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Banks' equity performance and the term structure of interest rates

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Abstract

Using an extensive global sample, this paper investigates the impact of the term structure of interest rates on bank equity returns. Decomposing the yield curve to its three constituents (level, slope and curvature), the paper evaluates the time-varying sensitivity of the bank's equity returns to these constituents by using a diagonal dynamic conditional correlation multivariate GARCH framework. Evidence reveals that the empirical proxies for the three factors explain the variations in equity returns above and beyond the market-wide effect. More specifically, shocks to the long-term (level) and short-term (slope) factors have a statistically significant impact on equity returns, while those on the medium-term (curvature) factor are less clear-cut. Bank size plays an important role in the sense that exposures are higher for SIFIs and large banks compared to medium and small banks. Moreover, banks exhibit greater sensitivities to all risk factors during the crisis and post-crisis periods compared to the pre-crisis period; though these sensitivities do not differ for market-oriented and bank-oriented financial systems.

KEYWORDS

Banks, Economic Cycles, Equity Return, Interest Rate Risk, Yield Curve

JEL CLASSIFICATION

C32, E43, G21

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1 | INTRODUCTION

The specialness of financial intermediaries and banking in particular is well discussed in the finance literature with emphasis on the unique structure of the bank's balance sheet (Beston, 2004; Saunders & Cornett, 2017). The "new" originate-to-distribute model, adopted by banks, has enabled them to tap into new funding channels (e.g., asset-backed securities, derivatives, etc.), which in turn has broadened their investment activities via the creation of new asset classes such as collateralised asset obligations and other structured products (Purnanandam, 2011; Shin, 2009). Recent findings on the causes of the 2007 financial crisis point to the balance sheet structure of the banking firm (Brunnermeier & Oehmke, 2013; Farhi & Tirole, 2012), while the inherent leverage-adjusted duration/convexity gap of the bank's assets and liabilities underlines its exposure to interest rate fluctuations (Anderson & Cakici, 1999; English, Van den Heuvel, & Zakrajsek, 2018; Entrop, Memmel, Wilkens, & Zeisler, 2008; Alessandri & Nelson, 2015; Flannery & James, 1984a).

The significance of interest rate changes was documented much earlier by Merton (1973) and Long (1974) where, under the assumption of a stochastic risk-free rate, investors are exposed to another kind of risk, namely, the risk of unfavorable shifts in the investment opportunity set. In reality, the bank's portfolio (assets/liabilities) contains a wide range of instruments with different maturities and, thus, broader yield curve features highlight the evolution of market expectation in response to changing economic conditions and the bank's risk exposure. This point is reinforced by the recent Basel Committee on Banking Supervision (2016) where banks are required to measure their 12-month net interest income while balancing the multiple maturities in their portfolio.

Yield curve properties have a distinctive influence on the investors' perception about risk-return relationships as they are linked to business cycle conditions (Aguigar-Conraria, Martins, & Soares, 2012; Dewachter & Lyrio, 2006; Diebold, Rudebusch, & Aruoba, 2006) and consequently to the bank's equity performance. Thus, using a single point of the yields' distribution (e.g., three-month T-bill) overlooks the impact of the whole spectrum of yield changes on the market value of the bank's overall portfolio. This issue becomes nontrivial when investment portfolios with expected and contingent cash flows of different maturities are considered. Therefore, the limitations of analysing bank equity's yield sensitivity on the basis of yield point changes, as opposed to yield curve changes, become economically relevant (see surveys by Staikouras (2003, 2006) on financial intermediaries' interest rate risk exposure).

The current paper investigates the potential exposure of banks' stock returns to interest rate risk by explicitly taking into account the level, slope and curvature of the entire term structure of interest rates (yield curve). More specifically, the present study contributes to the literature in four fronts. First, it deploys the level, slope and curvature of the term structure of interest rates, derived from a three-factor interest rate model, to examine the exposure of bank's equity to yield curve fluctuations across all maturities. These three-factors are used as independent risk factors in the banks' equity return generating process. The decomposition of the yield curve into its three components provides a research design that aims to overcome the caveats of earlier work focusing on fixed maturity yield changes and ignoring the effect of changes in the shape of the term structure or that of a "twist" in the yield curve¹. Previous empirical studies have tried to resolve the issue by considering multiple yield measures with different maturities and/or term spreads with the exception of Czaja, Scholz, and Wilkens (2009). Yet, an important consideration is that yield changes across different maturities are not perfectly correlated and, thus, using different maturities in isolation can lead to misleading results. Second, the paper sheds light on the interface between the dynamics of the wider economy and the yield curve exposure of the banking firm by incorporating a period long enough to embrace different phases of the business cycle, as well as both the crisis and non-crisis periods. One stylized fact of the yield curve is that its shape is intimately connected to the cyclical dynamics of the economy (Diebold et al., 2006). The yield curve tends to be steeper near the trough of the business cycle, while relatively flat near its peak. This feature directly influences banks' risk profile, since their leverage and credit generating capacity (balance-sheet size) are determined by the interest rate environment where they operate². Thus, when the yield curve is upward sloping during an economic boom, banks expand their balance sheet through leverage, subject to regulatory capital requirement, to take advantage of the carry spread (Adrian & Shin, 2008). On the other hand, during an economic downturn, banks may experience difficulties to rollover these debts as a result of shortage in funding liquidity (Acharya & Viswanathan, 2011). Using a dataset covering both the

pre-, during and post-financial crisis periods allows this research to present fresh evidence of the banks' yield sensitivities during different business cycles. Third, the research setup allows for potential time-variation in yield betas by employing the diagonal dynamic conditional correlation multivariate GARCH (diagonal DCC-MGARCH) model. Unlike the conventional regression models, this econometric framework allows for the dynamic evolution of the institutions' interest rate risk exposure and facilitates pair-specific correlation dynamics and asymmetries in the conditional variances. Moreover, it accommodates the heteroscedastic nature of equity returns and overcomes the issue of multicollinearity among exogenous variables³. Fourth, the analysis is based on a global sample of banking firms across major market-oriented (U.S./U.K.) and bank-oriented (Japan/Europe) financial systems⁴. To this end, equally weighted country banking portfolios are constructed, which are further divided into size portfolios, based on total asset value, in order to differentiate between systemically important financial institutions (SIFI), large, medium and small size banks.

The remainder of the paper is organized as follows. Section 2 presents the methodological framework employed. Section 3 describes the data. Section 4 discusses the empirical findings, while Section 5 concludes the paper.

2 | METHODOLOGY

2.1 | Yield curve term structure model

Interest rate risk exposure has been traditionally measured by the coefficients from a two-factor multiple regression model between equity returns and changes in the market factor and interest rate factor with a fixed maturity (Bessler & Kurmann, 2014; Elyasiani & Mansur, 1998; Elyasiani, Mansur, & Pagano, 2007; Flannery & James, 1984b; Oertmann, Rendu, & Zimmermann, 2000 among others). Banking institutions, however, hold assets and liabilities across a wide spectrum of maturities. Therefore, measuring changes in interest rates of a specific maturity fails to recognize the full impact of the yield curve changes on the bank's equity value. Thus, to capture the changes in the entire yield curve the paper employs the Nelson-Siegel (1987) three-factor model. The paper uses Diebold and Li's (2006) parsimonious representation, which imposes only a small number of parameters and provides flexibility to reflect a range of monotonic, humped and S-type shapes typically observed in yield data.

Let three latent factors $\beta_{1,t}$, $\beta_{2,t}$ and $\beta_{3,t}$ be the long-term (level), short-term (slope) and medium-term (curvature) factors of the yield curve at time t , with corresponding factor loadings $[1, (1 - e^{-\tau\lambda_t})/\tau\lambda_t, (1 - e^{-\tau\lambda_t})/\tau\lambda_t - e^{-\tau\lambda_t}]$ and parameter λ_t is an optimal-fit parameter (decay factor) governing the shape of the second and third factor loadings⁵ at time t . In this setting, the spot zero-yield curve⁶ $y_t(\tau)$ with maturity τ at time t is formulated as follows:

$$y_t(\tau) = \beta_{1,t} + \beta_{2,t} \left(\frac{1 - e^{-\tau\lambda_t}}{\tau\lambda_t} \right) + \beta_{3,t} \left(\frac{1 - e^{-\tau\lambda_t}}{\tau\lambda_t} - e^{-\tau\lambda_t} \right) \quad (1)$$

Eq. (1) can be estimated via the OLS with fixed λ . To obtain the time series of the interest rate risk factors, first $\beta_{1,t}$, $\beta_{2,t}$ and $\beta_{3,t}$ are estimated by fitting Eq.(1) to the yield curve. Then, the first order differences of $\beta_{1,t}$ (level), $\beta_{2,t}$ (slope) and $\beta_{3,t}$ (curvature) are computed to capture yield curve changes. Nelson-Siegel components have a clear interpretation as proxies of long, short and medium-term yields. In particular, a shock in $\beta_{1,t}$ affects uniformly all maturity yields, thereby causing a parallel shift in the location of the yield curve; as such, it is viewed as a long-term yield factor (this is called *level*). Loading $\beta_{2,t}$ is viewed as a short-term yield factor because it has a maximal impact on short maturities and a minimal effect on the distant yields, thereby causing a flattening/steepening of the curve (this is called *slope*). Finally, $\beta_{3,t}$ achieves its maximum at medium maturities thereby affecting medium term yields more than the short- and long-term rates (this is called *curvature*).

2.2 | A dynamic conditional correlation model for time-varying betas

Multiple regression models typically employed in the banking literature do not explicitly address the time-varying nature of the bank's market and interest rate risk exposure. Betas obtained within these models are constant over the entire estimation period or defined over lengthy sub-samples by either using binary dummy variables (Faff, Hodgson, & Kremmer, 2005) or by splitting the sample period (Oertmann et al., 2000). Alternative approaches, such as rolling

window estimation, although they do allow for time-variation in the coefficients, they restrict the betas to be constant over the embedded sub-samples. Song (1994) is the first to apply the ARCH estimation framework arguing that betas should change as new information arrives in the market. Subsequent research such as Faff et al. (2005) and Carson, Elyasiani, and Mansur (2008), Flannery, Hameed, and Harjes (1997) use different GARCH models to investigate banks' interest rate exposure. For example, Elyasiani and Mansur (1998) deploy a GARCH in mean approach to study the effect of yield changes and their associated volatilities on bank stock returns distributions.

In the current study, we derive the yield betas from the conditional covariances between the interest rate (IR) risk factors (level, slope and curvature) and the banks' equity (BK) returns:

$$\beta_{IR,t} = \text{cov}_t (r_{BK,t}, r_{IR,t}) / \text{var}_t (r_{IR,t}); \quad (2)$$

where $\beta_{IR,t}$ is the time-varying IR beta of the bank equity return ($r_{BK,t}$) upon changes in the IR risk factor ($r_{IR,t}$) at time t ; $\text{cov}_t(r_{BK,t}, r_{IR,t})$ is the conditional covariance between equity return ($r_{BK,t}$) and the IR risk factor ($r_{IR,t}$) at time t , while the $\text{var}_t (r_{IR,t})$ is the conditional variance of the IR risk factor ($r_{IR,t}$) at time t . Conditional covariances and variances are obtained from a diagonal dynamic conditional correlation multivariate GARCH model, henceforth, DCC-MGARCH model. The model has the following functional form (for more technical details, see Engle, 2002):

$$r_t = \varepsilon_t \sim N(\mu, H_t), \quad (3)$$

$$H_t = D_t R_t D_t, \quad (4)$$

where r_t is a $[5 \times 1]$ vector containing bank portfolio returns, market returns, and level, slope and curvature factors of the term structure in week t . H_t is the $[5 \times 5]$ conditional covariance matrix among the five series. D_t is a $[5 \times 5]$ diagonal matrix with its main diagonal equal to the standard deviation ($h_{i,t}^{1/2}$) of the five variables in r_t generated by an EGARCH (1,1) model; to accommodate asymmetries in the conditional variance dynamics. R_t is a $[5 \times 5]$ conditional correlation matrix, which is derived as:

$$R_t = (Q_t^*)^{-1} Q_t (Q_t^*)^{-1}, \quad (5)$$

$$Q_t = \bar{Q} - A' \bar{Q} A - B' \bar{Q} B + A' \varepsilon_{t-1}^* \varepsilon_{t-1}^{*'} A + B' Q_{t-1} B, \quad (6)$$

where Q_t^* is a $[5 \times 5]$ diagonal matrix with its main diagonal elements equal to the square root of the diagonal elements of Q_t to ensure correlations lie within the bounds $[-1, 1]$. Q_t is a $[5 \times 5]$ symmetric matrix and $\bar{Q} = E[e_t^* e_t^{*'}]$ is the unconditional covariance of standardized innovations estimated by its sample counterpart $(1/T) \sum_{t=1}^T \varepsilon_t^* \varepsilon_t^{*'}$. ε_t^* is a $[5 \times 1]$ vector containing the standardized innovations ($\varepsilon_t^* = \frac{\varepsilon_t}{h_t}$) of the series.

To capture the diversity in pair-specific correlation dynamics, A and B are set to $[5 \times 5]$ diagonal parameter matrices, so that, the ARCH (GARCH) coefficients for each DCC pair are $a_{ij} a_{jj}$ ($b_{ij} b_{jj}$), where, a_{ij} and a_{jj} (b_{ij} and b_{jj}), respectively, are the i^{th} and j^{th} element of the constant diagonal matrix A (B). The diagonal DCC model allows for a distinct structure in each correlation process offering a richer representation of real-world dynamics. This modeling approach facilitates the direct estimation of conditional betas using the time-dependent conditional correlations and variances of asset returns and factor dynamics (Longin & Solnik, 2001)⁷. The coefficients of the model are estimated by quasi-maximum likelihood.

3 | DATA

The dataset includes bank equity prices from the United States (US) and the United Kingdom (UK) during the period from December 10, 1997 to June 15, 2016, as well as from Japan (JP) and Europe (EU) during the period February 5, 2003 to June 15, 2016⁸. The whole sample amounts to 360 banks and only those listed on the main stock exchanges of

TABLE 1 Summary statistics of bank portfolio returns

	Mean	Std	Skew	Kurt	JB test	Q(5)	Q(10)	Q ² (5)	Q ² (10)	N
Panel A: US Sector Portfolios										
SIFI	-0.946	33.91	-0.440	11.49	2933.8***	19.46***	33.18***	168.7***	238.6***	8
Large	0.310	28.70	-0.671	12.33	3578.2***	35.18***	44.92***	227.3***	260.9***	11
Medium	0.780	23.26	-0.456	8.474	1239.7***	9.615*	21.45**	82.51***	132.1***	30
Small	2.610	18.57	-0.074	10.93	2529.2***	4.943	21.12**	90.86***	122.1***	<u>172</u>
										221
Panel B: UK Sector Portfolios										
SIFI	-4.576	35.60	-1.115	19.28	10862***	26.65***	31.84***	152.3***	172.8***	<u>5</u>
										5
Panel C: EU Sector Portfolios										
SIFI	-4.155	35.34	-0.064	5.856	237.30***	18.53***	26.33***	148.2***	181.1***	3
Large	-8.460	29.50	-0.033	4.644	78.642***	12.70**	23.97***	67.19***	104.7***	21
Medium	-5.668	15.68	-0.545	6.248	340.85***	56.58***	65.62***	65.97***	78.29***	50
Small	0.017	16.93	-0.302	5.074	135.49***	24.59***	28.49***	49.29***	63.77***	<u>10</u>
										84
Panel D: JP Sector Portfolios										
SIFI	-0.294	39.90	-0.425	7.758	678.26***	18.11***	40.56***	124.4***	129.6***	7
Large	-1.092	26.63	-0.460	7.017	493.18***	14.72**	30.11***	49.16***	49.30***	17
Medium	-2.506	23.62	-0.578	6.651	426.08***	16.60***	22.57**	27.35***	28.91***	19
Small	-3.130	21.04	-0.256	10.13	1485.5***	8.531	9.857	22.22***	23.19**	<u>7</u>
										50

Note: The dataset contains bank equity prices from the United States (US) and the United Kingdom (UK) during the period from December 10, 1997 to June 15, 2016, and from Europe (EU) and Japan (JP) during the period February 5, 2003 to June 15, 2016. "Mean" and "Std. Dev." stand for the annualized average return and standard deviation for each banking portfolio, respectively. "JB" refers to the Jarque–Bera (1980) normality test statistics. Q(n) refers to the Ljung–Box (1978) test for the n^{th} order serial correlation in the return series. Q²(n) is the Engle's (1982) test for ARCH effects with n lags. "N" is the number of banks that form each of the portfolios across markets.

***, ** and * indicate significance at the 1%, 5% and 10% level of significance, respectively.

each market are considered. The breakdown of the banking portfolios, by country and size, is provided in Table 1. For the European banking sector, the analysis focuses on four major markets, namely Germany, France, Spain and Italy. The current sample represents approximately 50% of the total market share of global financial assets (bonds, equities and bank assets). Moreover, these markets contribute more than 45% to the global GDP and around 60% to the total stock market capitalization in 2013 (Global Financial Stability Report, Oct. 2014).

Midweek⁹ equity prices for the banks in the sample along with the corresponding equity market indices are collected in local currency terms from Thomson Reuters DataStream. The equity indices used are S&P 500, FTSE 100, NIKKEI 225 and EURO STOXX for the US, UK, Japan and EU market, respectively. To eliminate the impact of survivorship bias, the sample consists of all banks with available data during the sample period even if data availability begun after the starting date and/or finished before the end date of the sample period. The weekly term structure of interest rates in the US, UK and Japan is represented by the zero-yield curves with 11 maturities from 3-month to 10-year (3, 6, 12 months, 2, 3, 4, 5, 7, 8, 9, 10 years), while for the European market, the yield curve is based on European AAA-rating treasuries. The zero-yield curve is derived from government treasury strips with all data provided by Bloomberg.

Equally weighted banking portfolios are constructed within each market¹⁰. Four size portfolios are formed: the systemically important financial institutions (SIFIs), the large, medium and small bank portfolios for each country where

possible. The SIFIs are identified by the Financial Stability Board (FSB) across the four markets examined¹¹. The large, medium and small banks are grouped according to the average size of their asset value over the sample period. Following Elyasiani and Mansur (1998), banks with average asset value exceeding 50 billion US dollars are categorized as either SIFIs or large banks; to avoid overlapping, SIFIs are excluded from the large bank portfolio. Banks with average asset value in excess of 10 billion US dollars, but no more than 50 billion US dollars, are categorized as medium. The remaining banks, with asset value less than 10 billion US dollars, form the small portfolio. Banks with an average asset value less than 1 billion US dollars are excluded from our sample. These are community banks and their yield exposure may be smaller or larger because they do not have access to derivatives-based hedging (they could restrict exposure, though, through balance sheet choices and/or asset-liability management). The UK banks are all in the same portfolio given that all of them are categorized as SIFIs.

Table 1 contains the descriptive statistics for the weekly returns of the banking equity portfolios. For each category, summary statistics along with the respective autocorrelation tests and the squared series are reported. Annualized mean returns are relatively low as a direct result of the financial crisis and they range from -8.46% for the large EU banks to 2.61% for the small US banks. The realized mean returns of the SIFI, large and medium banking portfolios are, on average (across countries), -2.49% , -3.08% and -2.46% respectively; while small banking portfolios have performed slightly better (i.e., -0.17%) evident also from the reported EU and US returns. The annualized standard deviation, across all portfolios, ranges from 15.68% for the medium EU banks to 39.90% per annum for the Japanese SIFIs and is positively associated with size i.e., larger banks experience higher volatility. The overall average standard deviation of the small, medium, large and SIFI portfolios is 18.8% , 20.9% , 28.3% , and 36.2% per annum respectively. In addition, the negative skewness and excess kurtosis signify that the unconditional distribution of bank returns is not normal. This is confirmed with the use of Jarque and Bera (1980) test indicating departures from normality for all the bank returns, at 1% significance level. Based on the Ljung-Box (1978) Q statistics on the first five and ten lags of the sample autocorrelation function, all series exhibit positive serial correlation at conventional significance levels. Exceptions are the small US (fifth lag) and small JP banking portfolios (fifth and tenth lag). The ARCH test, carried out as the Ljung-Box Q statistic on the squared series, indicates the existence of heteroscedasticity. This provides preliminary evidence in support for the use of time-varying conditional variance for the bank stock return data.

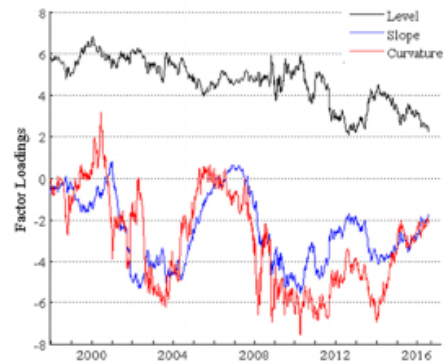
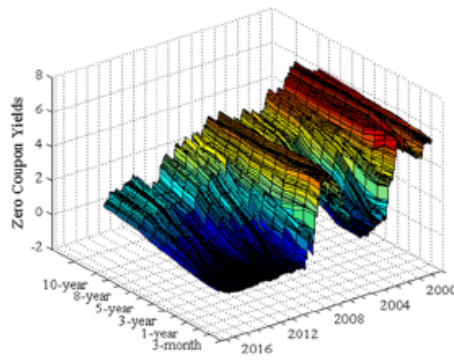
Note that prior to the 2007 financial crisis all portfolios exhibited higher average returns ranging from 1% to even 28% in excess of those presented in Table 1. In particular, prior to August 2007 all returns are positive (only exception is the JP small portfolio) with relatively lower standard deviation by 70 bp to 1,600 bp compared to the figures in Table 1, which refer to the whole sample period. For example, during the period December 1997 to August 2007 (August 2007 to June 2016) the US SIFIs mark an average return of 4.31% (-6.7%) p.a. with an annual standard deviation of 27.3% (39.9%). The recent financial crisis amplified the banks' riskiness as their equity returns' standard deviation increased noticeably and their stocks plummeted during that period. All the aforementioned results are available from the authors upon request.

4 | EMPIRICAL ANALYSIS

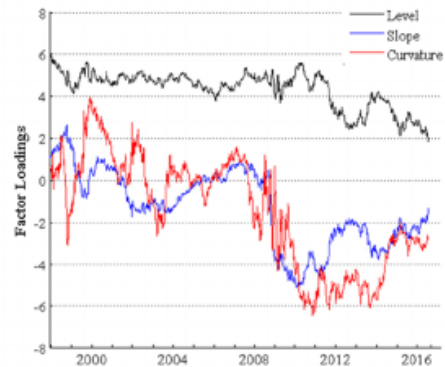
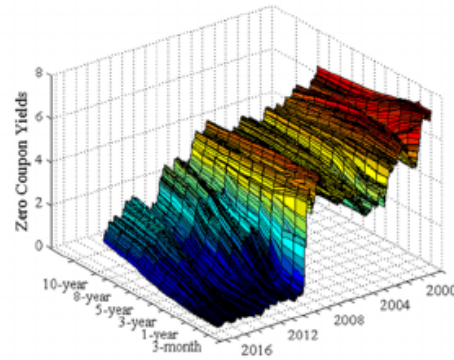
4.1 | Term structure model estimates

The yield curves and the estimated level, slope and curvature factors over the sample period are presented in Figure 1 for the US, UK, EU and JP. According to Figure 1, significant changes occurred in all yield curves during the sample period. Specifically, the short-end of the US, UK and EU yield curves increased gradually during the build-up of the most recent financial crisis before dropping sharply at the end of 2007. The policy of lower interest rates conducted by the Federal Reserve during the late 2007 and 2008, the Troubled Asset Relief Program (TARP; US Congress, Oct. 2008), the Fed's quantitative easing (QE) policies and the bailout decisions during and after the crisis were all aimed to restore stability and ease the liquidity pressure in financial markets. In contrast, the interest rate environment in Japan

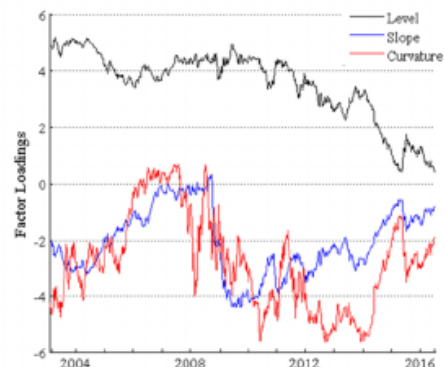
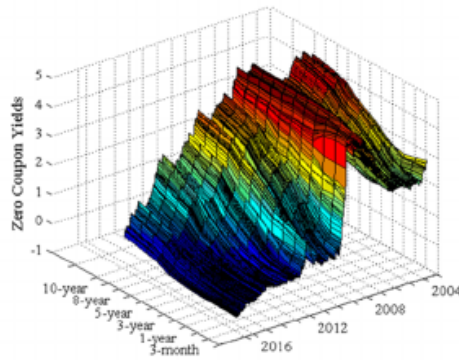
Panel A: US Market



Panel B: UK Market



Panel C: EU Market



Panel D: JP Market

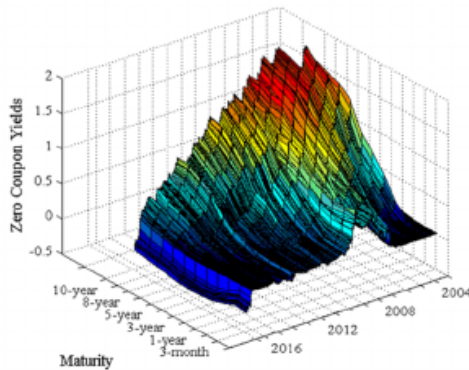


FIGURE 1 Yield curve and factor loading estimates [Color figure can be viewed at wileyonlinelibrary.com]
 Note: The diagrams illustrate the weekly zero-yield curves as well as the level, slope and curvature factor loading estimates across the US, UK, EU and JP [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Summary statistics of yield curve factors

	Mean	Std	ρ	PP ₁	PP ₂	Q(5)	Q(10)	Q ² (5)	Q ² (10)	RMSE
Panel A: US Yield Curve Factors										
Level	4.652	1.093	0.923***	-1.472	-31.97***	5.516	28.99***	129.7***	285.8**	0.823
Slope	-2.520	1.679	-0.995***	-1.864	-32.83***	9.429*	22.12**	56.33***	130.3***	0.263
Curve	-3.001	2.327	0.992***	-2.419	-32.87***	30.29***	34.53***	131.3***	207.7**	0.076
Panel B: UK Yield Curve Factors										
Level	4.309	0.863	0.916***	-1.556	-32.11***	5.991	15.45	81.96***	181.6***	0.610
Slope	-1.308	1.799	-0.999***	-1.709	-30.99***	9.327	18.73**	99.95***	122.8**	0.208
Curve	-1.502	2.605	0.991***	-1.851	-35.04***	13.48**	46.41***	120.1***	242.1**	0.060
Panel C: EU Yield Curve Factors										
Level	3.512	1.222	0.961***	-0.709	-26.26***	0.898	5.520	63.22***	99.18***	0.651
Slope	-2.070	1.185	-0.998***	-1.503	-23.70***	16.79***	18.93**	209.1***	218.3***	0.223
Curve	-2.781	1.669	0.963***	-2.337	-26.54***	15.97***	25.72***	137.6***	275.2**	0.058
Panel D: JP Yield Curve Factors										
Level	1.488	0.633	0.978***	-0.589	-26.12***	17.52***	37.31***	32.74***	88.58**	0.380
Slope	-1.215	0.590	-0.995***	-1.174	-27.25***	24.63***	42.89***	36.15***	56.72***	0.172
Curve	-2.229	0.941	0.991***	-1.596	-27.90***	13.75**	16.08**	41.03***	54.40***	0.064

Note: PP is the Phillips and Perron (1988) unit root test, which tests the null hypothesis that the variable is non stationary, $I(1)$, against the alternative that the variable is stationary, $I(0)$; PP₁ and PP₂ refers to the series tested i.e., levels or changes, respectively. ρ is the unconditional correlation of the yield factor with the empirical proxies proposed by Diebold et al. (2006); the row "Level" refers to the unconditional correlation between the estimated level factors and the 10-year yields, $y_t(120)$; row "Slope" refers to the unconditional correlation between the estimated slope factors and the difference between the 10-year and 3-month yields, $y_t(120) - y_t(3)$; row "Curve" refers to the unconditional correlation between the estimated curvature factors and twice the two-year yield minus the sum of the ten-year and three month yields, $2y_t(24) - y_t(3) - y_t(120)$. The significance of ρ is based on the Student's t -test with t -statistic = $\rho/[(1-\rho^2)/(N-2)]$, where N is the number of weekly observations. RMSE is the Root Mean Squared Error of fitting the Nelson and Siegel (1987) model of Eq. (1) to the term structure of zero coupon yields; this is reported cumulatively i.e., when only the level factor is considered - row "Level", when both level and slope factors are considered - "Slope" and when all three factors are taken into account - "Curve". Ljung-Box (1978) and Engle's (1982) test for ARCH effects are performed on the factor changes. See also notes in Table 1.

appears relatively stable with the short-term rate almost zero over the whole sample period apart from a small jump before the crisis. Since the mid-90s, the low interest rate environment observed in Japan is mainly due to the central bank's policy to stimulate economic growth. This policy, however, has been unable to pull the country out of deflation and fuel economic boom over the last decade.

Looking at the changing economic conditions (business cycles), one can notice that the slope tends to reach its peak just before the recession, while the yield curve tends to flatten near the top of the business cycle. There is prior literature on the interaction between the term structure factors and macro-variables/business cycles where different relationships, including directional influences, are identified (Ang & Piazzesi, 2003; Estrella & Mishkin, 1998; Evans & Marshall, 2007). The literature documents that slope relates to business cycle conditions, while level relates to inflation expectations. It also identifies monetary policy as a factor explaining most of the changes in the slope and thus relating economic expansion/contraction to interest rate increases/decreases (Aguigar-Conraria et al., 2012; Dewachter & Lyrio, 2006; Diebold et al., 2006). Actually, the interbank borrowing cost increased dramatically following the liquidity squeeze in August 2007, which led to the financial panic in the Fall of 2008 (Acharya & Merrouche, 2013).

To investigate the credibility of the estimated factors to represent the level, slope and curvature, the correlation between the estimated factors and standard empirical proxies is examined in Table 2. We use $y_t(120)$, $y_t(120) - y_t(3)$ and $2y_t(24) - y_t(3) - y_t(120)$ as empirical proxies for the level, slope and curvature, respectively; where $y_t(3)$, $y_t(24)$

and y_t (120) represent the short- (3-month), medium- (2-year) and long-term (10-year) yields (Diebold & Li, 2006). The estimated factors are highly correlated with the corresponding empirical proxies (in line with Diebold et al., 2006) and as such they sufficiently represent the shape of the yield curve. It is worth noting, however, that since the long-end of the yield curve is relatively stable over time and as term to maturity approaches infinity, the three-factor term structure model collapses to a single factor model represented by the level factor loading (i.e., $y_t(\infty) = \beta_{1,t}$ see Eq.1). Thus, the slope factor is mainly driven by the short-term rates and is a proxy for either the yield spread or just the short-end of the yield curve (Diebold et al., 2006).

Moreover, Table 2 reports the descriptive statistics of the yield factor data. Non-parametric unit root tests (Phillips & Perron, 1988) indicate that all series contain unit roots, while their first differences are stationary. First differences exhibit signs of serial correlation and heteroscedasticity supporting the use of time-varying conditional variance. Table 2 reports the Root Mean Squared Errors (RMSE) in cumulative terms i.e., start with the level factor, then add the slope and finally add the curvature factor. The results imply that all three factors are essential to describe the yield curve. That is, the RMSE reduction is in the range of 55% to 68% (83% to 91%) when comparing the two (three) factor model to the one factor benchmark.

4.2 | The dynamics of conditional correlation

Before analyzing the bank's time-varying yield exposure, the estimation results from the diagonal DCC-MGARCH model, across all markets, are presented. A two-stage procedure is employed (Engle, 2002). The first step involves the estimation of univariate EGARCH (1,1) models for the dynamics in conditional variances of the bank portfolios as well as market, level, slope and curvature factors (results available upon request). The second step involves the estimation of conditional correlations dynamics. Table 3 reports the estimation results from the second step of the MGARCH estimation.

Table 3, Panel A reports the estimated parameters along with their estimated standard errors. The DCC-MGARCH estimates a_{ij} (Eq. 6), measuring the sensitivities of bank portfolio and factor correlations to market shocks, are statistically significant in nearly all equations with figures ranging between 0.0547 and 0.4009. Estimates b_{ij} , measuring the sensitivity of current correlation to past correlation values, range from 0.7763 to 0.9960 with all parameters being statistically significant. The coefficients for each DCC pair, i.e., bank portfolio – risk factor, that correspond to sensitivities of correlations to market shocks is given by the product $a_{Portfolio}a_{Factor}$ (see Eq. 6), which ranges between 0.0048 (EU small; $a_{Portfolio}a_{Market}$) to 0.0468 (UK SIFI; $a_{Portfolio}a_{Slope}$) and tend to be higher for the portfolio-level and the portfolio-slope pairs. The coefficients that measure the sensitivity of current correlation to past correlation values ($b_{Portfolio}b_{Factor}$), range from 0.6078 (JP small; $b_{Portfolio}b_{Slope}$) to 0.9902 (JP SIFI; $b_{Portfolio}b_{Market}$).

As shown in Table 3, Panel B, the degree of persistence in conditional correlation between bank equity returns and risk factors is less than unity (ranging between 0.6297 and 0.9972) implying that dynamic correlations are all stationary. Persistent co-movements lend support to the presence of predictable patterns in correlation dynamics and reflect slow mean reversion in correlations due to the existence of transitory trends. For example, with the exception of JP (large, medium, small portfolios) persistence in conditional correlations between bank portfolios and interest rate factors is in all cases high and above 0.92. This finding has important implications for risk and portfolio management. Specifically, it implies that the impact of a shock in the yield curve on the conditional correlation between the interest rate risk factors and the bank's equity will have long lasting effects i.e., shocks to both yield curve and bank equity returns have a prolonged impact on the subsequent dependency. On the other hand, models for the JP portfolios, except from SIFIs, produce less persistence in correlation (from 0.6297 to 0.8773) compared to US, UK and EU; yet, overall all correlations are persistent.

4.3 | Banks' time-varying yield curve exposure

The conditional beta estimates for the market factor and the three yield curve components (level, slope and curvature), derived from the DCC-MGARCH model, are plotted in Figure 2. Since same factor betas exhibit similar patterns across

TABLE 3 Diagonal DCC multivariate GARCH estimation results

Sector Portfolios:	US				UK				EU				JP				
	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small	
Panel A. Estimated Coefficients DCC																	
$\alpha_{Portfolio}$	0.1212 (0.011)	0.1226 (0.017)	0.1116 (0.016)	0.1126 (0.017)	0.1617 (0.024)	0.0912 (0.014)	0.0863 (0.017)	0.0547 (0.009)	0.1073 (0.016)	0.0912 (0.014)	0.1558 (0.019)	0.1634 (0.010)	0.1625 (0.013)	0.1112 (0.069)	0.1152 (0.057)	0.1204 (0.045)	0.1038 [†] (0.081)
α_{Market}	0.1322 (0.015)	0.1403 (0.014)	0.1433 (0.013)	0.1361 (0.014)	0.1059 (0.020)	0.1121 [†] (0.083)	0.0964 (0.019)	0.0877 (0.015)	0.0932 (0.018)	0.0964 (0.019)	0.1521 [†] (0.115)	0.1484 [†] (0.119)	0.2431 (0.018)	0.1828 (0.098)	0.1791 (0.101)	0.0711 (0.040)	0.1139 (0.068)
α_{Level}	0.2774 (0.038)	0.2695 (0.031)	0.2679 (0.035)	0.2712 (0.036)	0.2888 (0.027)	0.2426 (0.012)	0.2477 (0.015)	0.2501 (0.015)	0.2465 (0.011)	0.2426 (0.012)	0.1558 (0.019)	0.1634 (0.010)	0.1625 (0.013)	0.1112 (0.069)	0.1152 (0.057)	0.1484 [†] (0.119)	0.2109 [†] (0.147)
α_{Slope}	0.2533 (0.046)	0.2429 (0.038)	0.2408 (0.036)	0.2457 (0.039)	0.2895 (0.036)	0.2368 (0.021)	0.2422 (0.017)	0.2431 (0.018)	0.2365 (0.023)	0.2368 (0.021)	0.1558 (0.019)	0.1634 (0.010)	0.1625 (0.013)	0.1112 (0.069)	0.1152 (0.057)	0.1791 (0.101)	0.2111 [†] (0.147)
α_{Curve}	0.1990 (0.056)	0.2180 [†] (0.185)	0.2383 (0.113)	0.2270 (0.102)	0.1911 (0.105)	0.1558 (0.019)	0.1634 (0.010)	0.1625 (0.013)	0.1565 (0.029)	0.1558 (0.019)	0.1558 (0.019)	0.1634 (0.010)	0.1625 (0.013)	0.1112 (0.069)	0.1152 (0.057)	0.1204 (0.045)	0.4009 (0.077)
$b_{Portfolio}$	0.9918 (0.002)	0.9848 (0.006)	0.9872 (0.004)	0.9812 (0.007)	0.9426 (0.017)	0.9890 (0.006)	0.9862 (0.006)	0.9940 (0.003)	0.9860 (0.007)	0.9890 (0.006)	0.9890 (0.006)	0.9862 (0.006)	0.9940 (0.003)	0.9960 (0.003)	0.8759 (0.066)	0.8718 (0.035)	0.7763 (0.280)
b_{Market}	0.9871 (0.004)	0.9877 (0.002)	0.9891 (0.002)	0.9882 (0.003)	0.9922 (0.006)	0.9842 (0.030)	0.9883 (0.008)	0.9887 (0.007)	0.9886 (0.009)	0.9842 (0.030)	0.9890 (0.006)	0.9862 (0.006)	0.9940 (0.003)	0.9942 (0.003)	0.9808 (0.023)	0.9745 (0.050)	0.8374 (0.199)

(Continues)

TABLE 3 (Continued)

Sector Portfolios:	US			UK			EU			JP		
	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small
Panel A. Estimated Coefficients DCC												
b_{Level}	0.9595 (0.011)	0.9617 (0.009)	0.9618 (0.010)	0.9604 (0.010)	0.9522 (0.011)	0.9644 (0.003)	0.9657 (0.003)	0.9632 (0.005)	0.9622 (0.004)	0.9696 (0.031)	0.9732 (0.027)	0.8599 (0.111)
b_{Slope}	0.9651 (0.013)	0.9681 (0.011)	0.9689 (0.010)	0.9678 (0.011)	0.9569 (0.010)	0.9662 (0.008)	0.9667 (0.006)	0.9645 (0.004)	0.9640 (0.004)	0.9677 (0.030)	0.9703 (0.029)	0.7829 (0.136)
b_{Curve}	0.9578 (0.027)	0.9496 (0.093)	0.9375 (0.057)	0.9408 (0.051)	0.9432 (0.052)	0.9943 (0.001)	0.9938 (0.001)	0.9936 (0.001)	0.9938 (0.001)	0.9757 (0.034)	0.9793 (0.013)	0.8737 (0.035)
Panel B. Persistence in Correlation with Portfolio												
Market	0.9951	0.9899	0.9924	0.9850	0.9523	0.9848	0.9835	0.9830	0.9875	0.9962	0.8677	0.6619
Level	0.9853	0.9801	0.9793	0.9729	0.9443	0.9773	0.9771	0.9713	0.9701	0.9797	0.8703	0.6895
Slope	0.9878	0.9832	0.9833	0.9773	0.9487	0.9781	0.9776	0.9721	0.9715	0.9809	0.8715	0.6297
Curve	0.9741	0.9619	0.9520	0.9487	0.9200	0.9972	0.9970	0.9940	0.9966	0.9822	0.8716	0.7198

Note: **Panel A** refers to the estimated coefficient from the diagonal DCC-MGARCH model (Eqs. 3 - 6) over the sample period; “ c_t ” and “ b_t ” refer to the elements within the parameter matrix A and B in the dynamic of conditional correlation (Eq. 6); “Portfolio” represents the corresponding banking portfolio; “Market” refers to the market risk represented by the equity market return; “Level”, “Slope” and “Curve” are the first difference of the level, slope and curvature factors which represents the changes in the yield curve. In **Panel B**, the persistence in the correlation is measured by the sum of cross-products of parameter a_i and b_i between the portfolio and corresponding risk factors, i.e., the level of persistence in correlation with portfolio for the slope factor is equal to $a_{Portfolio} \times a_{Slope} + b_{Portfolio} \times b_{Slope}$. All the estimated coefficients are significant at conventional significant levels except for the ones with “+” sign, which are insignificant.

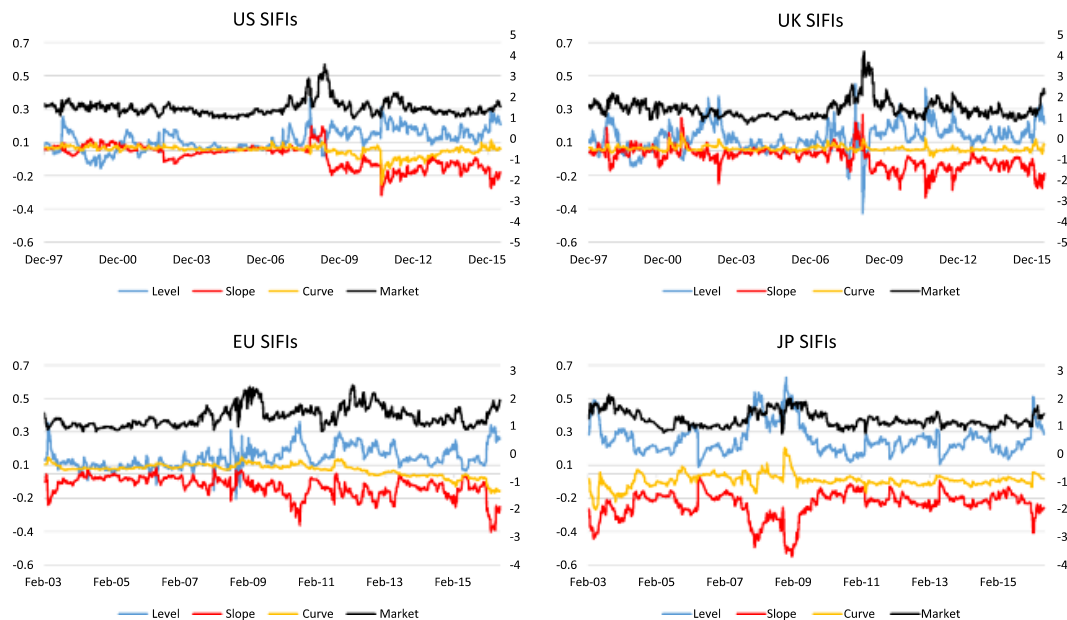


FIGURE 2 Dynamics of Conditional Betas [Color figure can be viewed at wileyonlinelibrary.com]

Note: The diagrams illustrate the weekly conditional beta estimates derived from the diagonal DCC model for the US, UK, JP and EU SIFIs. The magnitude for market beta is on the right-hand side axis, while the magnitude for level, slope and curvature factor betas is on the left-hand side axis [Color figure can be viewed at wileyonlinelibrary.com]

size-portfolios, and due to space limitations, only the graphs for the SIFIs are presented (full results available upon request). Figure 2 illustrates the evolutions of the time-varying conditional betas for SIFIs.

The impact of the level factor (long-term rates) on banks' equity returns is largely positive, implying that an increase in long-term yields increases the value of the bank's equity, while changes in the slope factor (short-term rates) have the opposite effect¹². The time-variation in the estimates is in line with previous studies (Oertmann et al., 2000; Song, 1994). In particular, the model-implied time series of betas (market, level, slope and curvature) is closely linked to the global economic cycles. That is, banks' market and yield exposures (betas' absolute values) are lower during the pre-crisis period compared to the period from the onset of the crisis and beyond.

Following from the above, the average weekly betas over the whole sample period are presented in Table 4. Market betas are highly significant and positive, while their magnitude increases with the bank's size. For example, the market beta of the US SIFIs is 1.4589 whereas the ones of the large, medium and small banking portfolios are 1.1379, 0.9843 and 0.7687, respectively. This is in line with banks (especially large ones) being highly leveraged with an increased appetite for risky investments and engagement in off-balance-sheet activities (De Nicoló, Bartholomew, Zaman, & Zephirin, 2004; Demsetz & Strahan, 1997). It is also worth noting that most of the largest banks are included in the market index and, thus, their correlation with the market return is naturally higher.

Turning to the banks' overall yield exposure, the equity returns of all portfolios are significantly affected by all three components of the yield curve. Bank size is an important determinant of the extent of yield curve exposure as the factor loadings are higher for SIFIs and large banks compared to medium and small banks. For the curvature, the effect is overall positive, with the exception of the Japanese portfolios where the impact is negative. The effect of curvature is less clear-cut, however, and there is no macroeconomic variable associated with this latent factor (Diebold et al., 2006). Shocks to the yield curve level (slope) factor have a significant positive (negative) impact on the banking portfolio's equity returns over the whole sample period.

Looking closer at the slope and level factors of the yield curve, a couple of arguments can be put forward. The significant negative beta associated with the yield curve's slope (short-term) factor may be due to the fact that changes in the term structure of interest rates are closely related to the business cycle (Diebold et al., 2006, 2008; Estrella & Mishkin, 1998) and inflation (Bernanke & Gertler, 2001). At the same time, future real economic activity is driven

TABLE 4 Average weekly beta for banking portfolios

Factors	SIFI	Large	Medium	Small
Panel A: US				
Market factor	1.4589	1.1379	0.9843	0.7687
Level factor	0.0603	0.0387	0.0390	0.0296
Slope factor	-0.0345	-0.0327	-0.0338	-0.0244
Curvature factor	0.0027	0.0064	0.0038	0.0035
Panel B: UK				
Market factor	1.4110			
Level factor	0.0775			
Slope factor	-0.0443			
Curvature factor	0.0098			
Panel C: EU				
Market factor	1.3657	1.1010	0.4892	0.4425
Level factor	0.0911	0.0797	0.0315	0.0252
Slope factor	-0.0760	-0.0671	-0.0214	-0.0156
Curvature factor	0.0223	0.0167	0.0087	0.0108
Panel D: JP				
Market factor	1.2776	0.9153	0.8133	0.6616
Level factor	0.2023	0.1169	0.1002	0.0720
Slope factor	-0.1888	-0.1144	-0.0989	-0.0692
Curvature factor	-0.0388	-0.0080	-0.0129	-0.0096

Note: The table presents the average weekly beta over the whole sample period derived from conditional variance-covariance matrices estimated from the diagonal DCC-MGARCH model; weekly beta equals to the covariance between the risk factor (F) and portfolio return (R_p) divided by the variance of the risk factor (i.e., $\text{Cov}(R_p, F)/\text{Var}(F)$); "Market" refers to the market risk represented by the equity market return; "Level", "Slope" and "Curve" are the first difference of the level, slope and curvature factors which represent the changes in the yield curve. The statistical significance of the average betas is computed by the t -stat. = $\bar{\beta} / SE(\bar{\beta})$, where $\bar{\beta}$ is the average weekly beta estimates over the estimation period and $SE(\bar{\beta}) = \text{stdev}(\bar{\beta}) / \sqrt{N}$; N is the number of weekly observations. All the estimated betas are significant at the 1% significance level.

by the current monetary policy (Fischer, 1993; Kormendi & Meguire, 1985). An expansionary monetary policy will steepen the yield curve and enhance the short-term real economic growth (Estrella, 2005). Steepening of the yield curve, for banks experiencing a negative maturity gap, will enhance their profitability. That is, short-term financing costs will remain below the long-term investment returns, which in turn this widening yield spread (steepening yield curve) will serve as a conduit of increasing the bank's net interest income. During the 2002–07 economic boom, banks chose to expose themselves to yield curve changes as they took advantage of the low short-term rate environment by rapidly expanding their balance sheets through short-term borrowing (Adrian & Shin, 2008; Maddaloni & Peydro, 2011). Banks are, therefore, more likely to ride the steepening yield curve (negative slope factor beta)¹³ as a result of frequently refinancing their short-term liabilities (Acharya, Gale, & Yorulmazer, 2011).

Turning to the level factor, its positive and significant beta can be attributed to the fact that an increase in long-term interest rates mirrors higher long-term inflation expectation (Diebold et al., 2006). Moreover, an increase in the long-end of the yield curve (higher level factor) can be associated with loosening of monetary policy, which implies a reduction in the short-end of the yield curve. That means banks can benefit from positive shocks in the level factor indirectly through the increase in short-term credit supply. To this end, an impulse response function is employed to endorse the inverse relationship between the level and slope of the yield curve. The results (available upon request)

indicate that there is a lead-lag effect between changes in the level and slope factors. Specifically, shocks in the level factor have a negative and long-lasting impact on the slope – in line with Diebold et al. (2006).

Finally, yield curve fluctuations can influence banks' equity returns via macro factors. Corporate default rates are highly related to the business cycle, which in turn are influenced by the real economic activity (Pesaran, Schuermann, Treutler, & Weiner, 2006). Since relative changes in the level and the slope of the yield curve are leading indicators of the real economic activity and business cycle (Estrella & Mishkin, 1998), they can also be deployed to assess the business loans' default risk (Carling, Jacobson, Linde, & Roszbach, 2007). A prolonged flattening yield curve can have a negative impact on real economic activity, which may point out towards an economic recession. In particular, positive shocks in the slope factor can mirror an increase in corporate default rates, which in turn have a negative impact on the bank equity capital through the rise in debt write-offs (Drehmann, Sorensen, & Stringa, 2010).

4.4 | The impact of crisis on yield curve risk exposure

August 9, 2007 and June 30, 2009 mark the start and the end of the recent financial crisis¹⁴. The financial crisis began when BNP Paribas stopped the redemption of its investment funds, followed by the liquidity squeeze in global financial markets; while the end of the crisis is based on the S&P 500 having noticeably bypassed its lowest point (March 2009) and following an upward trend well above the last trough. Table 5 summarizes the average weekly beta by splitting the sample into pre-crisis, crisis and post-crisis periods to further investigate the bank's equity yield exposure over different market conditions.

Starting with the wide market effect, the US SIFIs' exposure increased from 1.334 during the pre-crisis period to 1.921 during the crisis and then fell to 1.508 after 2009. In other words, banks were almost twice as risky as the general market. Although a few were included in the market index, some were too big or too systemically relevant to fail and were expected to be bailed out. Their riskiness was due to the fact that they were highly engaged in the asset-backed securities market. The changes in the banking sector's market exposure are associated with the global economic conditions at that time. Their increased exposure during the crisis period makes economic sense and is intertwined with liquidity conditions in home markets, their potential systemic nature and/or bailout possibilities. The reduced exposure, post 2009, is attributed to the optimism of the whole stock market (e.g., S&P 500 rises), which came as a result of the government aid through the bailouts of various institutions, the TARP and the quantitative easing initiatives.

Turning to the bank's yield exposure, over these distinctive economic phases, there is a worth noting swift in the sign of the slope risk factor, while its significance remains high. Interestingly, the slope factor beta turns from negative to positive for the US SIFIs and large banks during the financial crisis. In tranquil periods, banks' short-term funding cost (LIBOR rates) is tied to the short-end of the Treasury yield curve. With New Century Financial and Lehman Brothers filing for bankruptcy, Wachovia and Washington Mutual's fall, the near collapse of AIG and every other major US financial institution reflecting on the consequences of this turmoil, investor's confidence weakened as the crisis deepened in mid-September 2008. As a result, the difference between the US dollar LIBOR rates and the Treasury yields widened in late 2008¹⁵. Thus, during the peak of the crisis, the short-end of the Treasury yield curve has an inverse relationship with the short-term interbank funding costs. The slope factor proxies changes in short-term yields, hence, its relationship with the US SIFIs and large banks' equity returns became positive during the crisis period.

Looking at the size of the yield beta estimates, the level beta has increased significantly from 0.037 (until 2007) to 0.085 during the crisis, while this increase persisted after the crisis as well (value of 0.086 over the post-crisis period). Similar are the findings for the slope factor: a beta of -0.016 for the pre-crisis increasing to 0.036 during crisis and then plummeting to -0.079 during the post-crisis period. As for the curvature, results are 0.006 (pre-crisis) rising to 0.018 (during crisis) and then down to -0.005 (post-crisis), all being statistically significant. In all cases, more than 80% of the time, the sensitivities during the crisis and the post-crisis periods are, on average, higher in magnitude than the corresponding pre-crisis sensitivities. Additional *t*-tests, reported in Table 5, show that equality of the average weekly betas over the pre-crisis and during the crisis periods cannot be confirmed. On the other hand, a distinction between the crisis and post-crisis period indicates very little evidence in support of the hypothesis that beta values moved back

TABLE 5 Average weekly betas for banking portfolios pre- and post-crisis

Factors	Pre-Crisis				During Crisis (2007-2009)				Post-Crisis			
	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small	SIFI	Large	Medium	Small
Panel A: US												
Market	1.334	0.921	0.772	0.611	1.921	1.749	1.345	1.019	1.508	1.274	1.181	0.920
Level	0.037	0.017	0.022	0.018	0.085	0.047	0.033	0.036	0.086	0.066	0.065	0.044
Slope	-0.016	-0.016	-0.017	-0.014 [‡]	0.036	0.004	-0.007	-0.010	-0.079	-0.066	-0.065	-0.043
Curve	0.006	0.007	0.004	0.004	0.018	0.023	0.016	0.013	-0.005	0.001 [†]	0.000 [†]	0.000 [†]
Panel B: UK												
Market	1.234				2.081				1.475			
Level	0.070 [‡]				0.078				0.088			
Slope	-0.032				-0.007 [†]				-0.072			
Curve	0.009				0.016				0.010 [‡]			
Panel C: EU												
Market	1.084	0.743	0.330	0.427	1.595	1.164	0.595	0.477	1.486	1.315	0.563	0.443 [‡]
Level	0.059	0.042	0.017	0.025	0.106	0.095	0.039	0.031	0.108	0.100	0.039	0.024 [‡]
Slope	-0.042	-0.031	-0.012 [‡]	-0.015 [‡]	-0.069	-0.055	-0.013	-0.014	-0.100	-0.094	-0.030	-0.016 [‡]
Curve	0.023	0.019	0.007	0.008	0.059	0.039	0.020	0.016	-0.012	-0.010	0.007 [‡]	0.011
Panel D: JP												
Market	1.317	0.902	0.804 [‡]	0.687	1.586	0.985	0.786	0.584	1.169	0.905 [‡]	0.827	0.666
Level	0.178	0.092	0.079	0.062	0.324	0.143	0.116	0.071	0.185 [‡]	0.126	0.110	0.079
Slope	-0.158	-0.081	-0.071	-0.056	-0.309	-0.135	-0.113	-0.065	-0.176	-0.130	-0.113	-0.079
Curve	-0.050	-0.008	-0.011 [‡]	-0.002	-0.015	-0.005	-0.010	-0.005	-0.038	-0.008 [‡]	-0.015	-0.012

Note: The table presents to the average weekly beta over the pre-crisis, crisis and post-crisis period. The differences between the pre-crisis betas against the betas during and after the crisis for each risk factor are investigated based on Welch's Student's t-test; all highly significant at the 5% confidence level of significance except for the ones with “†” sign, which are insignificant. Additional t-tests are also reported in the form a “‡” sign under the pre-crisis and post-crisis columns implying that the null hypothesis of equality of the average weekly betas over the pre- and during crisis, and over the pre- and post-crisis periods, respectively, cannot be rejected at 5% significance level. See also notes in Table 4

to their pre-crisis levels with very few exceptions such as the market, level and slope factor betas of the EU small bank portfolio.

Given the aforementioned discussion, what underpins the reported results can be broadly attributed to endogenous (within the bank) and/or exogenous factors (outside the bank), as well as/or changes in investors' behavior. Starting with the endogenous factors, balance sheet restructuring could well be one of the attributing factors to such yield sensitivity; off-balance sheet items have also played a significant role in exposing banks to various risks depending on the nature of the products involved. Banks have certainly altered the product/duration mix of their funding sources as well as their investment choices due to the deteriorating market conditions. Fluctuations in interest rates are correlated with cyclical changes in economic conditions and exert their own influence on the different components of a bank's profitability.

Turning to the exogenous factors, short-term interest rates started declining (late 2007) through a series of rate cuts aiming to ease the funding liquidity pressure in the financial system. The significant slope factor indicates that banks have benefited from the lower funding rates provided by central banks. Market interventions, during and after the crisis period, have also played a role in the increased slope factor sensitivity (i.e., short-term end of the yield curve). The enhanced slope factor effect may also be attributed to the deteriorating funding conditions during late 2007 (Ashcraft, McAndrews, & Skeie, 2011; Acharya & Merrouche, 2013), which have forced banks to rely more on short-term liabilities (demand deposits, commercial papers *etc.*) for liquidity, compared to the pre-crisis period. Therefore, banks' equity returns experience an inverse relationship with changes in short-term interest rates. Banks also issued a large amount of loan commitment that did not, in general, expect to be exercised but serious liquidity shortages (i.e., market freeze) led loan commitment holders to draw down on the commitments, forcing banks to seek funds more vigorously. This may have made bank stocks more sensitive to changes in yields.

Finally, changes in investors' behavior during the crisis period may have contributed to the increased level effect. The flight-to-quality phenomenon is commonly observed during economic downturns as investors switch from risky investments to safe securities with lower credit risk exposure (Chari, Christiano, & Kehoe, 2008). Since the demand for Treasury bonds is closely related to the liquidity condition in the stock market,¹⁶ investors' flight-to-quality behavior tends to depress the banks' equity prices, while pushing the Treasury bond prices up (long-term yields drop). As a result, the relationship between banks' equity returns and long-term yields would be strengthened during the crisis, which is evident from the increase in the level factor betas.

One interesting finding is that although all banking institutions become more vulnerable to short-term rate changes (i.e., negative slope factor betas), during and after the crisis period, the effect seems to be more notable for the SIFIs and large banks. One could argue that the bank's yield sensitivity is the direct result of its nominal contracting (Flannery & James, 1984a; Gomez, Landier, Sraer, & Thesmar, 2016). That is, some of the banks will unavoidably have wider/narrower maturity gaps than others resulting in a more sensitive balance sheet structure when short-term yield changes hit the market. To take the matter further, such yield sensitivity also depends on the banks' liquidity positions as well as on their loan commitment obligations. For instance, the slope factor effect for the Japanese SIFIs banking portfolio has increased in magnitude from -0.158 to -0.309 during the crisis period, while the one for the small banking portfolios had a marginal change of 0.009 (-0.056 to -0.065). Moreover, the observed size effect (i.e., the increase in the absolute value of slope factor beta is higher for SIFIs and large banks during the crisis) may stem from the precautionary hoarding¹⁷ of liquidity during the recent financial crisis. It is indeed true that banks were reluctant to lend money to each other during the 2007 financial crisis due to liquidity constraints and needs for self-insurance against payment uncertainties, especially for smaller banks with high credit risk (Acharya & Merrouche, 2013; Ashcraft et al., 2011). In general, during the crisis market participants become more responsive to any event and require a higher premium for a given unit of risk, which translates into higher sensitivity. Large banks are usually net borrowers and rely heavily on short-term interbank funding, so the funding liquidity shortage during and after the crisis increased the associated fear of being left with no liquidity, therefore, heightening those institutions' short-term yield sensitivity relative to the smaller banks.

5 | CONCLUDING REMARKS

Over the last three decades, global financial markets have witnessed a variety of events making the banking sector an interesting landscape to observe and analyze. To this end, the paper provides new information about a) the bank's equity behavior when accounting for the yield curve's short-, long- and medium-term components (slope, level, curvature), which they enter the equity return generating process as exogenous risk factors; b) the bank's equity function using the comprehensive econometric framework of DCC-MGARCH allowing for time variation in factor loadings, c) the bank's yield sensitivity when banks are separated according to size and their systemic risk, d) banks belonging to market-oriented and bank-oriented economic systems, and e) the importance of economic cycles on banks' stock market performance in relation to yield curve changes.

The findings suggest that the empirical proxies for level, slope and curvature of the yield curve are statistically able to explain variation in equity prices above and beyond the wide market effect. There is evidence of time variation in the interest rate risk factors whose magnitude is linked to the global economic cycles. That is, absolute values of pre-crisis betas are lower than those in the period from the onset of the crisis and beyond. Shocks to the slope factor have overall a negative impact on bank equity returns with the findings being pretty much consistent across markets and institutions. For the US SIFIs and large banks, the changing sign as well as the size of the slope factor coefficient is something worth mentioning, as it turns (from negative) positive and becomes larger at the peak of the economic crisis. Unexpected changes to the level factor unveil a positive correlation with expected returns, a consistent finding across our international banking sample. Shocks in the level factor have a negative impact on the slope and banks are indirectly benefited from such shocks through an increase in the short-term credit supply. The impact of the curvature is less clear-cut since there is no precise pattern either among banks with different sizes or between financial systems (bank-oriented versus market-oriented). Market risk exposure is, as expected, positively correlated with bank size irrespective of the financial system observed. The systematic market exposure is more pronounced with larger banks, across all markets, and in many cases over twice as strong when we look at small banks versus SIFIs. Finally, when distinct economic cycles are taken into account, the bank equity exposure to all systematic risks is noticeably different across these cycles. In all cases considered, more than 80% of the time, the sensitivities during the crisis and the post-crisis periods are, on average, higher in magnitude than the corresponding pre-crisis estimates.

The present work has important implications for various aspects of modern financial markets and opens avenues for future research. First, by recognizing that the yield curve can be independently treated as a systematic risk factor, inevitably one recognizes its interface with areas such as central bank policy, investment theory, regulation and bank management. Given that monetary policy affects the short-end of the yield curve (Fed fund rate), its impact via the yield curve spread on real economic activity is not questionable (Friedman, 1996). Second, the yield curve as a systematic risk factor provides insight into the investment/corporate arena by a) simultaneously assessing the importance of yield and market risk to guide fund managers towards their portfolio mix (debt/equity) or to embrace income-oriented equities, b) evaluating performance measurement within an asset pricing framework and/or when funds mix bonds and low-beta securities, c) analyzing the extent to which the risk premia are priced by the market, d) looking at the market portfolio as a "risk surrogate", and e) emphasizing the wider contribution of corporate risk management to shareholder value (Bartram, 2000). Third, and within an asset-liability management framework, bankers and supervisors can a) use the yield curve to establish short- and long-term margin targets, as well as to evaluate the maturity mix of their assets and liabilities along with their respective repricing intervals and b) regularly assess the impact of the yield curve changes on the banking book and subsequently on value of the bank's net-worth. Fourth, and as a consequence of the above discussion, regulators can consider bank performance as well as capital requirements, small business finance and economic growth by embracing a more comprehensive risk-return structure assuming an impartial macro-prudential framework.

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ENDNOTES

- ¹ The Bank of International Settlements has recently increased the requirement for the banks' interest rate risk exposure further emphasizing the importance of the yield curve changes. See Basel Committee on Banking Supervision (2016) – <https://www.bis.org/bcbs/publ/d368.htm>.
- ² Maddaloni and Peydro (2011) argue that the main driver behind the recent financial crisis (2007-09) was the prolonged and low short-term interest rates as a result of the monetary policy observed in the U.S. and the Euro-area. The low short-term rates soften the lending standard for household and corporate loans and encourage banks to rely heavily on short-term borrowing that leverages up their balance sheets.
- ³ Previous studies try to sidestep the issue of interdependence between the market and interest rate risk factors by orthogonalizing the risk factors (Flannery & James, 1984b; Oertmann, Rendu, & Zimmermann, 2000), but the orthogonalization approach can introduce estimation bias to the regression model (Giliberto, 1985).
- ⁴ Under a bank-oriented financial structure the main contributor of capital allocation, provision of risk management platforms and savings' mobilization is the bank. On the other hand, under a market-oriented system security markets alongside banks function to move savings to corporations and to exercise corporate control (Thakor, 1996; Allen, 1999).
- ⁵ The parameter λ determines the maximum loading of the curvature factor and the exponential decay rate of the slope. Large (small) values of λ generate fast (slow) decay and can better fit the curve at short (long) maturities. We follow Diebold and Li (2006) who fix λ at 0.0609 so that the loading on the curvature component is maximized at the medium term; that is, 30 months.
- ⁶ A zero-coupon yield curve is the yield curve that maps zero-coupon Treasury bond yields to different maturities. Zero-coupon bonds have a single payment at maturity, so these curves enable us to price fixed-income instruments. To obtain a continuous yield curve, and since zero coupon bonds are available for a limited number of maturities, bootstrapping and interpolation techniques are employed.
- ⁷ A generalized asymmetric version of the DCC-MGARCH model is also tested. This specification captures the asymmetric impact of positive and negative shocks between the endogenous and one exogenous factor (at a time) on conditional correlations. Asymmetric effects on conditional correlations, however, were found to be insignificant and, hence, not accounted for.
- ⁸ The start date for these regions is set to February 5, 2003 because Japanese and European yield curve data are only available from January 2003 and May 2002, respectively.
- ⁹ The paper employs weekly data because daily returns departures from the normal distribution are more pronounced (Fama, 1976; Trzcinka, 1986). In particular, daily returns are subject to a high level of skewness and results of the APT tests improve when every other observation is used (Roll & Ross, 1980). Moreover, the use of lower sampling frequency (monthly compared to weekly data) reduces not only the noisiness of the data but also the number of observations, which might reduce the significance of the interest rate beta estimates and consequently the reliability of the coefficient estimates and tests.
- ¹⁰ The choice of the equal weighting is based on the presence of size-homogeneity since the equity portfolios are grouped according to bank's size. One may also argue that stocks within a portfolio are not under-/over-weighted due to mispricing or mirroring emotions over the short-term and thus pricing errors remain random.
- ¹¹ The list of systemically important banks is reported in the FSB announcement "Policy Measures to Address Systemically Important Financial Institutions" on November 4, 2011. The FSB was established in April 2009 as the successor to the Financial Stability Forum (FSF). The FSF was founded in 1999 by the G7 Finance Ministers and Central Bank Governors. In the FSB announcement 29 bank holding companies have been labeled as systemically important financial institutions (SIFIs) due to

their importance to the global financial stability, out of which 23 are based in the U.S., UK, Japan and EU. FSB last update was on November 6, 2014. For further discussion on the size effect of financial intermediaries' risk exposure, please see Demsetz and Strahan (1997), De Nicoló, Bartholomew, Zaman, and Zephirin (2004) and Elyasiani, Mansur, and Pagano (2007) among others.

- ¹² The positive relationship between long-term rates and equity returns can be attributed to the negative maturity gaps, that banks usually run, which in turn increases the bank's net interest income.
- ¹³ Under these circumstances, banks enjoy an increased net interest income from the *carry trade*, where long-term high yield investments are financed by short-term low-cost liabilities. Under these circumstances, banks enjoy an increased net interest income from the *carry trade*, where long-term high yield investments are financed by short-term low-cost liabilities.
- ¹⁴ For a broader academic discussion see Acharya and Merrouche (2013). For market reactions, regarding the start of the crisis, see the financial press: *The New York Times*, August 9, 2007 "BNP Paribas suspends funds because of subprime problems"; *Financial Times*, August 12, 2007 "Scramble for cash reflects fears for system"; *The Guardian*, August 5, 2008 "Credit crisis - how it all began". After the BNP announcement, The European Central Bank pumped €95bn into the Eurozone banking market to allay fears about a sub-prime credit crunch (see *BBC News*, August 9, 2007 "ECB moves to help banking sector"). During June 2009, a number of events took place that contributed to signify the end of the financial turmoil. Such events (in addition to the S&P500 upward trend) include: ten large banks allowed to exit the Troubled Asset Relief Program (TARP) with the Treasury receiving \$68.3 billion (09/06) – more than a quarter of the bailout funds that banks have received since October 2008; the Fed extends and modifies a number of its liquidity programs (09/24); and AIG and the Federal Reserve Bank of New York entered into an agreement to reduce AIG's debt (09/25); and finally the TED spread fell at 35 basis point – a decrease of more than 400 basis points from October 2008.
- ¹⁵ The LIBOR rates and short-term Treasury yields commonly move in the same direction. The TED spread (LIBOR minus T-bill rates) is regarded as a measure of liquidity and credit risk. In other word, an increasing TED mirrors the lack of interbank trust and a corresponding credit tightening for all other counterparties.
- ¹⁶ When there is high selling pressure in the stock market, equity liquidity drops; but liquidity in the Treasury bond market increases as buying pressure is high (Li, Wang, Wu, & He, 2009).
- ¹⁷ Precautionary hoarding occurs when banks hold more reserve and liquidity than the level needed to self-insure against shocks. This hoarding reduces the amount of available funding for the interbank loan market. As a result, liquidity shortages in the interbank market had a greater impact on the US banks than those in Japan. The roots of hoarding liquidity, in general, can be either speculative or precautionary (Ashcraft, McAndrews, & Skeie, 2011; Acharya & Merrouche, 2013)

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