexible enough to generate a variety of time-varying curve shapes as follows,

$$s_t(\theta;\tau) = \beta_{1t} + \beta_{2t}\left(\frac{1-e^{-\lambda_t\tau}}{\lambda_t\tau}\right) + \beta_{3t}\left(\frac{1-e^{-\lambda_t\tau}}{\lambda_t\tau} - e^{-\lambda_t\tau}\right), \tag{4}$$

where $s_t(\theta;\tau)$ is the zero-coupon basis swap (ZCS) spread at time t with maturity τ and θ is a four-parameter vector, $\theta = (\beta_{1t}, \beta_{2t}, \beta_{3t}, \lambda_t)$, to be estimated. In particular, parameter β_{1t} is usually interpreted as a level factor because $s_t(\theta;\infty) \to \beta_{1t}$. Parameter β_{2t} is a decreasing function of τ, and it is usually intended as a slope factor; and parameter β_{3t} is the curvature factor, which is a concave function of τ. The λ_t parameter determines both the maturity at which the curvature loading is maximized and the exponential decay rate associated with the term $e^{-\lambda_t\tau}$. This parameter λ_t is usually fixed in the estimations (see Diebold and Li, 2006). The model generates BS spreads that approach the instantaneous rate $\beta_{1t} + \beta_{2t}$ when maturity τ approaches zero and the value β_{1t} when maturity τ tends to infinity in the limit. Notice that, although the Nelson and Siegel (1987) model is presented as a static model, Diebold and Li (2006) interpret their parameters as dynamic latent factors, where β_{1t}, β_{2t} and β_{3t} are level, slope and curvature factors, respectively. Then, the time series statistical properties of these factors capture the underlying dynamic patterns of the curve. All parameters in vector θ have a subscript t because they are estimated at each point in time.

The Nelson and Siegel (1987) model is formulated in terms of continuous forward and zero-coupon yield curve rates. Unlike in the Nelson-Siegel model, market BS spreads are quoted as simply compounded swap rates instead of zero-coupon continuously compounded interest rates. Thus, to apply this model, we transform those BS spreads into zero-coupon rates by bootstrapping, a standard approach for constructing interest rate curves. We next present our procedure, which builds on the relationship between swap

[8] See Diebold and Li (2006) for a discussion of the different methods available.

BS spreads, and simple forward spreads associated with BS for future periods. This relationship is an artificial construct that allows us to derive the zero-coupon BS curve by applying bootstrapping. In this way, we first recursively infer simple forward spreads using the following formula:

$$\Delta_{x,y} = \frac{\sum_{j=1}^{n_x} P_d\left(t, T_{x,j}\right) \tau_x\left(T_{x,j-1}, T_{x,j}\right) Fwdspread\left(T_{x,j-1}, T_{x,j}\right)}{\sum_{j=1}^{n_z} P_d\left(t, T_{z,j}\right) \tau_z\left(T_{z,j-1}, T_{z,j}\right)}, \tag{5}$$

where the information about the discount rate curve $P_d(.)$ is obtained from OIS quotes and the forward spread curve is simply extracted from equation (5), possibly by a non-linear technique. Then, the ZCS are recursively calculated using the relationship

$$\left(1 + ZCSpread_S\left(t, T_{x,j}\right)\left(T_{x,j} - t\right)\right) = \prod_{i=1}^{j}\left(1 + FwdSpread\left(T_{x,i-1}, T_{x,i}\right)\tau_x\left(T_{x,i-1}, T_{x,i}\right)\right). \tag{6}$$

Finally, simple ZCS spreads are transformed into continuous spreads taking into account the relationship between simple and continuously compounded rates as follows:

$$ZCSpread_C\left(t, T_{x,j}\right) = \frac{\ln\left(1 + ZCSpread_S\left(t, T_{x,j}\right)\left(T_{x,j} - t\right)\right)}{\left(T_{x,j} - t\right)}. \tag{7}$$

This procedure is applied to each BS spread term structure associated with a given Euribor underlying tenor. Finally, the model parameter vector θ is estimated by OLS regressions for each point in time. The parameter λ_t is fixed at 0.206, the value that maximizes the loading on the medium-term factor at 9 years. [9]

4.2. Parameter estimates

Figure 5 depicts the time series of the estimated Nelson-Siegel model factors. Some interesting conclusions arise from the inspection of this figure. For example, the evolution of the level factor β_{1t} (upper graph) shows that, overall, the term structure exhibits a downward trend beginning in September 2008. This observation is extensible to all tenors, suggesting a reduction of financial tensions in the eurozone. Notably, financial crisis events, such as the collapse of Lehman Brothers in September 2008 and the worsening of the European sovereign debt crisis around November 2011, are associated with

[9] The choice of this maturity coincides with the point at which the BS data curvature component expressed with respect to maturity is maximized.

remarkable peaks of the β_{1t} coefficient around those dates, reflecting an increment of the interbank risk level. As expected, the BS spreads level factor increases monotonically with the tenor.

[FIGURE 5 ABOUT HERE]

The evolution of the β_{2t} coefficient (Figure 5, middle graph) also exhibits significant increases during times of financial distress. At a first glance, this pattern seems counterintuitive because higher slopes in the term structure are not linked to distress periods. This puzzle is solved by Diebold and Li (2006), who notice that an increment in β_{2t} reflects an increment in short-term yields more than long-term yields because the short-term rates rely on β_{2t} more heavily. In this way, higher values of β_{2t} during distress periods are reflecting an increment of compensation at shorter maturities. Finally, the time series of parameter β_{3t} are displayed in the bottom graph of Figure 5. Parameter β_{3t} remains close to zero most of the time; however, some isolated and extremely high departures are observed when unexpected crisis events take place.

The beta coefficients increase in size and volatility as the tenors increase.[10] Moreover, the evolution of the β_{1t} coefficient exhibits lower volatility than the β_{2t} or β_{3t} coefficients, reflecting that slope and curvature react more intensively to financial distress situations. Additionally, the autocorrelation coefficients of the β_{1t} factor reveal that persistence in the level series is high.

In accordance with the empirical findings for BS spreads reported in Section 3.2, Figure 5 suggests the existence of commonalities among the time series of estimated factors. To assess this aspect, we perform a PCA of the standardized parameter time series. Table 3 summarizes the nature of the principal component structure. We observe that factors strongly comove across BS tenors, as indicated by the fact that only one component tends to explain almost the entire joint variability (92.73%, 91.74% and 89.74%, respectively, for the level, slope and curvature factors). Regarding the loadings, the first principal component arises from an equally weighted average, which could be interpreted as a level factor. The second and third principal components capture the slope and concavity of the Nelson-Siegel parameter curves across different reference rate tenors, respectively.

[TABLE 3 ABOUT HERE]

[10] An additional summary of the descriptive statistics is shown in Appendix C of this article.

4.3. Residuals and noise measure

According to Hu et al. (2013), the abundance of liquidity in credit markets tends to smooth out the Treasury yield curve because arbitrage forces minimize deviations between fundamental and market prices. During times of distress, liquidity shortages can lead to price deviations from fundamental values. These deviations, or noise, seem to contain valuable information, especially about liquidity issues (see, for example, Berenguer et al. (2013) and Rubia, Sanchis-Marco and Serrano, 2014). Interested in this issue, we implement the noise measure of Hu et al. (2013), the RMSE between the market observed BS quotes and the Nelson and Siegel (1987) model-implied spreads,

$$Noise_t = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[BS_t^{market} - BS_t^{model}\right]^2}, \tag{8}$$

where N is the number of maturities in the BS spread curve, BS_t^{market} is the BS quote, and BS_t^{model} is the model-implied BS spread corresponding to maturity i and time t.

Figure 6 displays the time series of the noise measure for different tenors. Noise is time-varying, exhibiting remarkable increases during periods of financial distress and liquidity/credit crises, such as the Lehman Brothers collapse and European sovereign debt crisis. Notably, changes in noise are relatively more intense for longer BS tenors. This is consistent with the idea that longer maturities are more sensitive to changes in monetary policy, financial distress and market conditions, such as the exit of arbitrage capital from the marketplace (see Hu et al. (2013) and Rubia et al., 2014).

[FIGURE 6 ABOUT HERE]

5. The determinants of the multiple-term structures

This section develops a regression analysis to explore the economic covariates of the Nelson and Siegel (1987) factors previously estimated.

5.1. Variable descriptions

The number of variables that are potentially linked to the term structure is initially unbounded. Following the research design in Longstaff, Pan, Pedersen and Singleton (2011) and Groba, Lafuente and Serrano (2013), we focus on a panel of economic variables that are grouped into four categories: money and interest rate, stock market, credit market and risk aversion variables. Descriptions of the variables employed are provided here.

Money and interest rate market variables. The multi-curve setting is clearly linked to the risk of lending in the interbank market or interbank risk (Filipovic and Trolle, 2013). Therefore, the money and interest rate variables are the first group that draws our attention. This group includes the i) interest rate level in the euro area, as denoted by *IR Level*. The interest rate is the risk-free lending rate in the euro area, and it is proxied by the Eonia Index, which is computed as a weighted average of all actual overnight lending transactions executed by a panel of banks in the Euro money market. The panel of reporting banks is the same as the panel for Euribor rates; the interest rate data are calculated and provided by the ECB.

The ii) interest rate slope (*IR Slope*) is usually considered an indicator of overall economic health (see Collin-Dufresne, Goldstein and Martin (2001) and Groba, Diaz and Serrano, 2013). The risk-free interest rates slope in the euro area is proxied by the spread between 10- and 2-year Eonia swap quotes. Eonia swaps or, alternatively, OIS are similar to vanilla IRS transactions – they both are exchanges of a fixed and variable interest rates, where the variable rate is linked to the Eonia Index. The data are taken from Bloomberg. Finally, we use the iii) ECB liquidity indicator for the euro area money market (*ECB Liq*) published by the ECB. The composite indicator includes arithmetic averages of individual liquidity measures. The data sources for these measures are the ECB, Bank of England, Bloomberg, JPMorgan Chase & Co., Moody's KMV and ECB calculations.

Stock market variables. This group includes the iv) Euro Stoxx Banks Price Index, a capitalization-weighted index that reflects the stock performance of companies in the European Monetary Union (EMU) that are involved in the banking sector. The data source is Bloomberg. The time series of this variable is considered in *logs*. Additionally, we use the v) Euro Stoxx VIX Index, a market estimate of future volatility based on a weighted average of implied volatilities of options written on Euro Stoxx 50 stocks. It captures implied volatility on Eurex traded options with a rolling 30-day expiry. The source is also Bloomberg.

Credit market variables. The list includes the vi) Itraxx Senior Financials, an index that comprises 25 equally-weighted 5-year maturity credit default swaps (CDS) on investment grade European entities involved in the financial sector. The index is from Markit. Then, we consider vii) German CDS, the Federal Republic of Germany Senior CDS quotes in USD and 5-year maturity and is drawn from Bloomberg. This variable is named *German CDS*. Finally, the viii) AAA Fin - German Government yield (*FG Spread*), is the spread between 1-year maturity AAA EUR Financial Sector and the 1-year maturity German Government yields. Each yield is calculated as a composite yield of representative securities around the 1-year maturity. The source is Bloomberg.

Risk aversion variables. Finally, we include a risk aversion variable, the ix) ECB Risk Aversion Indicator, an euro area global risk aversion indicator published by ECB and denoted as *ECB RA*. The indicator is constructed as the first principal component of five risk aversion indicators, namely, the Commerzbank Global Risk Perception, UBS FX Risk Index, Westpac's Risk Appetite Index, BoA ML Risk Aversion Indicator and Credit Suisse Risk Appetite Index. An increase in the indicator denotes an increase in risk aversion. This indicator comes from Bloomberg, Bank of America Merrill Lynch (BoA ML), UBS, Commerzbank and ECB calculations.

To avoid the risk of using variables with similar information content, we compute the correlation matrix for all candidate variables to be included in our regression analysis, which is reported in Table 4. We observe that the Euro Stoxx Banks and Euro Stoxx VIX are highly correlated with the Itraxx Financial and ECB risk aversion indexes. Additionally, the Itraxx Financial index exhibits a strong correlation with the German CDS. To avoid collinearity problems, we exclude the stock market variables and the Itraxx Senior Financial index. Standard stationarity tests systematically reject the existence of a unit root for the increments.

[TABLE 4 ABOUT HERE]

5.2. The determinants of curve factors and residuals

To study the determinants of the multi-curve framework, we develop a regression analysis of the factor coefficients and noise residuals from the Nelson and Siegel (1987) model previously estimated in Section 4. Let $\Delta\beta_{it}$ denote the increments of the factor i coefficients at time t; we model the conditional mean of this process. In particular, we consider the following OLS regression specification:

$$\begin{aligned}\Delta\beta_{it} = \alpha_i \quad &+ \quad \gamma_{1i} IRLevel_t + \gamma_{2i} IRSlope_t + \gamma_{3i} ECBLiq_t \\ &+ \quad \gamma_{4i} GermanCDS_t + \gamma_{5i} FGSpread_t + \gamma_{6i} ECBRA_t + \varepsilon_{it}, \qquad (9)\end{aligned}$$

where $\theta_i = (\alpha_i, \gamma_i')'$ denotes the main parameters of interest and ε_i denotes random disturbances.

Tables 5 and 6 report the resulting OLS estimates from projecting the respective factor and noise increments onto a set of regressors for each of the tenors BS spreads. We report the estimated parameters, White (1980) robust standard errors for individual significance, and adjusted R^2 coefficients. The results in Table 5 show that the bond spread between the AAA Financial and German government plays a leading role in explaining fluctuations in the level factor β_{1t}; when the financing costs of the financial sector increase, investors concerns' about market-wide credit conditions translate into higher BS spreads. Notably, this pattern remains qualitatively unchanged across maturities.

The β_{1t} level factor also accounts for the risk perceived by investors in the euro area when lending to financial institutions compared to more secure investment alternatives. Not surprisingly, the ECB risk aversion index is also statistically significant for longer tenors. In the case of higher tenor Euribor BS curves, changes in the level factor also appear related to the level of instability in economic conditions, as captured by the interest rates slope. Indeed, the adjusted R^2 shows that the explanatory ability of the model is clearly higher for the 6- and 12-month tenors.

[TABLE 5 ABOUT HERE]

Regarding the main drivers of fluctuations in the slope factors β_{2t}, we highlight the role of economic agents' perception of future uncertainty, as proxied by the ECB Risk Aversion indicator. This variable is statistically significant at conventional confidence levels for all tenors. While the explanatory ability of interest rate levels is important, the slopes only predict future movements for the 6- and 12-month tenors. Compared with the empirical findings for levels, the explanatory power of the linear model also increases with the tenor, but it is clearly higher for each tenor. Indeed, the adjusted R^2 reaches 46% for the 12-month maturity. Finally, as for the curvature, our results are qualitatively similar to those previously reported for the slope.

To complete our study, we develop an analysis to identify the explanatory variables for the noise measures underlying our linear regressions. Table 6 summarizes our empirical results. The key role in explaining departures from fitted curves is clearly played by liquidity. With the exception of the 1-month tenor, liquidity is statistically significant at standard confidence levels. Consistently, the adjusted R^2 increases with tenor, reaching its highest value for the 12-month case. ECB liquidity coefficients are negative, indicating that increments in price deviations are related to decreases in market liquidity. This result is remarkable, and it is fully consistent with previous literature regarding the information content embedded in this model's residuals (see Hu et al. (2013) and Rubia et al., 2014).

[TABLE 6 ABOUT HERE]

5.3. The joint dynamics of factors

As previously reported, empirical evidence about the determinants of the evolution of factors reveals that global credit and liquidity market conditions in the financial sector play significant roles in explaining the dynamics of levels and noises, respectively. To assess the relative importance of these two explanatory variables, we explore the nature of the joint dynamics for all tenors using a vector autoregression (VAR) model. Initially, we estimate a five-variable VAR for the first differences of levels (1, 3, 6, and 12 months), including changes in the spread between 1-year maturity AAA EUR Financial Sector and the 1-year maturity German Government yield. The lag length is chosen in accordance with the Hannan-Quinn information criterion, and we consider two lags in all cases.

For the sake of exposition, we limit the VAR analysis to Granger causality and some impulse-response functions. Table 7 reports the empirical values of the Wald statistic for testing the exclusion of groups of regressors for each equation in the VAR. We can observe two clear patterns: First, financial risk cannot be statistically excluded to anticipate futures movements of average interest rates, regardless of the tenor considered. However, causality running from level factors to credit risk arises only for the 1- and 12-month tenors. Second, as for cross interactions between level factors, only the 1-month BS could be better predicted using the information content of the 3-month rates.

[TABLE 7 ABOUT HERE]

Next, we examine the nature of the feedback effects within the VAR system through impulse-response functions. Taking into account the previous results concerning causality, we focus on the responses of level factors to a shock in credit market conditions. The Figure 7 depicts the estimated responses based on a Cholesky decomposition of the variance-covariance matrix; we assume that interest rate levels have no contemporaneous effects on changes in the spread between the 1-year AAA Financial and German Government yields. Additionally, we report standard error bands at the 95% confidence level, computed using Monte Carlo methods, to enable a visual check for significance. We observe a similar pattern of responses for all tenors, and the initial reaction of the 12-month is slightly larger. While the point estimated responses converge to zero after six weeks, the confidence interval at the 95% confidence level confirm that the transitory shock only produces significant contemporaneous responses. In all cases, such a reaction is positive, indicating that increases in the spread between 1-year AAA EUR Financial Sector and the 1-year German Government yield systematically produce and increase in BS levels for all maturities. This is consistent with the idea that higher uncertainty in euro area financial sector conditions is transferred to higher BS premiums.

[FIGURE 7 ABOUT HERE]

A similar analysis is repeated for the model price deviations. In this case, we include the ECB liquidity money indicator in the VAR system. This analysis could provide additional insights not only into the fitting ability of the Nelson-Siegel curve under alternative scenarios of liquidity but also into the relationships between errors across maturities. Table 8 reports the Granger causality concerning the five-variable VAR for the first differences of price deviations and liquidity. Three patterns should be highlighted: Firstly, as expected, the ECB liquidity indicator has significant explanatory power with respect to errors for all maturities. However, regardless of tenor, noise cannot explain liquidity, corroborating the exogenous nature of this variable in the system. Concerning the cross interactions between noises, the 3- and 12-month levels could not be explained by the remaining regressors in the corresponding equation at conventional significance levels. Lastly, the 1-year errors have significant explanatory ability for the short-run errors (1 and 6 months).

[TABLE 8 ABOUT HERE]

In accordance with the causality patterns detected, we only pay attention to the impulse-response functions for a liquidity shock. Figure 8 depicts the responses of level factors to a shock in the ECB liquidity indicator. The immediate effect of an increase in liquidity is a reduction of errors for all maturities. In other words, the observed term structure and estimated term structure tend to diverge under market liquidity shortages. According to the confidence intervals, the effect of liquidity tends to be more persistent over medium- and long-term horizons. For the 6- and 12-month levels, the effect vanishes after five weeks, while the remaining maturities become statistically negligible after two weeks. In sum, a positive liquidity shock tends to increase the goodness of fit of the Nelson-Siegel model, and the effect could remain significant for over five weeks.

[FIGURE 8 ABOUT HERE]

6. Conclusions

Credit derivative markets have experienced structural change since August 2007. Concerns about the increasing risk of counterparty defaults and the impossibility of financing future positions have prompted to a preference for receiving payments earlier. Consequently, the replication of interest rate derivatives using deposit interest is no longer consistent. This novel situation has led to a new pricing framework based on multiple discount curves, which is currently employed by interbank market agents. Evidence of this new paradigm in the financial markets is provided by the departure of deposit and OIS rates, the differences between implicit forward rates and deposit and FRA rates, and the dramatic increase in BS spreads, a floating-to-floating version of interest rate swaps.

This article studies the economic drivers behind the multi-curve framework that arose in the interbank market. The information embedded in BS spreads is employed to analyze the multiple curve differentials. The main features of these spreads are captured by three independent factors associated with the level, slope and curvature using the Nelson and Siegel (1987) model. Then, we develop a time series analysis of the factors inspired by the methodology of Diebold and Li (2006).

The empirical results presented in this article show that the multi-curve framework mirrors the standard single-curve setting in terms of level, slope and curvature factors. A projection of the time series coefficients onto a set economic variables highlights the role of credit and liquidity risk as determinants of the multi-curve framework. In particular, the factor level covaries significantly with a proxy for systemic risk, the spread between AAA Financial and German sovereign yield. In a posterior commonality analysis, we found that this level factor captures a 90% of the total variation in the curves. Additionally, our approach considers the informational content embedded in the deviations from the BS pricing curve, similarly to Hu et al. (2013) for the US Treasuries. These curve residuals are significantly correlated with interbank liquidity, as proxied by the ECB liquidity indicator. Finally, a dynamic analysis using a VAR model shows that systemic risk seems to be a significant economic driver of the BS level factors, and price deviations are mainly explained by the liquidity in the euro area money market.

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Table 1: Contract details concerning Basis Swap Spread Market Quotes.

Interest rates	Tenors	Type of contract	Payment Frequency	Calculation basis
Panel I.- Contract details concerning basis swap spread Market quotes				
Euribor vs. Eonia	3M vs overnight	2 swaps	Annually	Act/360
Euribor vs. Eonia	3M vs 1M	2 swaps	Annually	30/360
Euribor vs. Eonia	6M vs 3M	1 swap	Quarterly	Act/360
Euribor vs. Eonia	6M vs 1M	2 swaps	Annually	30/360
Euribor vs. Eonia	12M vs 3M	2 swaps	Annually	30/360
Euribor vs. Eonia	12M vs 6M	2 swaps	Annually	30/360
Panel II.- Derivation details concerning Euribor vs OIS Basis Swap spreads				
Euribor vs. Eonia	1M vs OIS	(1) Euribor 3M vs OIS - Euribor 3M vs Euribor 1M		
		(2) Euribor 6M vs OIS - Euribor 6M vs Euribor 1M		
Euribor vs. Eonia	3M vs OIS	Direct Market Quote		
Euribor vs. Eonia	6M vs OIS	Euribor 3M vs OIS + Euribor 6M vs Euribor 3M		
Euribor vs. Eonia	12M vs OIS	(1) Euribor 3M vs OIS + Euribor 12M vs Euribor 3M		
		(2) Euribor 6M vs OIS + Euribor 12M vs Euribor 6M		

Table 2: Summary statistics

		Mean	Std.	Median	Min	Max	Skew.	Kurtosis	ρ_N			N
									4	12	24	
E1m vs OIS	1y	18.31	15.99	12.43	3.10	85.30	1.47	4.66	0.91	0.69	0.33	274
	5y	16.92	9.24	14.60	2.70	53.85	1.01	3.67	0.90	0.75	0.46	274
	10y	16.02	7.21	14.78	3.35	41.95	0.76	3.18	0.89	0.77	0.56	274
	20y	15.03	6.47	13.38	2.50	33.60	0.55	2.66	0.92	0.81	0.65	274
	30y	14.54	6.28	12.80	2.20	30.90	0.47	2.47	0.92	0.81	0.68	274
E3m vs OIS	1y	40.79	22.98	34.10	12.10	106.55	0.95	3.04	0.95	0.76	0.40	274
	5y	32.61	10.10	31.85	13.30	68.45	0.34	2.94	0.91	0.72	0.39	274
	10y	28.66	6.95	28.90	13.95	53.65	0.08	3.11	0.88	0.70	0.42	274
	20y	24.80	5.93	25.35	12.20	43.30	-0.09	2.66	0.90	0.75	0.55	274
	30y	23.11	5.81	23.57	10.65	39.90	-0.11	2.41	0.91	0.76	0.61	274
E6m vs OIS	1y	61.20	27.33	53.95	24.10	143.50	0.90	3.42	0.95	0.71	0.31	274
	5y	46.29	9.86	46.33	29.10	74.95	0.17	2.42	0.90	0.66	0.22	274
	10y	39.10	6.21	40.00	25.54	57.25	-0.05	2.25	0.84	0.55	0.16	274
	20y	32.02	5.04	32.13	20.50	46.35	-0.06	2.50	0.85	0.58	0.28	274
	30y	29.04	5.17	28.88	18.00	42.25	0.04	2.53	0.86	0.63	0.41	274
E12m vs OIS	1y	86.49	42.50	71.40	37.25	237.20	1.35	4.58	0.93	0.64	0.22	274
	5y	59.61	14.37	55.29	37.10	99.85	0.72	2.48	0.93	0.70	0.27	274
	10y	48.81	8.61	46.95	31.90	71.60	0.42	2.52	0.88	0.65	0.26	274
	20y	38.86	5.25	38.60	28.60	52.95	0.18	2.28	0.83	0.52	0.11	274
	30y	34.74	4.62	35.01	24.00	48.05	0.15	2.32	0.79	0.46	0.12	274

Descriptive statistics for different Euribor tenor versus OIS Basis Swap spreads term structures. The table presents the mean, standard deviation, median, minimum, maximum, skewness, kurtosis and 4, 12 and 24 lag autocorrelations of the term structures whose selected maturities are 1, 5, 10, 20 and 30 years. The distinct Euribor tenors are 1, 3, 6 and 12 months. The historical series are expressed in basis points and correspond to weekly data from June 2nd, 2008 to August 31st, 2013.

Table 3: PCA factors

	β_{1t}			β_{2t}			β_{3t}		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
E1mOIS	-0.49	-0.69	-0.52	-0.48	-0.78	-0.35	0.45	-0.87	0.14
E3mOIS	-0.51	-0.11	0.74	-0.51	-0.13	0.70	0.52	0.09	-0.70
E6mOIS	-0.52	0.10	0.14	-0.51	0.41	0.21	0.51	0.36	-0.11
E12mOIS	-0.49	0.71	-0.41	-0.50	0.46	-0.59	0.51	0.32	0.70
Variance	92.93	5.86	0.88	91.76	6.02	2.12	89.80	8.64	1.25

PCA results for the Nelson-Siegel level, slope and curvature factors. The table presents the factor loadings of the first three principal components and the percentage variance explained by each component. These figures are computed by performing a principal component analysis separately for the level, slope and curvature factors associated with the distinct Euribor tenor vs OIS Basis Swap spread term structures. The distinct Euribor tenors are 1, 3, 6 and 12 months. The historical series of the factors correspond to weekly data from June 2nd, 2008 to August 31st, 2013.

Table 4: Pairwise correlations of increments of explanatory variables

	IR Level	*IR Slope*	*ECB Liq*	*EuroStoxxBanks*	*EuroStoxxVix*	*Itraxx Fin.*	*German CDS*	*FG Spread*	*ECB RA*
IR Level	1.00								
IR Slope	0.03	1.00							
ECB Liq	0.12	-0.18	1.00						
EuroStoxxBanks	-0.00	-0.06	0.10	1.00					
EuroStoxxVix	0.12	0.18	-0.19	-0.67	1.00				
Itraxx Fin.	0.05	-0.16	-0.03	-0.71	0.46	1.00			
German CDS	0.04	-0.06	-0.16	-0.51	0.37	0.60	1.00		
FG Spread	0.13	0.22	-0.37	-0.19	0.26	0.23	0.23	1.00	
ECB RA	0.11	0.17	-0.17	-0.66	0.82	0.54	0.43	0.26	1.00

Table 5: OLS robust regressions of BS factor components

	Level				Slope				Curvature			
Variables	1M	3M	6M	12M	1M	3M	6M	12M	1M	3M	6M	12M
Constant	-0.0425	-0.0856	-0.1005	-0.1019	-0.0343	-0.1285	-0.0892	-0.0742	0.0449	0.3481	0.4417	0.5122
	(0.1549)	(0.1594)	(0.1454)	(0.1807)	(0.1988)	(0.2054)	(0.1908)	(0.2863)	(0.5292)	(0.5432)	(0.5975)	(0.9081)
IR Level	0.9901	0.7989	0.9001	1.7358	4.3208***	2.4105	3.5688**	6.0949**	-9.3117**	-7.4823**	-12.1386***	-19.3707***
	(1.0387)	(0.7169)	(0.7563)	(1.2578)	(1.6330)	(1.6795)	(1.4325)	(2.3812)	(4.2381)	(3.3987)	(3.8524)	(7.2879)
IR Slope	2.4664	3.6731	6.8222***	13.7108***	-1.9503	-0.1594	6.2614**	21.0284***	-14.9685	-20.7851**	-41.1972***	-81.7927***
	(2.7391)	(2.3779)	(2.3399)	(3.0256)	(2.8339)	(2.8960)	(2.7022)	(4.2956)	(9.7135)	(9.1292)	(11.2563)	(16.3723)
ECB Liq	-1.0556	-0.5716	-0.1768	-2.0453	-1.0465	-0.5955	-4.2867*	-9.8534**	8.6292	12.3584*	16.4656**	31.0617***
	(1.7978)	(1.5557)	(1.3917)	(1.8769)	(2.5872)	(2.4005)	(2.2162)	(3.8199)	(7.4693)	(6.6060)	(6.7528)	(11.6305)
German CDS	-0.0322	-0.0481	-0.0482	-0.0760*	0.0919**	0.1757***	0.1602***	0.1108	0.1180	0.0803	0.1231	0.2616
	(0.0316)	(0.0317)	(0.0312)	(0.0433)	(0.0441)	(0.0438)	(0.0447)	(0.0873)	(0.1093)	(0.1084)	(0.1150)	(0.2262)
FG Spread	6.0817**	7.5278**	7.6327***	9.0437***	4.6584	3.7101	5.6403	10.0496	-13.5029	-13.9832	-14.0002	-21.0975
	(3.0825)	(3.1519)	(2.7486)	(3.0838)	(4.8579)	(4.6758)	(4.3733)	(6.2942)	(10.2093)	(10.1273)	(8.8135)	(14.8808)
ECB RA	-0.1723	0.0107	0.4072**	0.8657***	0.6822*	0.9194**	1.2510***	2.8271***	-0.9310	-1.3510*	-3.2001***	-6.2824***
	(0.2461)	(0.2554)	(0.2008)	(0.2859)	(0.4112)	(0.3553)	(0.3340)	(0.5760)	(0.8516)	(0.7629)	(1.1275)	(1.8527)
Adj-R^2	4.75	7.18	15.02	28.33	15.11	16.79	33.68	46.06	11.67	16.49	30.79	41.04
N	273	273	273	273	273	273	273	273	273	273	273	273

OLS robust regressions of the Basis Swap Nelson-Siegel factors. The table reports the OLS results from regressing changes in the different Euribor tenor basis swap spreads Nelson-Siegel parameters against different macro-financial variables. These results correspond to OLS coefficient estimates, robust standard errors and Adjusted R2 values. The Nelson-Siegel parameters are associated with level, slope and curvature factors, and the distinct Euribor tenors are 1, 3, 6 and 12 months. The sample period corresponds to weekly data from June 2nd, 2008 to August 31st, 2013. *, ** and *** denote the significance at 10%, 5% and 1%, respectively.

Table 6: OLS robust regressions of noise components

	Noise			
Variables	1M	3M	6M	12M
Constant	0.0032	-0.0007	0.0040	0.0069
	(0.0257)	(0.0261)	(0.0296)	(0.0397)
IR Level	0.1512	0.1782	0.2526	0.3494*
	(0.1397)	(0.1373)	(0.1569)	(0.2007)
IR Slope	-0.1119	0.1807	0.3980	1.4760**
	(0.4378)	(0.4209)	(0.5257)	(0.6569)
ECB Liq	-0.2590	-0.5136**	-0.8924***	-1.6557***
	(0.2620)	(0.2411)	(0.2940)	(0.3691)
German CDS	-0.0005	0.0007	-0.0004	-0.0135
	(0.0053)	(0.0064)	(0.0072)	(0.0112)
FG Spread	0.2756	0.1930	0.4869	0.4505
	(0.4259)	(0.4432)	(0.3991)	(0.6493)
ECB RA	-0.0187	-0.0059	0.0085	0.1922**
	(0.0458)	(0.0433)	(0.0644)	(0.0830)
Adj-R^2	-0.09	3.39	11.42	26.06
N	273	273	273	273

OLS robust regressions of noise components. The table reports the OLS results from regressing changes in the different Euribor tenor basis swap spread curves noise components against different macro-financial variables. These results correspond to OLS coefficient estimates, robust standard errors and Adjusted R^2 values. The noise components are computed as the RMSE between the different Euribor tenor market observed basis spreads and the Nelson-Siegel model implied spreads. The distinct Euribor tenors are 1, 3, 6 and 12 months. The sample period corresponds to weekly data from June 2nd, 2008 to August 31st, 2013. *, ** and *** denote the significance at 10%, 5% and 1%, respectively.

Table 7: Granger causality for VAR models

Equation	Excluded	χ^2 statistic
$\Delta\beta_{1M}$	$\Delta\beta_{3M}$	6.0882**
	$\Delta\beta_{6M}$	0.7929
	$\Delta\beta_{12M}$	2.6568
	$\Delta FGSpread$	14.7710***
	All	44.6680***
$\Delta\beta_{3M}$	$\Delta\beta_{1M}$	0.0879
	$\Delta\beta_{6M}$	0.7399
	$\Delta\beta_{12M}$	2.2869
	$\Delta FGSpread$	12.4420***
	All	37.8740***
$\Delta\beta_{6M}$	$\Delta\beta_{1M}$	0.4588
	$\Delta\beta_{3M}$	2.2925
	$\Delta\beta_{12M}$	4.1712
	$\Delta FGSpread$	12.905***
	All	31.0430***
$\Delta\beta_{12M}$	$\Delta\beta_{1M}$	2.8670
	$\Delta\beta_{3M}$	3.2928
	$\Delta\beta_{6M}$	0.0423
	$\Delta FGSpread$	16.3660***
	All	30.3140***
$\Delta FGSpread$	$\Delta\beta_{1M}$	1.7249
	$\Delta\beta_{3M}$	5.3141*
	$\Delta\beta_{6M}$	3.6336
	$\Delta\beta_{12M}$	9.9698***
	All	19.1720**

Granger causality Wald tests on the significance of all the lags from the excluded variable. Variables β_{1M}, β_{3M}, β_{6M} and β_{12M} are the level coefficients of Nelson and Siegel (1987) model. The variable FG Spread stands for spread between the 1-year maturity AAA EUR Financial Sector and the 1-year maturity German Government yield. The model lags have been selected according to the Bayesian Information Criterion. *, ** and *** denote the significance at 10%, 5% and 1%, respectively.

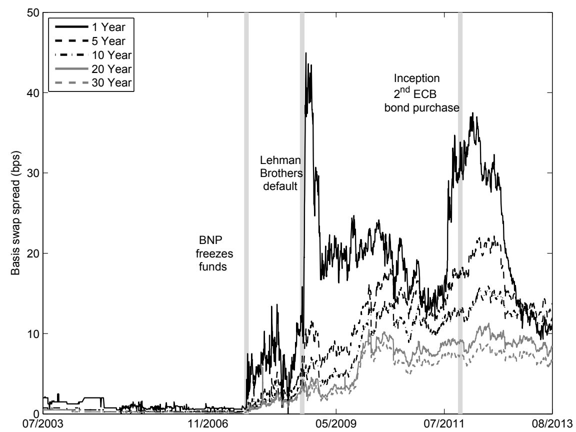
Table 8: Granger causality for VAR models

Equation	Excluded	χ^2 statistic
$\Delta Noise_{1M}$	$\Delta Noise_{3M}$	0.3475
	$\Delta Noise_{6M}$	2.0316
	$\Delta Noise_{12M}$	5.3911*
	Δ ECB Liq	9.1338***
	All	18.6320**
$\Delta Noise_{3M}$	$\Delta Noise_{1M}$	2.8075
	$\Delta Noise_{6M}$	1.3384
	$\Delta Noise_{12M}$	1.0947
	Δ ECB Liq	11.1450***
	All	38.9240***
$\Delta Noise_{6M}$	$\Delta Noise_{1M}$	4.6181*
	$\Delta Noise_{3M}$	1.1670
	$\Delta Noise_{12M}$	5.3279*
	Δ ECB Liq	18.0570***
	All	66.1950***
$\Delta Noise_{12M}$	$\Delta Noise_{1M}$	2.2536
	$\Delta Noise_{3M}$	0.1573
	$\Delta Noise_{6M}$	0.2937
	Δ ECB Liq	28.8590***
	All	43.7030***
Δ ECB Liq	$\Delta Noise_{1M}$	0.1851
	$\Delta Noise_{3M}$	2.4660
	$\Delta Noise_{6M}$	4.4353
	$\Delta Noise_{12M}$	1.0249
	All	8.7269

Granger causality Wald tests on the significance of all the lags from the excluded variable. Variables $Noise_{1M}$, $Noise_{3M}$, $Noise_{6M}$ and $Noise_{12M}$ are the residuals of Nelson and Siegel (1987) model. The variable ECB Liq stands for the ECB liquidity indicator of the money market for the Euro Area published by the ECB. The model lags have been selected according to the Bayesian Information Criterion. *, ** and *** denote the significance at 10%, 5% and 1%, respectively.

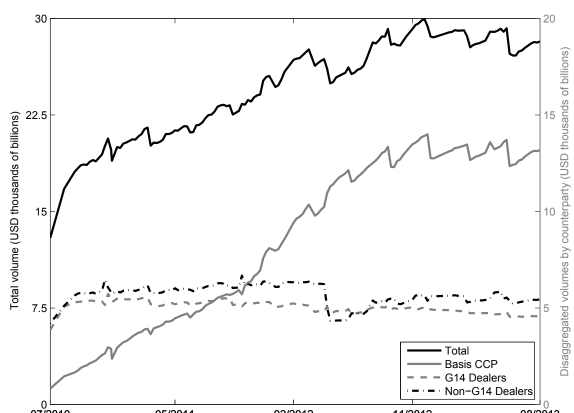
7. Figures

Figure 1: Euribor 6M vs Euribor 3M basis swap spread corresponding to different maturities.



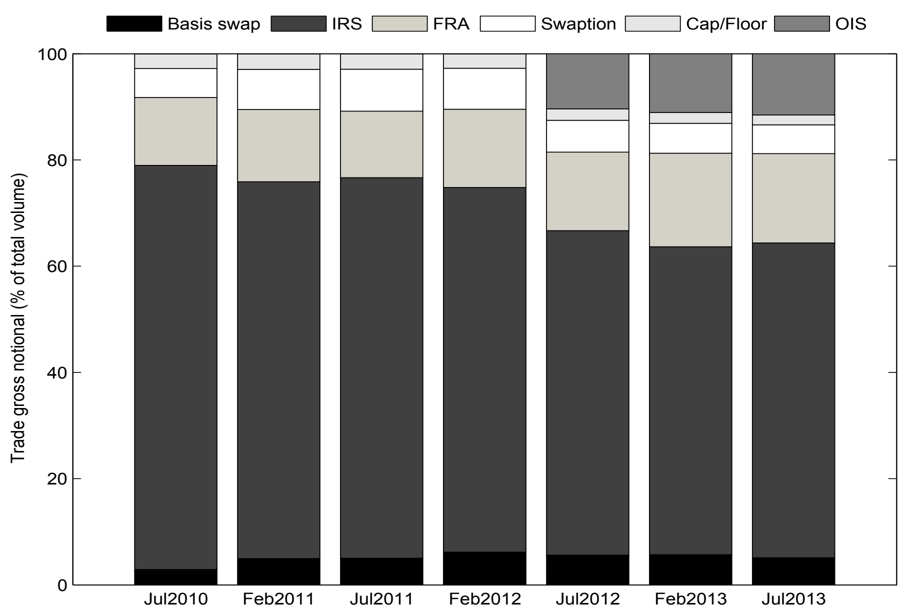
Time series of the Euribor 6M versus 3M basis swap spread. Data period ranges from July 28th, 2003 to August 30th, 2013.

Figure 2: Basis swap trades gross notional disaggregated by the type of counterparty.



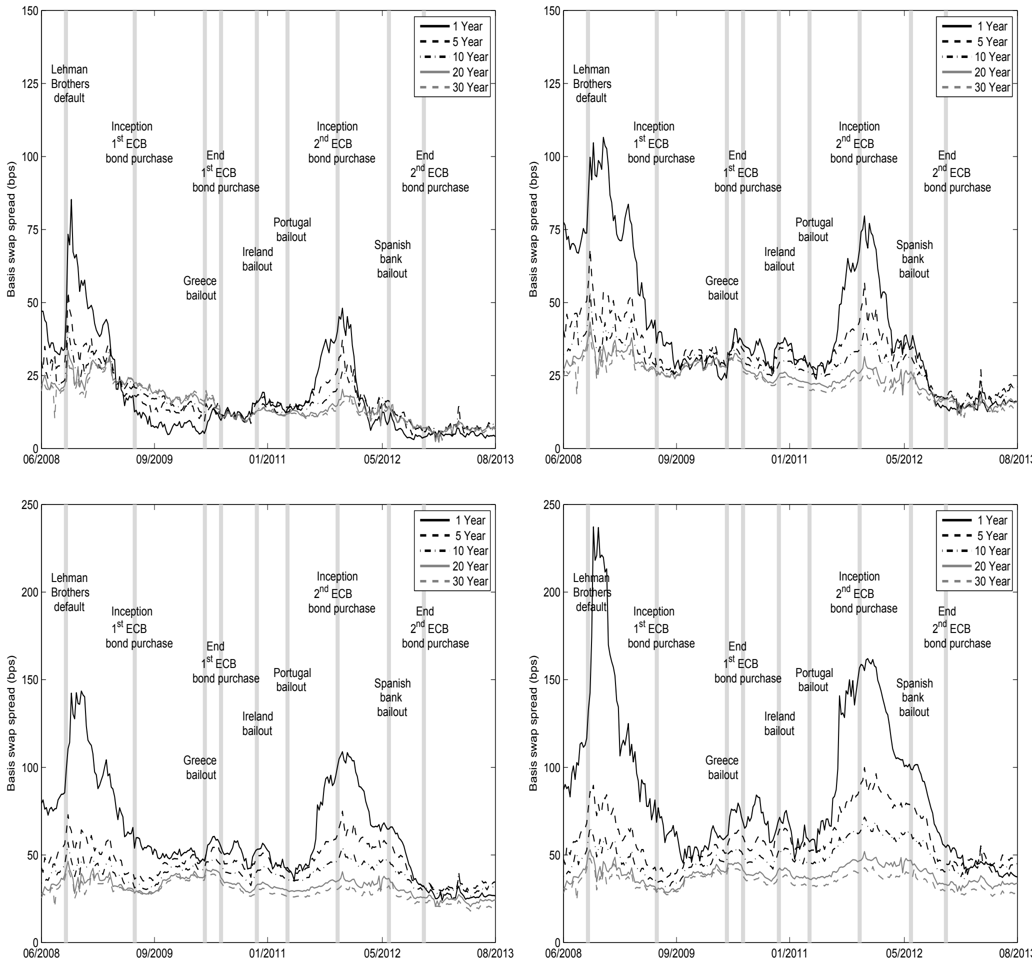
Basis swap trades gross notional disaggregated by the type of counterparty. Basis swap outstanding trades gross notional data correspond to left axis. Basis swap disaggregated by type of counterparty are in right axis. Outstanding trades gross notional data are in billions of USD and it is based on 14 financial entities interest rate derivatives transaction weekly reports. Data are disaggregated by the type of counterparty: G14 dealers, non-G14 dealers and central clearing counterparties (Basis CCP). The sample period ranges from July 30th, 2007 to August 30th, 2013. Data have been extracted from DTCC and TriOptima.

Figure 3: Gross notional in percentage of the traded total volume



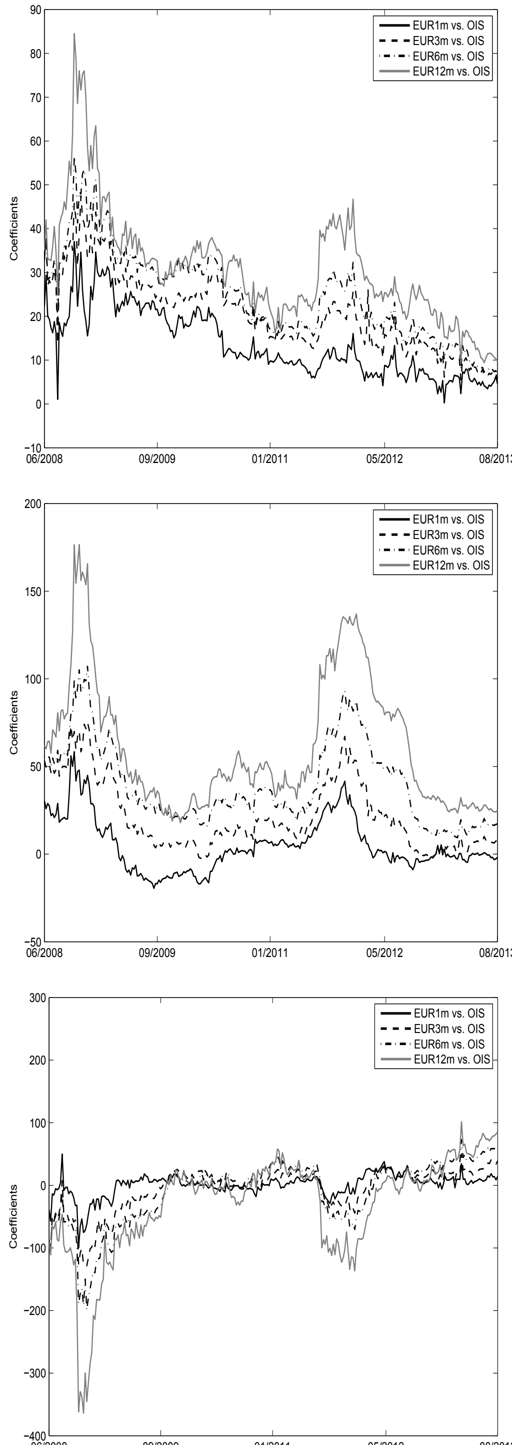
Each bar contains the BS, IRS, FRA, Swaption and Cap/Floor Trades Gross Notional. Data ranges from July 2010 until July 2013, with the exception of OIS series, which starts in April 2012. Data are extracted from DTCC and Trioptima.

Figure 4: Euribor versus OIS basis swap spreads at different maturities.



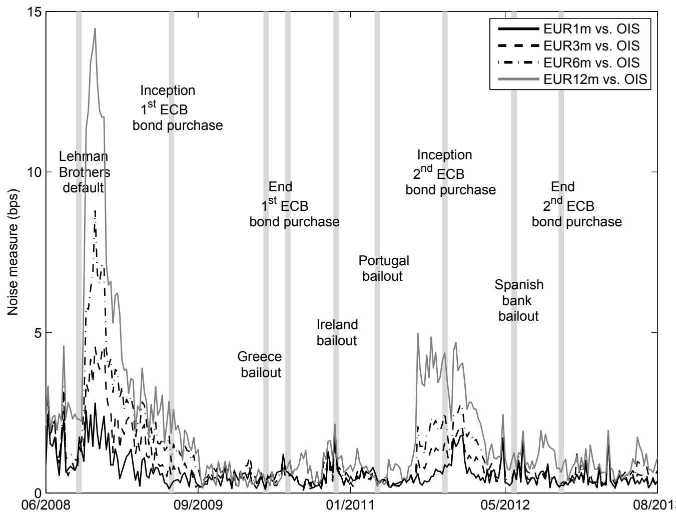
Time series of the Euribor versus OIS basis swap spread. Data period comprises weekly data from June 2nd, 2008 to August 30th, 2013.

Figure 5: Time series of Nelson and Siegel (1987) model coefficients for different basis swap instruments



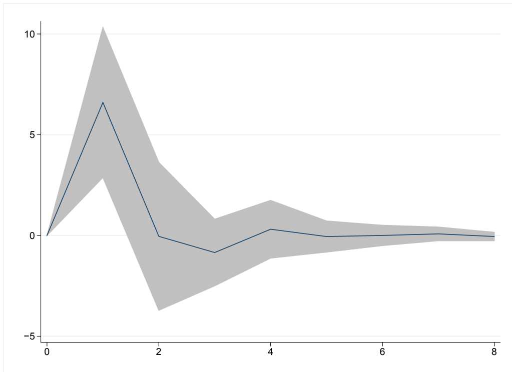
Time series of the Nelson and Siegel (1987) coefficients for basis swap spreads at different tenors. β_1 coefficient is upper graph. β_2 and β_3 are middle and lower graphs, respectively. Data frequency is weekly and ranges from June 2nd, 2008 to August 30th, 2013.

Figure 6: Time series of Hu et al. (2013) noise measure

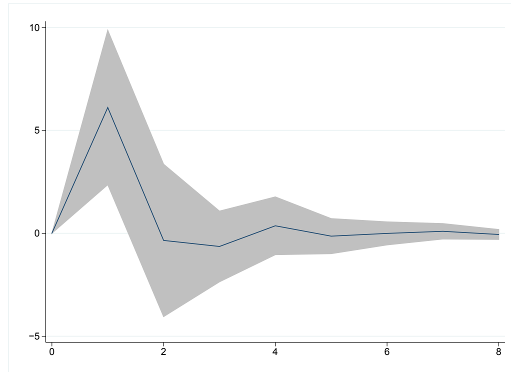


Time series of the Hu et al. (2013) noise measure applied to the basis swap spreads at different tenors. Data period ranges from June 6th, 2008 to August 30th, 2013.

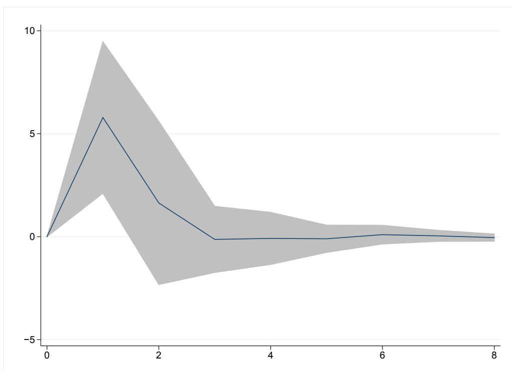
Figure 7: Impulse-response functions for increments of level factors in VAR(5)



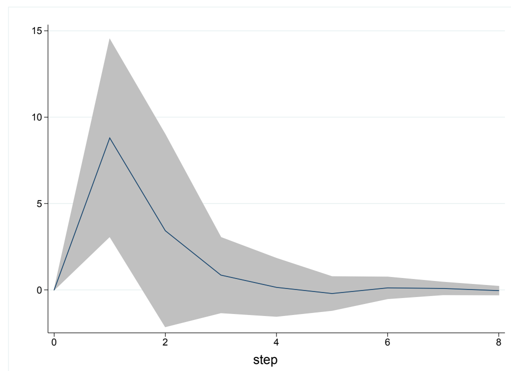
Response of 1-month level to shock in FG spread



Response of 3-month level to shock in FG spread



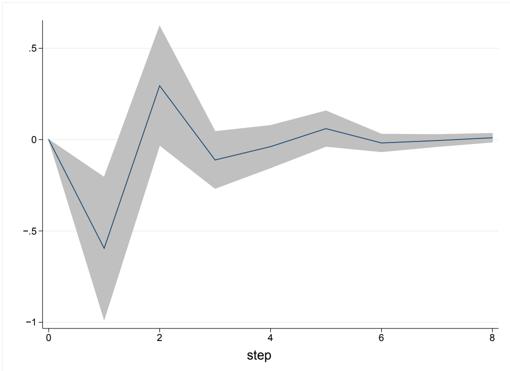
Response of 6-month level to shock in FG spread



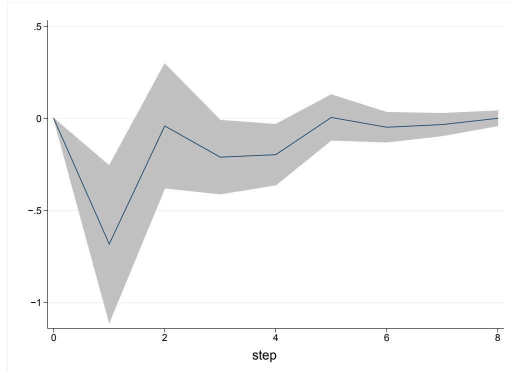
Response of 12-month level to shock in FG spread

A five-variable VAR is estimated with the increments of level factors of four tenors (1, 3, 6 and 12 months) and the increments of spread between the 1-year maturity AAA EUR Financial Sector and the 1-year maturity German Government yield (FG Spread). The Figure shows the response to shocks in FG Spread over eight weeks after the impulse. The shadow areas depicts the standard error bands.

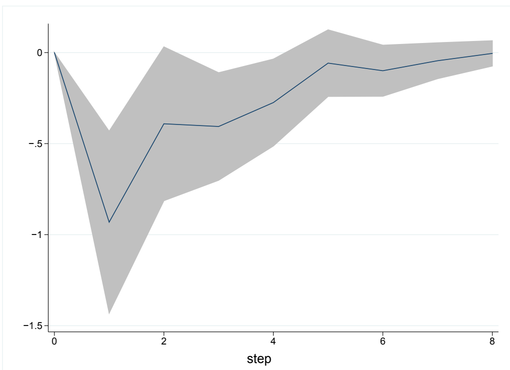
Figure 8: Impulse-response figures for increments of price deviations in VAR(5)



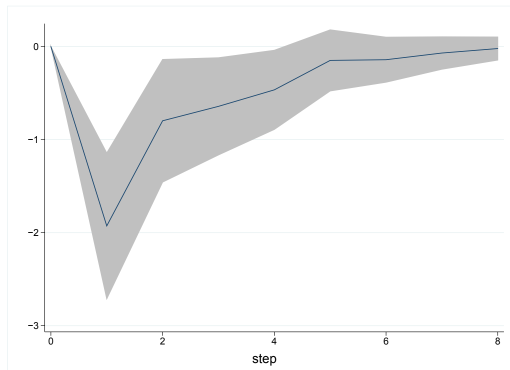
Response of 1-month noise to shock in liquidity



Response of 3-month noise to shock in liquidity



Response of 6-month noise to shock in liquidity



Response of 12-month noise to shock in liquidity

A five-variable VAR is estimated with the increments of the noise variable at four tenors (1, 3, 6 and 12 months) and the increments of the ECB liquidity indicator of the money market for the Euro Area (ECB Liq) published by ECB. The Figure shows the response to shocks in the ECB liq over eight weeks after the impulse. The shadow areas depicts the standard error bands.

Appendix A. Interest rate swaps and the multi-curve framework

Due to multi-curve setting, IRS floating payments do depend on floating rate periodicity. To fix notation, denote as $L(T_{x,j-1},T_{x,j})$ the interbank deposit rate with tenor x associated with an interest rate swap floating leg with date schedule $T_x = \{T_{x,0},..,T_{x,n_x}\}$. Similarly, we denote as K the interest rate corresponding to a swap fixed leg with date schedule $T_z = \{T_{z,0},..,T_{z,n_z}\}$. The interest rate swap cash flows present value is

$$\begin{aligned} Swap(t;T_x,T_z) &= E_t\left(\sum_{j=1}^{n_x} e^{-\int_t^{T_{x,j}} r(s)ds}\tau_x\left(T_{x,j-1},T_{x,j}\right)L\left(T_{x,j-1},T_{x,j}\right)\right) \\ &- K\sum_{j=1}^{n_z} P_d\left(t,T_{z,j}\right)\tau_z\left(T_{z,j-1},T_{z,j}\right), \end{aligned} \tag{A.1}$$

where r_t is the instantaneous default-free interest rate at time t and $P_d(t,T)$ is the value at time t of the default-free zero-coupon bond with maturity T, $P_d(t,T) = E_t[e^{-\int_t^T r(u)du}]$. $E_t[.]$ is the expectation under the risk neutral measure. Finally, τ_x and τ_z denote the day count fraction between two particular payment dates according to the established calculation basis.

The IRS equilibrium rate is the swap fixed leg interest rate that makes null the swap present value, namely,

$$IRS(t;T_x,T_z) = \frac{E_t\left(\sum_{j=1}^{n_x} e^{-\int_t^{T_{x,j}} r(s)ds}\tau_x\left(T_{x,j-1},T_{x,j}\right)L\left(T_{x,j-1},T_{x,j}\right)\right)}{\sum_{j=1}^{n_z} P_d\left(t,T_{z,j}\right)\tau_z\left(T_{z,j-1},T_{z,j}\right)}. \tag{A.2}$$

If we substitute expression (1) on the last expression we are assuming that the following replication strategies for IRSs based on a single-curve framework hold. In the pre-crisis context, these replication strategies were consistent with market quotes.

$$Swap(t,T) = \frac{\sum_{i=1}^{n} P(t,T_i)\tilde{F}(t,T_{i-1},T_i)\tau(T_{i-1},T_i)}{\sum_{i=1}^{n} P(t,T_i)\tau(T_{i-1},T_i)} = \frac{P(t,T_0)-P(t,T_n)}{\sum_{i=1}^{n} P(t,T_i)\tau(T_{i-1},T_i)} \tag{A.3}$$

Appendix B. An alternative definition of the basis swap contract

The second type of basis swap contract is structured as a floating vs floating swap plus spread. In particular, the longer tenor Euribor rate $L(T_{x,j-1},T_{x,j})$ is exchanged for the shorter tenor Euribor rate $L(T_{y,j-1},T_{y,j})$. The date schedules corresponding to the swap floating legs linked to Euribor rates $L(T_{y,j-1},T_{y,j})$ and $L(T_{x,j-1},T_{x,j})$ are $T_y = \{T_{y,0},..,T_{y,n_y}\}$ and $T_x = \{T_{x,0},..,T_{x,n_x}\}$, respectively. To equalize the present value of these legs, a basis swap spread $\Delta_{x,y}$ must be added to the floating leg with shorter tenor. Therefore, the basis swap spread has the same payment frequency as the shorter tenor leg and is quoted against this leg. The value of the Basis Swap contract is as follows:

$$\begin{aligned} BasisSwap(t;T_x,T_y) &= E_t\left(\sum_{j=1}^{n_x} e^{-\int_t^{T_{x,j}} r(s)ds}\tau_x\left(T_{x,j-1},T_{x,j}\right)L\left(T_{x,j-1},T_{x,j}\right)\right) \\ &- E_t\left(\sum_{j=1}^{n_y} e^{-\int_t^{T_{y,j}} r(s)ds}\tau_y\left(T_{y,j-1},T_{y,j}\right)\left(L\left(T_{y,j-1},T_{y,j}\right)+\Delta_{x,y}\right)\right). \end{aligned} \tag{B.1}$$

The equilibrium basis swap spread satisfies

$$\Delta_{x,y} = \frac{\begin{pmatrix} E_t\left(\sum_{j=1}^{n_x} e^{-\int_t^{T_{x,j}} r(s)ds}\tau_x\left(T_{x,j-1},T_{x,j}\right)L\left(T_{x,j-1},T_{x,j}\right)\right) \\ -E_t\left(\sum_{j=1}^{n_y} e^{-\int_t^{T_{y,j}} r(s)ds}\tau_y\left(T_{y,j-1},T_{y,j}\right)L\left(T_{y,j-1},T_{y,j}\right)\right)\end{pmatrix}}{\sum_{j=1}^{n_y} P_d\left(t,T_{y,j}\right)\tau_y\left(T_{y,j-1},T_{y,j}\right)} \tag{B.2}$$

As can be observed from the previous equations, the difference between the two types of basis swaps contracts equilibrium spreads lays on the annuity term in the denominator, where the frequency and calculation basis in one case corresponds to the shorter tenor floating leg and in the other case to the swap fixed leg. In particular, the first type of contract basis spread, $\Delta^1_{x,y}$, can be deduced from the one corresponding to the second type of BS contract, $\Delta^2_{x,y}$, as follows:

$$\Delta^2_{x,y} = \frac{\sum_{j=1}^{n_z} P_d\left(t,T_{z,j}\right)\tau_z\left(T_{z,j-1},T_{z,j}\right)}{\sum_{j=1}^{n_y} P_d\left(t,T_{y,j}\right)\tau_y\left(T_{y,j-1},T_{y,j}\right)}\Delta^1_{x,y}. \tag{B.3}$$

Appendix C. Summary statistics of factors

Table C.9: Summary statistics of Nelson and Siegel (1987) factors

	BS Tenor (months)	Mean	Std.	Median	Min	Max	Skew.	Kurtosis	ρ_N 4	12	24	N
β_1	1	13.64	7.67	11.05	0.23	37.04	0.67	2.59	0.90	0.78	0.67	274
	3	20.82	8.86	20.21	5.50	47.51	0.47	2.71	0.93	0.80	0.60	274
	6	24.76	10.23	24.93	6.69	56.49	0.49	2.96	0.92	0.77	0.53	274
	12	31.05	12.95	29.88	9.41	84.51	1.25	5.59	0.91	0.65	0.29	274
β_2	1	5.05	15.35	0.96	-19.49	58.40	1.01	3.72	0.92	0.67	0.26	274
	3	21.73	19.67	14.68	-2.43	75.16	0.96	2.78	0.94	0.74	0.35	274
	6	39.43	23.40	31.30	9.33	107.14	0.90	2.88	0.94	0.71	0.30	274
	12	60.57	36.86	46.87	17.95	176.52	1.13	3.44	0.94	0.67	0.27	274
β_3	1	0.70	18.17	4.20	-99.65	49.93	-1.69	8.76	0.75	0.38	0.04	274
	3	-5.61	35.18	8.36	-129.31	49.99	-1.43	4.78	0.90	0.68	0.38	274
	6	-9.82	52.46	8.27	-199.02	73.11	-1.25	4.49	0.92	0.70	0.42	274
	12	-30.52	81.79	-4.15	-363.83	101.48	-1.63	6.62	0.91	0.63	0.29	274

Descriptive statistics for the Nelson-Siegel model factors corresponding to different Euribor tenor BS spread curves. The table presents the mean, standard deviation, median, minimum, maximum, skewness, kurtosis and 4, 12 and 24 lags autocorrelations of the BS spreads term structures. The distinct BS Euribor tenors are 1, 3, 6 and 12 months. The historical series correspond to weekly data from June 2nd, 2008 to August 31st, 2013.