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Understanding Chinese Bond Yields and their Role in Monetary Policy

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Understanding Chinese Bond Yields and their Role in Monetary Policy

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Abstract

China's financial prices are informative enough for the PBC to introduce a monetary policy framework centered around interest rates. While bond yields are not fully efficient—reflecting regulation, liquidity, and segmentation—we find they contain considerable information about the state of the economy as well as evidence of an emerging transmission channel: changes in PBC rates influence the structure of Treasury, financial, and corporate bond yield curves, which are then associated with changes in growth and inflation. Coporate spreads are also a leading indicator of growth and inflation. While further liberalization will strengthen both efficiency and transmission, several necessary elements to move towards indirect monetary policy are already in place.

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CONTENTS **PAGE**

I. INTRODUCTION

Monetary management in China is increasingly showing signs of tension. The continued reliance on quantitative targets and direct and administrative controls is not only resulting in increased instability in monetary aggregates, but has also increased the incentives for intermediation to move outside the regulated financial sector. The pace of this disintermediation has increased rapidly in recent times to avoid the impact of such quantitative controls (Chu, and others, 2010). While disintermediation may also partly reflect the financial development process, it suggests the need for a transition towards an indirect monetary policy framework. Not only might such a shift result in a more effective management of demand for credit in these circumstances, it could also increase the efficiency of intermediation (Feyzioglu and others, 2009). Such a shift will be most effective if financial prices are efficient and informative signals of economic conditions, and there is an effective transmission mechanism from the chosen policy rate to other financial prices, and ultimately the real economy.

Despite their large size (around ¾ of GDP), Chinese fixed income markets are relatively young, and have for much of their life been highly regulated (ICMA, 2005; Porter and Xu, 2009). Beyond regulation on the issuance of corporate bonds, trading in the bond market remains largely segmented between the exchanges and an (institutional) interbank market, thereby splitting liquidity. Moreover, while wholesale and foreign currency interest rates have been liberalized, the structure of retail interest rates remain regulated, potentially affecting the structure of market determined interest rates (Porter and Xu, 2009).

This paper investigates the efficiency and functioning of China's various bond markets. Our aim is to describe the current behavior of yields, including their response to changes in policy, as well as their interaction and impact on the aggregate economy. Specifically we ask four questions: How does regulation of retail interest rates influence market determined bond yields? Do the yield curves for different bonds interact? What are the macro-financial interactions between real variables and bond yields in China? Are Chinese bond yields efficient (arbitrage free)? The answers to these questions are relevant for understanding the potential for developing both a suitable benchmark for pricing financial assets as well as understanding the transmission channel for indirect monetary policy in China, as well.

We study these issues in four institutional (interbank) bond markets—for Central Bank paper (IBCB), Treasury bonds (IBTSY), Policy Banks bonds (IBPBB), and AAA-rated Corporate bonds (IBCAAA)—as well as the market for Treasury bonds traded on China's two stock exchanges (EXTSY). Each of these markets is central to financing of the government, quasi-government bodies, and the corporate sector in China, and potentially a key link in the monetary policy transmission channel. Given this, we specifically want to model both the interrelation between bond yields and macroeconomic conditions as well as across bond yields.

Methodologically, we start by estimating the simple statistical—Nelson-Siegel—representation of the various yield curves. This technique simplifies the term structure into three latent factors at each date. The first (level) factor captures the long-maturity yield, the second (slope) factor captures the behavior of short-maturity yields, while the third (curvature) factor captures the behavior of mid-maturity yields. This technique provides a small set of variables that summarize the entire behavior of each yield curve overtime, simplifying the study of the interaction of yields with regulated interest rates, across markets and maturities, and with economic variables (Diebold and Li, 2006, and Diebold and others 2006; Hoffmeister and others, 2010). Yield curves represented in this way can also be tested to see if they are arbitrage free, a feature we exploit.

In general we find that, despite inefficiencies in pricing, bond yields seem to be informative signals of macroeconomic developments, and signs of an emerging monetary transmission channel. Indeed, we find rejection of the hypothesis that bond yield curves are arbitrage-free, although the deviation seems largest at shorter maturities in the two largest bond markets. We also find strong evidence that regulated retail interest rates significantly affect bond yields, making this regulation one likely cause of pricing inefficiencies. Bond yields in China are also generally informative leading indicators of growth and inflation developments, thereby providing evidence that they already reflect macroeconomic developments in a coherent manner despite the impact of regulation. Moreover, (policy induced) changes in PBC yields significantly feed through to other yields and in turn macroeconomic aggregates, suggesting a nascent price-based transmission mechanism for monetary policy, in spite of the prevalence of non-price controls.

By studying various yield curves in such an environment, this paper makes several contributions. First, it contributes to the study of emerging market local currency bond markets. It also looks beyond sovereign yields, and considers quasi-sovereign as well as corporate bonds. Second, it presents evidence of the impact regulated interest rates have on wholesale market determined interest rates, including the influence on the entire structure of yields. Finally the paper documents substantial macro-financial linkages in China, a necessary condition for developing indirect monetary policy instruments.

The rest of the paper is organized as follows: The following section outlines the statistical model that we use to capture the key characteristics of the yield curve, as well as the methodology for testing whether the yield curves are arbitrage free. Section III, describes the PBC’s monetary tools as well as some of the institutional features in China’s money and bond markets, while section IV describes our data. Section V presents our results in terms of the behavior of yields, the interaction between the factors characterizing different yield curves, the interaction between the macro-economy and these financial variables, and, finally, presents the results of the no arbitrage tests. Section VI concludes.

II. STATISTICAL DESCRIPTION OF YIELD CURVES

In this section we outline our framework for describing the yields in the various markets, and our procedure for testing whether there are significant deviations from an arbitrage free curve.

A. Statistical Description of the Yield Curves

By now a commonly applied approach to modeling yield curves is to assume that the curve can be represented by a 3 factor Nelson-Siegel curve (see, e.g., Diebold and Li (2006), or Diebold and others, 2006). This curve provides at each date a highly parsimonious function of the maturity, with the entire yield curve approximated by 3 factors as follows:

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

The three β_{it} terms are interpreted as latent yield curve factors. Given the shape of each curve, each factor has a natural interpretation: given that $\lim_{\tau\to\infty} y_t(\tau) = \beta_{1t}$, and the loading on β_{1t} is one, the first factor represents the long-run level of interest rates; for a given λ_t the second factor loading declines monotonically from 1 to zero in the limit and so it should reflect a short-term factor; and for a given λ_t the loading on the third factor starts at 0 and initially increases before converging back to 0 at very long maturities, suggesting it is a medium-term factor. Given these characteristics, the factors are traditionally given the interpretation of the "level," the negative of the "slope," and the "curvature" of the curve (see Figure 1 for an illustration). The lambda parameter is the exponential decay rate along maturities for each factor, with a larger lambda producing a faster decay (Diebold and Li, 2006). This parameter also governs the maturity that maximizes the importance of the medium-term or curvature (β_{3t}) factor, with a higher λ_t lowering the tenor of the maximum impact of the medium-term factor.

We use a two-step procedure to estimate these curves. In the first step λ_t is estimated, and in the second step the three latent factors are estimated for a fixed λ (Diebold and Li (2006) propose fixing the value of λ_t over time to simplify the estimation). With lambda fixed the latent factors $\{\beta_{it}\}_{i=1}^{3}$can be estimated by OLS computing regressions of the various yields at each data on maturities. For US Treasury yield data Diebold and Li (2006) set λ_t=0.0609 which maximizes the impact of the medium-term factor at a maturity of 30 months. Since for Chinese yields we have no estimate of the maturity at which the curvature of each yield curve is at its highest, we estimate one for each curve as follows:[2]

1. For a given λ we use the Diebold and Li (2006) procedure to estimate the yield curve factors $\{\beta_{it}\}_{i=1}^{3}$ and record the residual sum of squares.

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[2] We would like to thank Ken Nyholm for suggesting a two-step estimation procedure.

2. We repeat this exercise until a value of λ that minimizes the residual sum of squares is found.

B. Comparing Statistical and No-Arbitrage Yield Curves

While the Nelson-Siegel yield curve provides a convenient statistical representation of the yield curve, there is no guarantee that these curves are arbitrage-free. That is, there may be arbitrage opportunities across maturities along the yield curve. In this section we outline a procedure used to test whether the curve is free of such arbitrage opportunities. We follow Coroneo and others (2008), who test whether the US Treasury yield curve is arbitrage free finding it generally to be. In simple terms, they estimate the distribution of the parameters (and therefore the factor loadings) in a (restricted) affine arbitrage-free term structure model conditional on the estimated Nelson-Siegel factors. The loadings of the statistical curve as appear in (1) can then be tested for equality with the implied arbitrage free ones.

Nelson-Siegel and No Arbitrage Models

The arbitrage-free affine yield curve model is consistent with imposing particular restrictions on the Nelson-Siegel model. Any linear term structure model can be expressed in the following matrix form:

$$y_t = a + bX_t + \varepsilon_t \tag{2}$$

where y_t is a vector of *N* maturity yields observed at date *t*, and X_t is a vector of *K* factors. The vector *a* is a set of constants that vary by maturity, while *b* is a $N \times K$ matrix of factor loadings. To fix ideas, the Nelson-Siegel curve shown in (1) above would be restated in this form with

$$a^{NS} = [0\ 0\ \ldots\ 0\ 0]' \tag{3}$$

and b^{NS} is given by (for a constant λ)

$$\left[1\ \left(\frac{1-e^{-\lambda_t\tau}}{\lambda_t\tau}\right)\ \left(\frac{1-e^{-\lambda_t\tau}}{\lambda_t\tau} - e^{-\lambda_t\tau}\right)\right]. \tag{4}$$

The class of Gaussian no-arbitrage affine term structure models can also be represented in the form of (2) where

$$X_t^{NA} = \mu + \Phi X_{t-1}^{NA} + u_t \tag{5}$$

Which means that the no-arbitrage factors follow a *K* order auto-regressive process with $u_t \sim N(0, \Sigma\Sigma')$. The constant and the factor loadings are also required to satisfy the following restrictions (Ang and Piazzesi, 2003):

$$a_\tau^{NA} = -\frac{A_\tau}{\tau}, \text{ and } b_\tau^{NA} = -\frac{B_\tau}{\tau}, \tag{6}$$

$$A_{\tau+1} = A_\tau + B_\tau'(\mu - \Sigma\lambda_0) + \frac{1}{2}B_\tau'\Sigma\Sigma' B_\tau - A_1, \tag{7}$$

$$B_{\tau+1} = B_\tau'(\Phi - \Sigma\lambda_1) - B_1', \tag{8}$$

where λ_0 and λ_1 govern the market price of risk, $\Lambda_t = \lambda_0 + \lambda_1 X_t^{NA}$, $A_0 = 0$ and $B_0 = 0$, and $A_1 = -a_1^{NA}$ and $B_1 = -b_1^{NA}$, come from the short rate equation

$$r_t = a_1^{NA} + b_1^{NA} X_1^{NA} + v_t. \tag{9}$$

Directly estimating no-arbitrage models is difficult given that both the loading and the factor are unobservable. Various approaches can be used to overcome these problems, including the use of observed factors or principal components. We follow Coroneo and others (2008) in using the estimated Nelson-Siegel factors. In addition to making the estimation tractable, it also allows a direct statistical comparison of the Nelson-Siegel loadings with the no-arbitrage loadings under the null hypothesis that the yield curve is arbitrage free. Given the standardized estimated Nelson-Siegel factors, a VAR(1) is estimated to obtain the parameters of (5), and (9) is estimated to obtain the short-rate factor loadings. The market price of risk parameters are then estimated by minimizing the sum of squared errors between actual and fitted yields.

No-Arbitrage Testing

We test whether the factor loadings of the statistical yield curve (expressed in (2) to (4) above) are not statistically different from the loadings of the no-arbitrage model in (6) to (9). Since these parameters vary by maturity, it is possible that the no-arbitrage conditions are satisfied at some maturities, but not at other. Specifically, for each maturity, the following four hypotheses are tested:

$$\begin{aligned} &H_0^1: a_\tau^{NA} = a_\tau^{NA} \equiv \mathbf{0} \\ &H_0^2: b_\tau^{NA}(1) = b_\tau^{NA}(1) \\ &H_0^3: b_\tau^{NA}(2) = b_\tau^{NA}(2) \\ &H_0^4: b_\tau^{NA}(3) = b_\tau^{NA}(3) \end{aligned} \tag{10}$$

To perform these statistical tests we use the block resampling procedure used by Coroneo and others (2008) to generate the bootstrap distribution over the no arbitrage model parameters. They note that this procedure ensures the following desirable statistical properties: "(i) the exact asymmetric recovery of all eigenvalues and eigenvectors of yields; the correct reproduction of the distribution of curvatures of the yield curve across maturities; (iii) the correct qualitative recovery of the transition from super- to sub-linearity as the yield maturity is increased in the variance of n-day changes; and (iv) satisfactory accounting of the empirically-observed positive serial correlations in yields." Using this bootstrap procedure to test the hypotheses in (10) we use the following steps.

(1) Construct the yield curve from the re-sampled data;
(2) Estimate the Nelson-Siegel factors;
(3) Estimate the no-arbitrage curve parameters using these Nelson-Siegel factors;
(4) Repeat steps (1) to (3) many times to build the distributions for $\tilde{a}_\tau^{NA}$ and $\tilde{b}_\tau^{NA}$; and

(5) Compare the distributions of $\tilde{a}_{\tau}^{NA}$ and $\tilde{b}_{\tau}^{NA}$ with the Nelson-Siegel factors.

III. Monetary Operations and Markets in China

The PBC has to-date relied largely on quantity-based monetary targets to steer monetary conditions, and despite increasing use of indirect instruments, it has not yet tried targeting a money market interest rate.[3] To achieve these quantity targets the PBC has a number of monetary policy tools to implement, ranging from market-based instruments to administrative instruments, and finally to standing facilities (see Figure 2). The *market-based instruments* are principally repo transactions (at maturities between 7 days and 6 months, and in recent years these have mostly been to drain liquidity), and PBC bill issuance (at maturities of 3 months, 6 months, 1 year, and 3 years). As *administrative tools* the PBC relies on window guidance, regulates benchmark retail deposit interest rates (as ceilings) and lending interest rates (as floors) across various maturities, and also has relied heavily on reserve requirements (which are differentiated by the size of institutions and are currently over 20 percent). In addition the government maintains a continued reliance "on quantitative limits to slow credit growth" (IMF, 2010). The PBC's *standing facilities* include lending windows (both intra- and inter-day), a rediscount facility, an excess-reserve deposit window, as well as term auction and FX swap facilities. The PBC has relied heavily on both reserve requirements and open market operations in recent years to manage monetary conditions by drain much of the liquidity resulting from its reserve accumulation.

China's money markets include both a collateralized (repo) market and an uncollateralized call-loan (CHIBOR market).[4] Collateralized lending activity clearly dominates, averaging 10 times the size of the unsecured market (which is largely restricted to the most credit worthy institutions), although almost all trading on these markets is at maturities of less or equal to 7 days (Porter and Xu, 2009). Given limited trading beyond very short maturities, the SHIBOR benchmark curve was introduced in 2007 based on daily quotes (up to a 12 month maturity) from 16 commercial banks. While these interbank markets are highly active, there are some apparent pricing anomalies. The three interest rates are usually tightly correlated, although at times diverge, with the collateralized repo interest rate typically highest during these periods despite the collateral (Figure 3). This surprising fact is likely to reflect the rise in market power of large banks with relatively more excess liquidity and higher relative counterparty risk of small banks (despite the collateral they provide) during times of stress (including around IPOs). Such spikes in rates are, in part possible, because the PBC seemingly does not ensure that its lending facility provides a binding upper bound on

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[3] Prior to 2009 the PBC announced both a broad money and a credit (new lending) target. Due to the stimulus response that followed the collapse of Lehman Brothers, the PBC canceled its 2008 targets, and did not announce any monetary or credit target for 2009. A broad money target was reintroduced in 2010.

[4] From May 2004, there have been two types of repo transactions. Under the *collateralized repo*, the underlying bond is placed with a custodian without the underlying ownership transferred, while in the *outright repo* the ownership of the bond is transferred. The collateralized repo market is by far the most active. In addition to funding, adding the outright repo allows for the short-term lending of securities. Consequently, for funding purposes, only the collateralized repo is relevant.

the overnight interest rate corridor (Figure 4). The PBC's own interest rates on repo transactions also seem to systematically diverge from those seen in the market (Figure 5).

China's bond markets have been segmented since the early 1990s, shortly after the creation of the interbank market (Porter and Xu, 2009), and have very different trading volumes across the various types of bonds (see Figure 6). China's bond market had its beginning in the resumption of Treasury bond issues in the 1980s. Initially, these bonds were traded over-the-counter, but there was a gradual shift to floor trading after the establishment of the Shanghai and Shenzhen exchanges, in 1990 and 1991, respectively. However, following the equity and real estate bubbles in the early 1990s, the PBC prevented commercial banks from trading on these exchange-based bond markets in 1997 to ensure that bank credit would not be used to finance speculation (including through repo activities). The exchange based bond market remained as a retail market, while the interbank bond market was limited to financial institutions. The relative size and extent of trading activity vary considerably across the markets. In particular, following the segmentation much of the Treasury bond activity moved to the interbank market. Moreover, despite a smaller stock of outstanding bonds, the turnover of Policy Banks (Financial) bonds is much larger than that of Treasury bonds, which are held to maturity by many banks for repo purposes (see Figure 6).[5]

IV. DATA

We have data on zero coupon yields from China Central Clearing and Depository. The yields cover both interbank (IB) and exchange traded treasury bonds (IBTSY), interbank traded PBC bills (IBCB), interbank bonds issued by China's financial banks (IBPBB),[6] and corporate AAA bonds traded on the interbank market (IBCAAA). Our data set, with the exception of PBC bills, comprises month-end data from April 2006 to May 2010, with the data for PBC paper yields starting in June 2007. The main descriptive statistics of the Chinese bond yields are presented in Table 1. Relative to the US Treasury yields studied by Diebold and Li (2006) or Coroneo and others (2008), Chinese bond yields display considerably less autocorrelation.

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[5] A similar pattern applied to the relative size and liquidity of PBC bills. As of the end of May 2010, outstanding Treasury bonds and PBC bills accounted for 30.0 percent and 22.8 percent of outstanding bonds, respectively. Nonetheless, the transaction volume for PBC bills far exceeds that for Treasury bonds. Between June 2007 and May 2010, the cumulative transaction volumes of Treasury bonds and PBC bills accounted for 9.6 percent and 40.0 percent, respectively, of cumulative bond market transaction volume.

[6] While the China Development Bank (CDB) continues to be the major issuer of policy financial bonds (accounting for over 70 percent of these bonds), in 2008 the State Council formally approved an overall reform plan for China Development Bank that explicitly called for its transformation into a commercial bank. Although the regulatory agencies have formulated transitional policies for CDB, the market's holding and trading preferences with respect to CDB bonds may have changed. However, as discussed below, despite this the behavior of these bonds does not seem out of line with that of other bonds during this period.

V. Results

In this section we seek to gain a deeper understanding of the efficiency of yields in Chinese bond markets as well as their potential role in monetary policy transmission. In doing so we answer four principle questions: (i) Are bond yields distorted by the structure of administered interest rates? (ii) Is there interaction between the yields on PBC paper and the yields on other bonds? (iii) What are the macro-financial linkages between bond yields and macroeconomic variables? (iv) Are Chinese bond yields arbitrage free and, in the sense, efficiently priced? To answer these questions we use the methodology described in Section II to description of the factors underlying the yields in the various markets, and to test for arbitrage possibilities. In general we find that while yields are influence by the structure of administratively set benchmark rates, PBC yields do influence the yields on other bonds, which influence (and inform about) changes in macroeconomic variables. Nonetheless, prices in Chinese bond markets are not fully efficient, reflecting the influence of interest rate regulation, illiquidity, and bond market segmentation.

A. Estimated Yield Curves and Market Behavior

The main descriptive statistics of the estimated errors and factors are presented in Tables 2 and 3. The estimated errors (as summarized by the root mean squared error) are typically small, with the largest errors in short-end PBC paper yields. Corporate and Treasury bonds have their largest errors at the 2 year maturity, while policy financial bonds have the largest errors at the 12 month maturity. The estimated errors are far less autocorrelated than the actual yields, with little significant autocorrelation beyond three months. The estimated factors on the other hand display (as expected) significant autocorrelation over a few months.

Our estimated statistical models of the yield curve clearly capture the shape of the observed yields, but the point of maximum curvature varies considerably across instrument and market. The estimated λ coefficients imply yield curves with maximum curvature (impact of medium-term factors) at around 3 years, somewhat longer than that in the US Treasury market (Diebold and Li, 2006), although the curves for both the exchange Treasury and PBC bills markets have shorter estimated maturities at which the curvature of the yield curve is maximized (see Table 4). For the PBC market it reflects that this market only contains short maturity paper, but for the exchange traded market it possibly reflects differences between the behavior of investors in each segment of the Treasury market. Figure 8 shows actual and fitted yields for our 5 markets at end-June 2007, the first common date in the sample that captures a situation just before the financial market turmoil broke-up in Europe and the USA. The actual yields are remarkably close to the fitted curves. The fitted curves also largely have shapes with the expected properties, with corporate and quasi-government (policy financial bonds) being strictly higher than their Treasury counterparts. However, the fact that the PBC paper market rates are uniformly (and increasingly) higher than Treasuries is surprising. In fact, for the relevant maturities (i.e. three- to thirty-six months) PBC bill rates are, on average, closely aligned with the rates on interbank Policy Banks bonds. This may reflect arbitrage across the two markets, given that for the PBC to drain liquidity through bond issuance the relevant alternative rate of return to PBC bills, for the institutions that participate to the PBC (competitive) tenders, are the rates on the Policy Banks bonds and AAA-corporate bonds. The relatively high spread between the interbank Treasury bond yields and the Policy Banks bonds yields likely reflects taxation differences.

The segmentation of the bond market, even if no longer complete, leads to inconsistent pricing—apparent profitable arbitrage opportunities—for treasury bonds in the two markets.[7] The interbank and exchange Treasury curves cross, which in a frictionless market would imply immediate arbitrage opportunities (see Figure 9). The observed patterns—higher longer yields and maximum curvature at lower maturity—would seem consistent with trading by less patient individuals in the exchange market (i.e. a retail market) than in the interbank market (i.e. a wholesale market). This is consistent with the significant "buy-and-hold" behavior by banks in the Treasury market. Nonetheless, the ongoing existence of such opportunities for otherwise identical assets suggests considerable ongoing frictions in the Treasury bond market. Potentially the most damaging is the relatively limited liquidity (and wide bid-ask spreads) at certain maturities, but the preliminary mechanics for transferring bonds between the two markets that have been established also mean that market opportunities are missed (or else the yields should be very close). The point of crossing (and the interest rate spread across the markets) varies considerably over time, around the median value of 12 months.[8] In fact regions of non-concavity of the yield curve can result in two crossing points (as happened in December 2009).

Short-term money market rates can differ considerably from the PBC and treasury curves, although SHIBOR curve tends to converge to the PBC yield at the 12 month maturity. Figure 10 displays the curve and money market rates at three dates: (i) end-June 2007 (the first common sample observation and a relatively normal period); (ii) end-November 2007 (the peak SHIBOR interest rates (before 2011) during a highly active IPO period); and (iii) end-December 2008 during the post-Lehman Chinese policy loosening. On all these dates the market overnight interest rate is below the level of the overnight interest rate implied by the Nelson-Siegel estimated Treasury bond and PBC bill curves; however, some longer money market rates are above the curves. During the period of IPO-induced market stress, the estimated PBC curve inverted slightly, although to a surprisingly small extent given the very short-term impact IPOs have on yields, a pattern seen in the repo interest rates.[9] The Treasury curve also followed the policy easing in late 2008. Despite sizable differences between the money market rates and the estimated yield curves at the very short end, the (non-traded) SHIBOR seems to converge to the PBC curve towards the longer end of the money market yield curve (i.e. one-year). This suggests that the offered rates submitted by the included banks may be based off PBC paper yields given that there is often no traded money market rate beyond one month. However, this is despite the rates having very different risk

[7] The PBC recently announced a pilot scheme in 2010 that allows some listed commercial banks to trade in the exchange market.

[8] The crossing point is calculated as the point the two estimated Nelson-Siegel yield curves are equal.

[9] IPOs have typically involved significant funds—multiples of the size of the IPO—being locked up for a period of around a week given the extent of oversubscription, and have been a large driver of interbank volatility (Porter and Xu, 2009).

characteristics—the SHIBOR rate is, in principle, the offered rate for unsecured lending. Consequently, the PBC curve may be in a position to provide a traded benchmark (in place of SHIBOR) as it has many on-the-run issues (given twice weekly PBC auctions) and a liquid secondary market. The PBC curve even partly mimics the convex shape shown by interbank rates in November 2007.

Still, as explained in Porter and Xu (2009), the very short-end of the money market yield curve displays highly idiosyncratic behavior (in mean and volatility) reflecting, among other, liquidity effects (e.g. timing of Chinese New Year, end-of-month, and within-week liquidity effects). Thus, the gap between the Nelson-Siegel implied overnight interest rate and the market overnight interest rate can be interpreted as a measure of a "liquidity effect". Interestingly, as the interbank market overnight interest rate seems to be systematically below the implied Nelson-Siegel overnight rate, this may suggest that, overall, there is (relatively) ample liquidity in the overnight interbank market. This is consistent with the Chinese banking system being in an aggregate liquidity surplus situation vis-à-vis the PBC. It may also reflect the fact that the PBC does not conduct open market operations on a daily basis or with overnight maturity.

B. Yield Curves and Monetary Policy Transmission

As described above, the three estimated factors—level, slope, and curvature—provide a convenient set of summary statistics for yield curve dynamics. We use these estimated factors to describe the behavior of the yield curve around key recent policy changes, as well as use them to trace the transmission of changes in PBC yields and administered interest rates to other bond yields, and then to macroeconomic indicators. Specifically we find that the short-term drivers of yields responded most to the post-crisis policy stimulus, that the regulated structure of benchmark retail interest rates has a significant impact on the structure of all bond yields, and that changes in yields on PBC paper do transmit to other yields and the real economy.

Yield Curve Dynamics

The three factors that underpin the yield curves behave in similar ways across all bond markets with the exception of the PBC curve (see Figure 11).[10] Aside from PBC paper, all the curves display remarkably little movement in the level of long run interest rates (level factor). After rising in mid-2007 (probably reflecting high inflation), the level only briefly came down around the time of the Lehman failure, before moving up again. Consequently the remarkable monetary stimulus beginning in late-2008 did not lower long-term interest rates perhaps because the monetary stimulus was accompanied by a large fiscal expansion or because it was perceived as only temporary. The policy response did, however, lower the level of PBC's rate structure. Although the maturities with which the PBC factors are

[10] Note all the factors displayed in Figure 7 are for yields expressed in monthly terms and divided by 100. Displayed slope parameters are the negative of the second estimated factor.

estimated are shorter than the other curves (maximum of 3 years rather than 10), there is, apparently, a disconnection.[11]

The policy loosening, which led to a decline in interest rates affected mainly the shorter- and medium-end of the bond markets yield curves. The policy response led to a parallel downward shift in the PBC's yield curve (since the slope factor remained largely constant). Interestingly, this policy resulted in a significant and persistent rise in the slope of all the other yield curves. Indeed, the medium-term (curvature) factor went from playing a (by-and-large) positive impact on yields, to a negative one around the time of the loosening.

Bond Yields and Regulated Interest Rates

The regulation of the structure of retail deposit and lending rates could affect the structure of bond yields. To investigate this, we estimate a simple VAR for the IBPBB yield curve, including the three factors, two macroeconomic variables (growth in real value added, inflation), and the regulated interest "margins" (difference between the administered benchmark lending and deposit rates) at 1, 3, and 5 year maturities. [12] The resulting (orthogonalized) impulse response functions are shown in Figure 12, and suggest a substantial impact of retail interest rate regulation on the structure of IBPBB bond yields.[13]

The level, slope and curvature of the IBPBB yield curve are affected by the regulated margins. In general, the long term (level) yield factor is affected by the all margins. The impact tends to be negative: an unexpected temporary widening of the margins tends to push the longer-term factor down. The short-term (slope) factor is also affected by unexpected changes in all regulated margins. The impact tends to be statistically significant and negative. That is to say an unexpected temporary widening of the margins tends to push the slope factor down or flatten the yield curve (effectively increasing short-term yields for a given long-term yield). However, an unexpected widening to the regulated margins lead to a temporary increase in the curvature factors. The margins also affect both economic growth and inflation in similar ways, with lower growth and inflation following an increase in the margins, consistent with relatively high short-term yields, and lower long term yields.

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[11] Note that the long-term factor estimated from the PBC bills yield curve is not directly comparable to the other long-term factors. The former includes information only up to three year yields whilst the latter include information up to ten year yields. Thus, the former is likely a biased estimate of the "true" underlying long-term interest rate as it is closer to the medium term yields (i.e. curvature factor of other yield curves). Interestingly, the level factor of the PBC yield curve behaves more like the curvature factor of the other yield curves (see Figure 7).

[12] Policy Bank (Financial) bonds (IBPBB) were chosen as the focus given their higher market liquidity.

[13] We report orthogonalized impulse response functions (OIRFs). The ordering of the variables is such that yield curve factors are ordered prior to macro variables, with policy variable(s) are put at the end, following the suggestion in Diebold and others (2006). Generalized impulse responses (GIRFs) which are independent of the ordering of the variables were also computed and give, broadly, qualitatively similar results. Similar results, not reported in the paper but available from the authors upon request, are obtained for other yield curves, e.g. IBTSY, and IBCAAA.

All in all, the impulse responses suggest that narrowing (widening) of regulated margins is associated with steeper (flatter) yield curves and lower (higher) levels of medium-term rates movements that can be attributed to a loosening (tightening) of monetary policy, leading to increasing (lower) growth rate and inflation.

Interrelation between Curves

Changes in the PBC bonds yield curve (IBCB) have a statistically significant impact on all factors of the IBPBB yield curve.[14] This is illustrated estimating a simple VAR with six variables (the three factors of the IBCB curve and the three factors of the IBPBB curve). Orthogonalized impulse response functions are shown in Figure 13. The level of the Policy Banks bonds yield curve (IBPBB) is statistically significantly affected by shocks to the level, the slope, and the curvature of the PBC's yield curve, but shocks to the level have the largest and most lasting impact. Unexpected changes in the slope of the PBC curve have an impact in the slope and curvature factors of IPPBB yield curve. Shocks to the curvature of PBC bonds yield curve have a statistically significant impact on the level (only contemporaneous and short-lived) and on the slope of the IPPBB yield curve. That is, changes in both the short-term and the long-term factors of PBC rates are associated with changes to the long-, short- and middle-term points in the IBPBB yield curve, although unexpected shocks to middle-tenor factors have a transitory impact.

That shocks to the factors of the Central Bank paper (IBCB) yield curve have a strong impact on the factors of the IBPBB yield curves highlights that one necessary element of a rate-based monetary policy transmission mechanisms seems to be working/emerging in China.

Macro-Financial Linkages

How do bond yields and macroeconomic variables interrelate? To answer this we study how key macroeconomic variables relate to our estimated yield curve factors. We again focus on the factors for the interbank Policy Bank bonds given the relatively high liquidity in this market. We also look at the cyclical properties of the implicit long term corporate (AAA) spread defined as the gap between the level factor for corporate (AAA) bonds (which trade in the interbank market) and that of the interbank treasury bonds. The macroeconomic variables we consider are monthly real industrial value added growth, and monthly CPI inflation, each in year-on-year terms.

Cross-correlation analysis (see the Appendix) shows that the level factor of Policy Banks bonds yields tends to lead the business cycle in China. In particular, the level factor is significantly negatively correlated with growth and positively correlated with inflation 12 to 20 months ahead. Thus the level factor of Policy Banks bonds yields may provide a proxy for near-term inflationary expectations. Interestingly, corporate spreads also seem to lead the cycle, with higher spreads related to lower growth and higher inflation in the future. Generally, these results suggest that expectations of near-term economic variables are priced into longer-term bond yields.

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[14] Similarly IBCB yield curve factors have also an impact on other yield curve factors e.g. IBTSY and IBCAAA.

The other factors tend to be more coincident or lagging with respect to growth albeit with different signs and coincident or leading with respect to inflation also with different signs. The short-term (slope) factor is negatively correlated with past growth (e.g. higher growth leads a flattening of the yield curve) and positively correlated with contemporaneous and future inflation (e.g. higher inflation leads a steeper yield curve). The medium-term (curvature) factor is positively correlated with current and future growth and negatively correlated with inflation a few months ahead.

Estimating a simple VAR between these variables, as well as the 3 month PBC bill rate as a proxy policy variable, reveals some inter-relations between real and financial factors. Although the 3 month bill rate is not directly a policy rate, it is chosen as a proxy since it has the longest continuous time series for a given PBC rate. Our basic results are as follows:

- Unexpected rises in the level factor of IBPBB yields have a dampening impact on growth after about half a year. A rise in the slope (lower near-term yields) raises growth after 3 months (although not significant) and inflation after 5 months. An increase in the curvature factor is associated first with a temporary increase in growth which dies out after about a year. Inflation seems to be strongly affected by unexpected changes in the curvature of IBPBB yields (medium-term factor) (see Figure 14).

- The slope and curvature factors affect the 3 month PBC rate with different signs the former negative the latter positive (see Figure 14). The 3 month PBC rate responds to corporate spread shocks and inflation shocks, but little to growth rate shocks (see Figure 15).

- Unexpected changes in corporate spreads tend to depress both growth and inflation (see Figure 15). PBC policy, as reflected in the PBC 3 month bill rate, also responds to changes in corporate spreads (see Figure 15). Quite strikingly, changes in the 3 month PBC rate affect all factors in the IBPBB yields (see Figure 16).

- While growth does not respond significantly to unexpected changes in the PBC bill rate, inflation and corporate spreads decline in a significant and persistent way (Figure 15).

Taken together this evidence suggests that a nascent monetary policy transmission channel is in place. Changes in PBC open market operation rates feed through to longer-term yields and corporate spreads. This occurs even despite the regulated interest rates (which we condition on). As the shape of these bond curves change, there is an impact on growth and inflation—higher longer-term Policy Bank yields and corporate spreads depress growth and inflation, as does a fall in the slope (higher short-term yields) of these yield curves. Consequently, this part of the transmission channel looks very much like that expected in countries that already target interest rates to manage monetary conditions. That is, changes in the central bank's policy rate change the funding costs faced by banks and corporates, this in turn influences their activity, ultimately affecting growth and inflation.

The China results may be contrasted with those found for the US (Diebold and others, 2006), as well as for the Czech Republic, Hungary, and Poland (Hoffmaister and others, 2010). Comparing the results presented in this paper with those in the other two papers, they are broadly similar, and the following features emerge:

- ***Slope.*** A rise in the slope factor (fall in short-term yields given the long-term factor), produces a similar policy and macroeconomic impact in all three regions.[15] Specifically, in China, the US and Hungary lower short-term bond yields tend to depress policy rates (the impact is insignificant for the Czech Republic and Poland). In both China and the US, shocks to growth and inflation tend to raise short-term yields (depress the slope factor).

- ***Level.*** The US and China show a similar impact from the rise in the level of yields on inflation, reflecting the role of the level factor as a market-based measure of inflation expectations. While a rise in the level factor tends to raise both growth (capacity utilization) and inflation in the US, it only increases inflation in China; near-term growth tends to decline. Shocks to the level factor have a negligible impact on macroeconomic variables in the three European EMs.

- ***Inflation and the level factor.*** *Long-term inflation expectations* may be better anchored in China than in the US. Surprises to US inflation appear to give a long-term boost to the level factor. Such a reaction is consistent with long-inflation expectations not being firmly anchored, allowing a surprise increase in inflation to feed through to higher future inflation expectations (raising the level factor). Shocks to Chinese inflation, however, do not appear to have an impact on the level factor. These reactions are consistent with long-term inflation being more strongly anchored in China than in the US.

- ***Curvature.*** In the US and China, shocks to macroeconomic variables mostly have little impact on the middle-tenor yields (curvature) factors (Chinese inflation being the exception). While the reverse is also true for the US (as well as these three European EMs), the impact of curvature factor has a significant impact on growth, inflation and PCB rates in China.

C. Are these Yields Curves Arbitrage Free?

We have seen that Chinese bond yields are distorted by regulation, but despite this are somewhat informative about economic and liquidity conditions. However, how efficient are they? As a concept of efficiency we take as a metric whether the yields curves appear to be free of arbitrage opportunities, using the test developed by Coroneo, et. al. (2008). This is a relatively weak concept of efficiency in that it does not require bond pricing to the consistent

[15] Recall in this paper the slope factor is defined as $-\beta_{2t}$, while in the other two papers, the slope factor is equated with β_{2t} directly. Diebold and others (2006) proxy growth using capacity utilization rather than using industrial production, as done in Hoffmaister and others (2010) and here.

with macroeconomic fundamentals or across bond markets. Clearly as discussed in Section V, China's Treasury market permits pricing with apparent arbitrage opportunities between the interbank and exchange markets, but this reflects distortions arising from the segmentation rather than non-optimizing behavior by market participants. We now ask whether there are arbitrage opportunities within individual bond markets unaffected by segmentation. The test compares the deterministic Nelson-Siegel factor loadings (see equation (1)) with the distribution of factor loading estimated using the arbitrage-free affine yield curve model (for the Nelson-Siegel factors we estimated in Section Va). If these deterministic factors lie outside the 95 percent confidence interval for the distribution for the estimated arbitrage-free loadings, then the null hypothesis of no-arbitrage is rejected.

Figure 17 shows the Nelson-Siegel (NS) factor loadings (depicted as dots) against the distribution of estimated arbitrage-free loadings.[16] All the four markets have some significant deviation from arbitrage free bond yields, although the degree of deviation varies considerably across markets. This contrasts with the patterns seen in the US Treasury market that is arbitrage free (Coroneo, et. al., 2008). The yields of Policy Bank and Treasury bonds trading on the interbank market, however, seem to be closer to not rejecting the no-arbitrage hypothesis.[17]

- For **interbank traded Treasury bonds**, the NS loadings on the factors driving the short- and middle-tenor yields (slope and curvature) deviate significantly from the arbitrage-free factors at short maturities (less than two years). As a result the weight on short-term factors is too high, and that on middle-tenor factors too low.

- In the **exchange traded Treasury market**, both the weight on the long-run level factors and the short-term factors are too high across all maturities. Only the weight on the middle-tenor (curvature) factor is seems to bet statistically consistent with the NS factors.

- The weight of short-term (slope) factor in the yields of **Policy Banks bonds** seem seems closest to that consistent with the arbitrage free hypothesis. However, the weight placed on the long-term level of rates seems too low at short and middle maturities (less than two years). There also seem to be some significant deviations from arbitrage free-pricing at middle-maturities (around 4-6 years).

- For the **Central Bank paper** market, the weights placed on all factors seem too high to be consistent with arbitrage free pricing. Since the maximum maturity in this market is 36 months, the large deviations from arbitrage-free pricing could be

[16] We use 500 simulations with sampling of blocks of 8 observations to construct the bootstrap distributions.

[17] We are grateful to Ken Nyholm for providing the MATLAB code used in Coroneo and others (2008) for the implementation of the no-arbitrage tests.

consistent with the fact that deviations in the other interbank bond markets are largest at these maturities.

Liquidity would seem to be one, but not the only, factor behind these deviations from efficiency. As measured by bid-ask spreads, both the interbank Treasury and Policy Bank markets are least liquid at very short maturity, seemingly consistent with deviations from arbitrage-free pricing at those maturities.[18] In the Policy Bank market, bid-ask spreads rise faster (from a maturity of 3 years) and higher than in the Treasury market, possibly accounting for deviations from efficiency seen at those maturities in this market. Other considerations would also seem important. The "efficient" weighting on the level factor in the Treasury Bond market, may reflect the buy and hold nature of that market (making correct pricing of longer yields important), while the "efficient" weighting on the short-term factor for Policy Bank bonds could reflect their higher use in short-term repo transactions and higher overall turnover. Moreover the fact that (at least) interbank yields seem more efficiently priced at longer maturities (loadings inside the estimated confidence bands) likely reflect the impact of the regulated structure of interest rates, that specifies the long-term retail interest rate structure at 5 years.

VI. Conclusions

This paper has studied the characteristics of yields in several Chinese fixed income markets, ranging from the PBC bill market, the largely segmented interbank and exchange traded Treasury Bonds market, the Policy Financial Bonds market, and the non-financial (AAA) corporate bond market. In particular, we use a simple and parsimonious statistical description of these yields using latent factor analysis. With this simple statistical model a special case of an affine no-arbitrage yield model, the restriction imposed on yields by no-arbitrage considerations can be tested. In some sense these separate segments of the bond market share similar risk characteristics, but resulting bond yields suggest a premium is required to hold these bonds other than treasuries, partly due to differential tax treatment.

In terms of efficiency, we find interbank Treasury and Policy Banks bond yields to be closest to not rejecting the arbitrage free hypothesis although both deviate from efficient pricing of shorter maturities. Central bank bills deviate from efficient pricing at similar maturities. These deviations seem consistent with the market liquidity along the yield curve as well as other factors. The introduction of some limited foreign participants, including central banks, into China's interbank bond market (as part of the reforms to internationalize the renminbi) may improve bond market liquidity since these participants are likely to pursue different trading strategies from the current participants. Aside from illiquidity, the failure of arbitrage along the yield curves may reflect the nature of trading in the various markets as well as the interaction between the administratively set benchmark retail deposit and lending rates and bond yields. In particular, we find that changes in the benchmark rates at different tenors affect different segments of the yield curve. Moreover, the fact that the interbank and exchange traded Treasury bond yield curves often cross, suggests the availability of arbitrage

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[18] The data on bid-ask spreads comes from Bloomberg, and due to limitations only covers April 2010 to June 2011.

opportunities, but exploiting these is unlikely to be profitable given the complications in moving bonds from one market to the other.

Despite any distortions in prices, the levels of bond yields seem to anticipate movements in macroeconomic conditions. Implied long term corporate spreads, in particular, are correlated with inflation up to 7 months hence and growth up to 2 months. Consequently, they may be able to provide guidance on changes in growth and inflationary expectations. Using simple VAR analysis, we also find changes in the Policy Banks bonds yield curve to drive changes in growth and inflation. Changes in the PBC rates directly affect all the factors of the Policy Banks bond yield curve. Consequently, we find that changes in short-term PBC interest rates do feed through to longer yields and other yield curves (including bank and non-financial corporate financing costs).

Our findings, therefore, suggest that the stage is set for increased use of interest rate targeting as the primary monetary policy tool. While inefficiencies exist, changes in the PBC's rates do feed through to other yields and macroeconomic aggregates, and financial prices are informative signals of macroeconomic and financial conditions. The increasing pace of disintermediation suggests that moving towards indirect policy tools is becoming urgent. With further liberalization of financial prices only likely to strengthen the link between financial prices and activity, it should also further strengthen the transmission channel from interest rates to activity and inflation.

FIGURES

Figure 1 Nelson-Siegel Factor Loadings

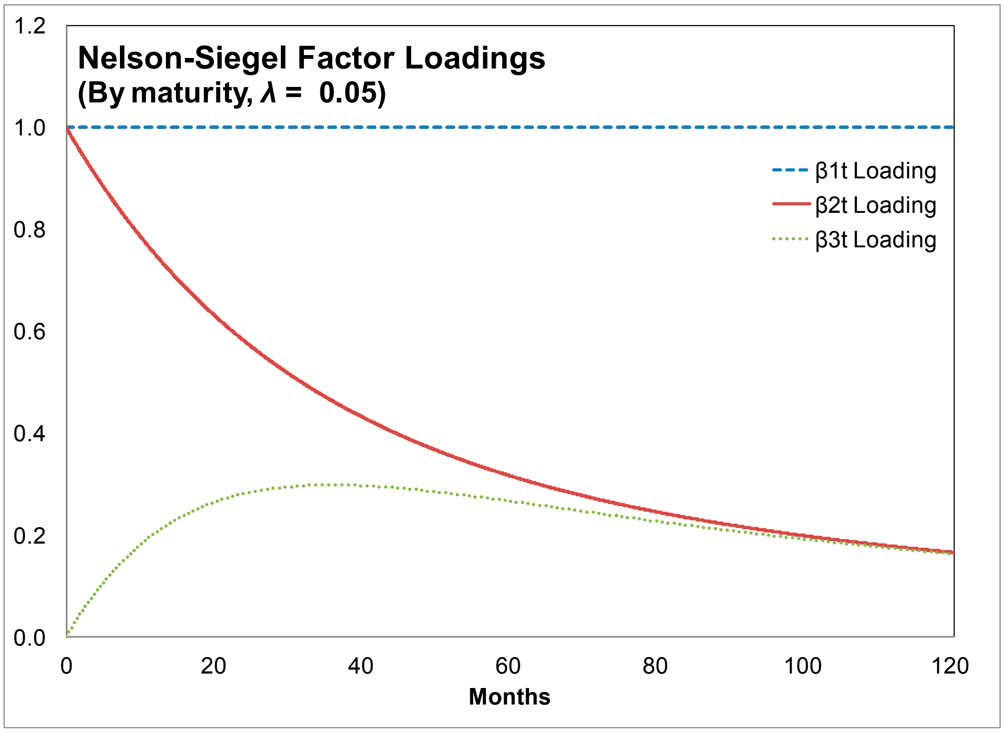


Figure 2. PBC Open Market Operations

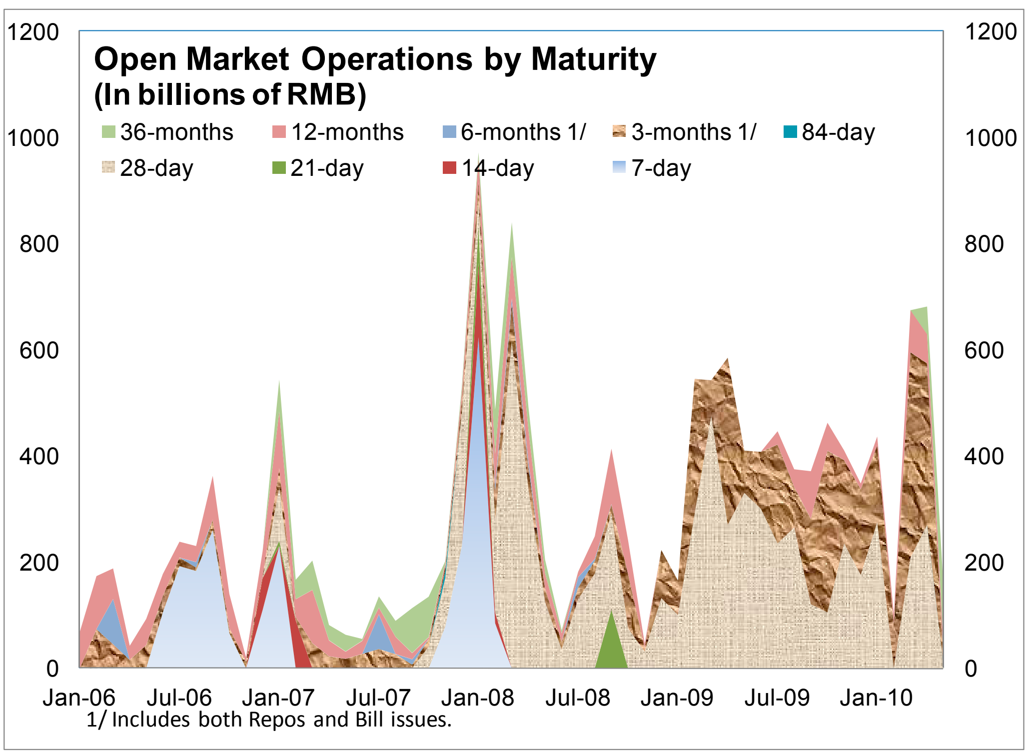


Figure 3. Overnight Interest Rates

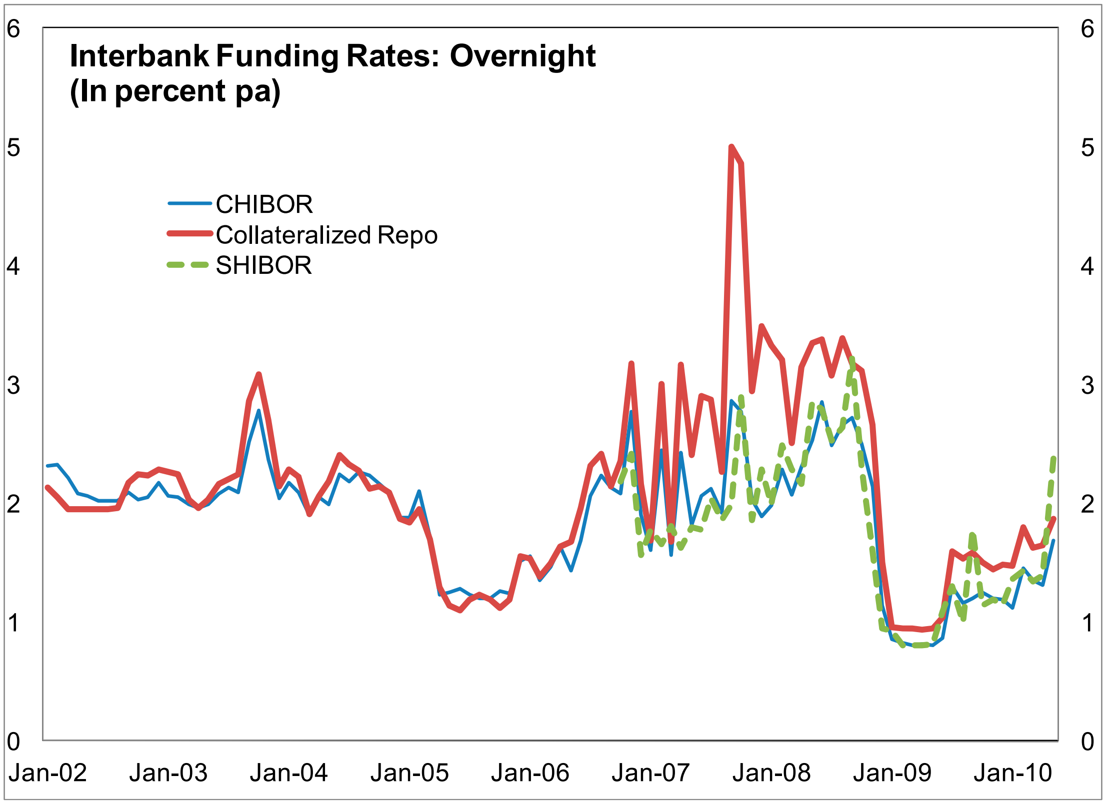


Figure 4. Interest Rate Corridor

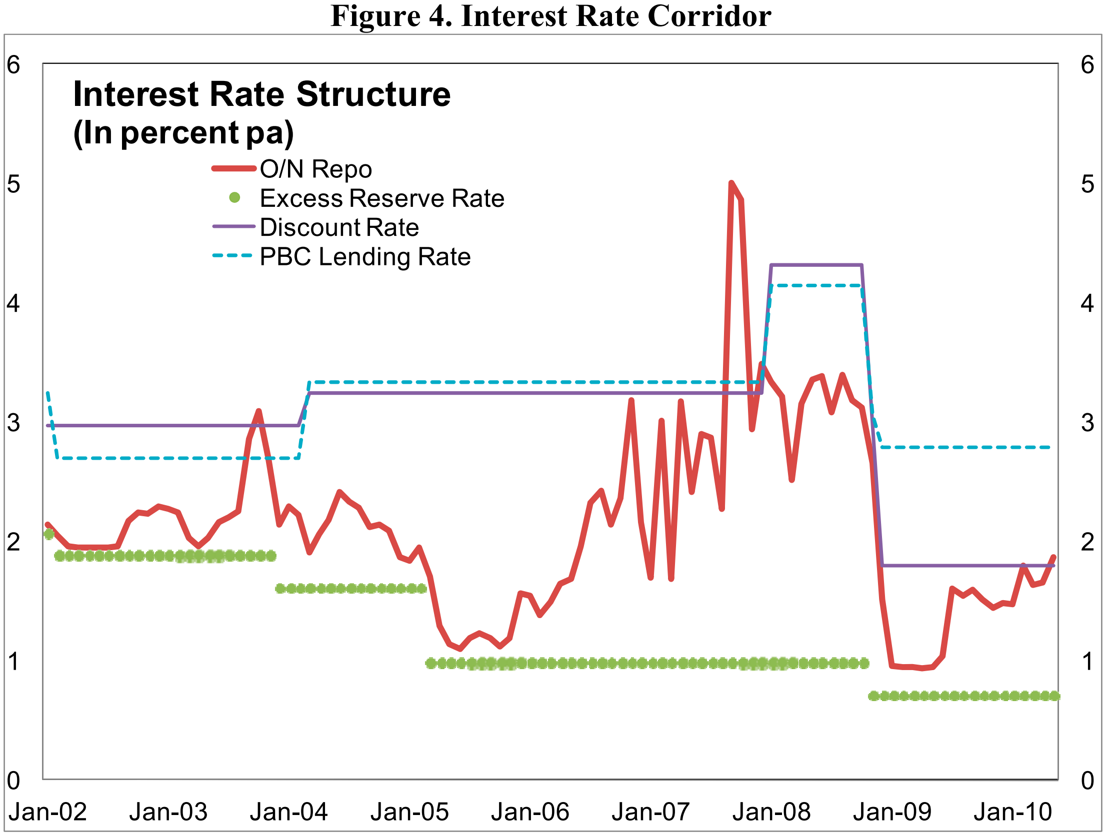


Figure 5. Interbank and Central Bank Repo Rates

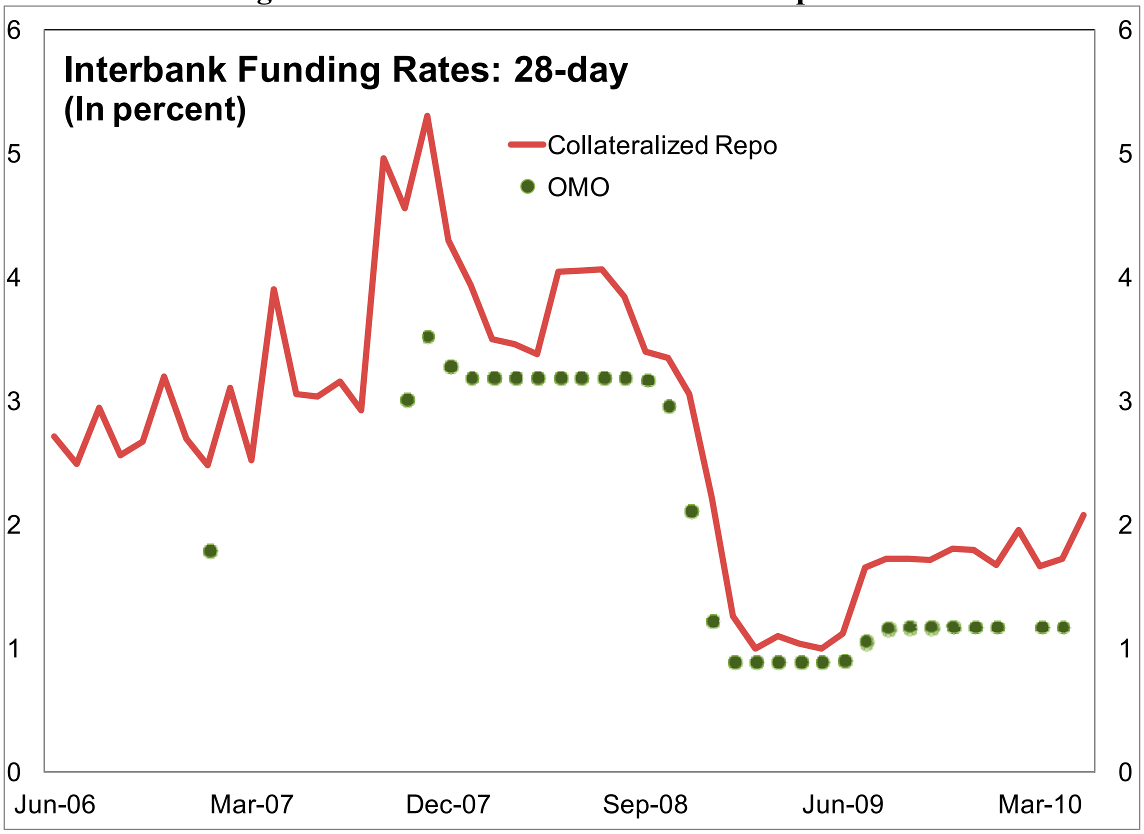
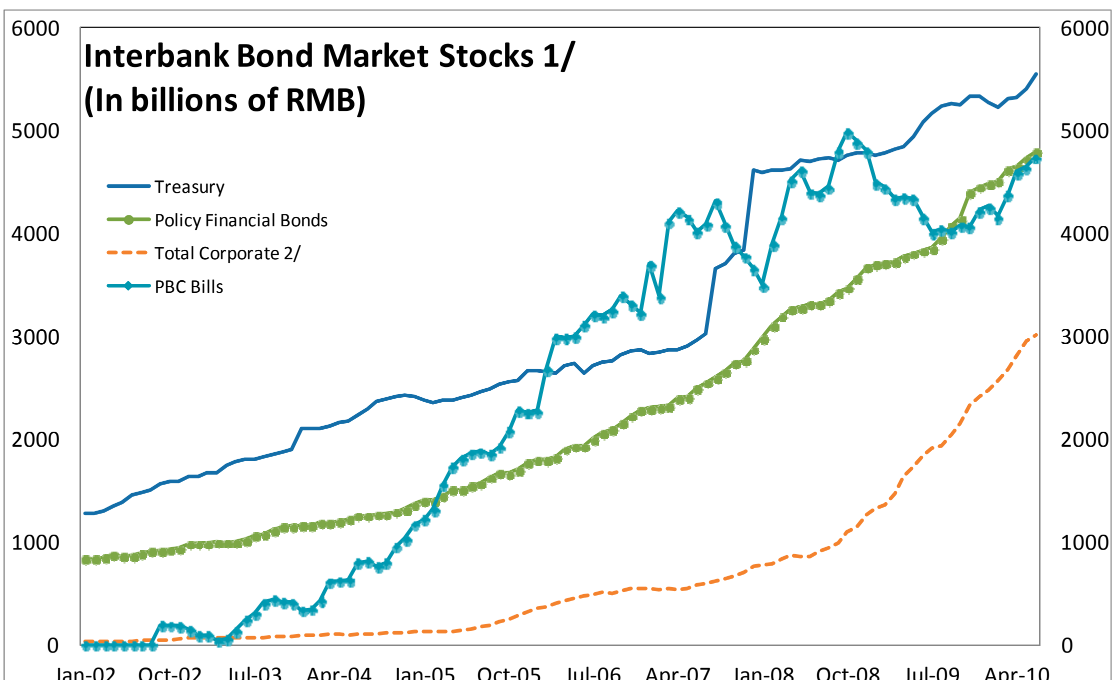


Figure 6. The Value of Bonds Outstanding



Source: CEIC Data Co. Ltd.

1/ The total holding of bonds in the CGSDTC depository is taken as the capitalization in the interbank market

2/ Total corporate includes corporate bonds, short-term financing notes, and middle term notes.

Figure 7. Bond Market Turnover

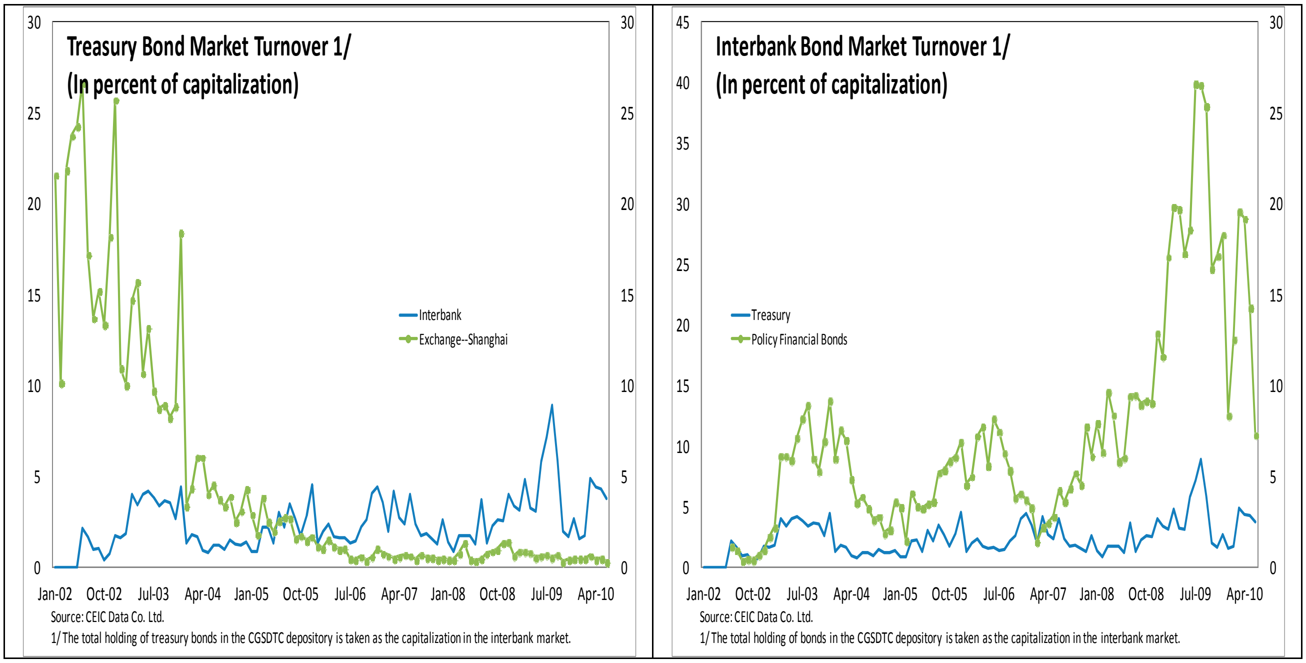


Figure 8. Actual and Estimated Yield Curves

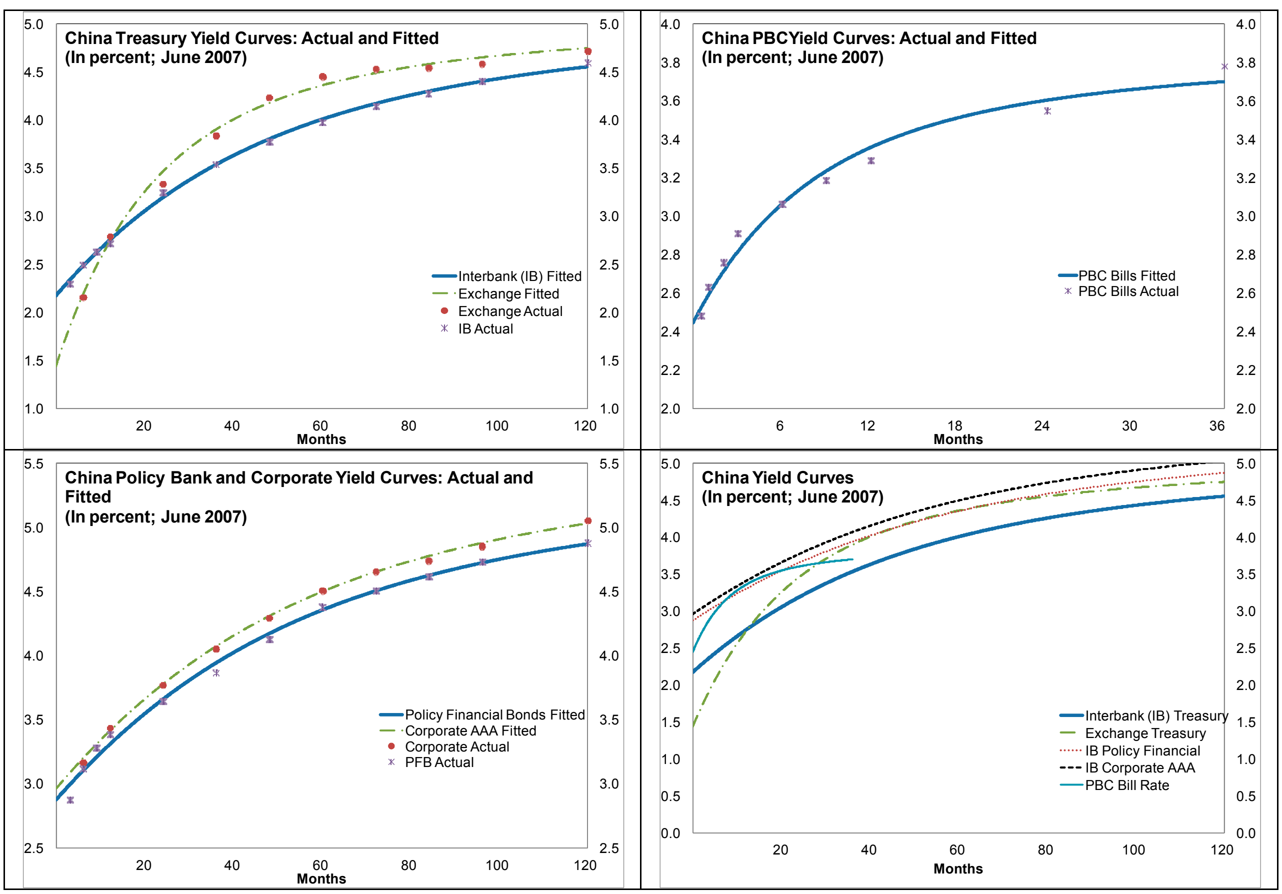


Figure 9. Intersecting Treasury Yield Curves

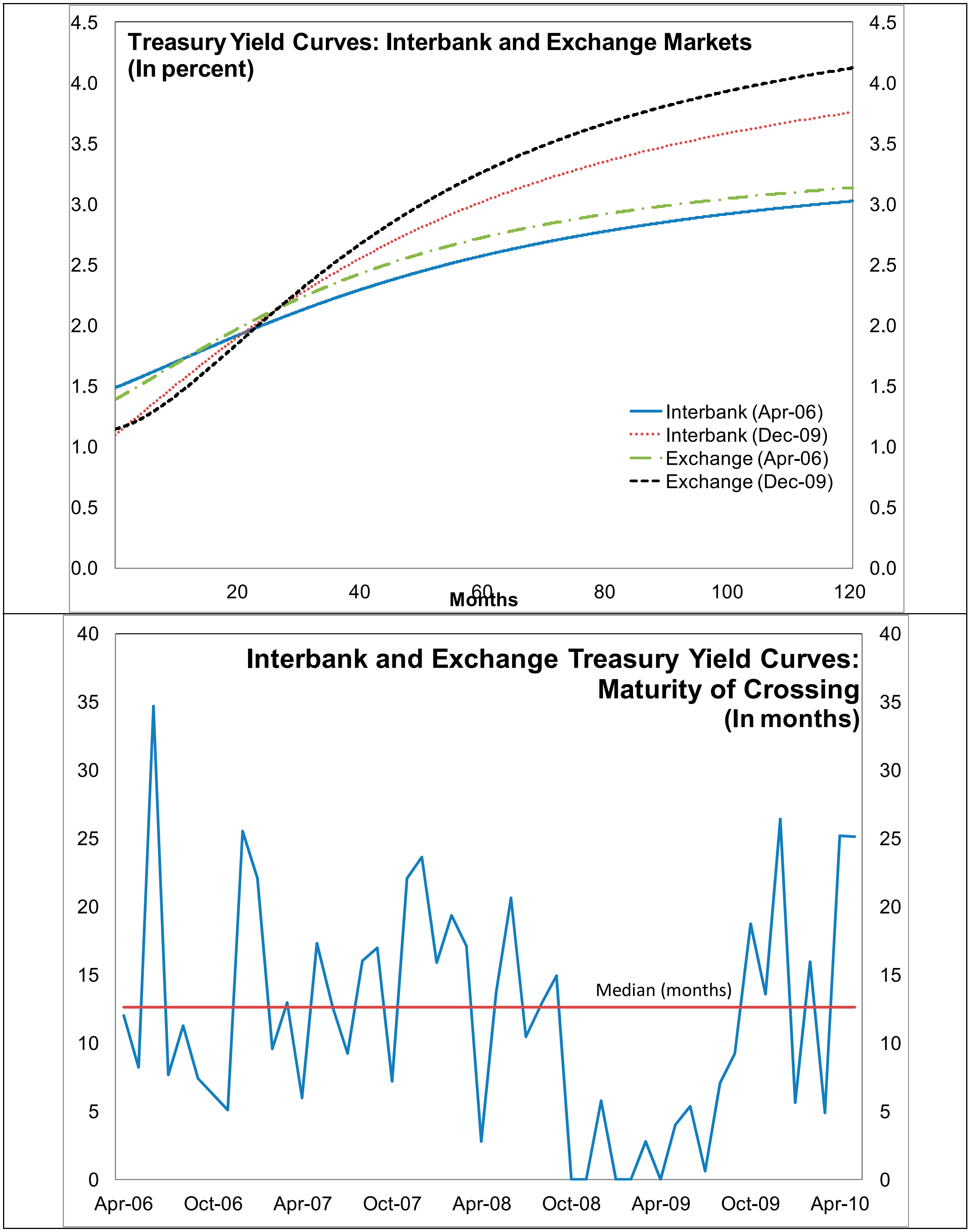


Figure 10. Money Market and Short-term Treasury Rates

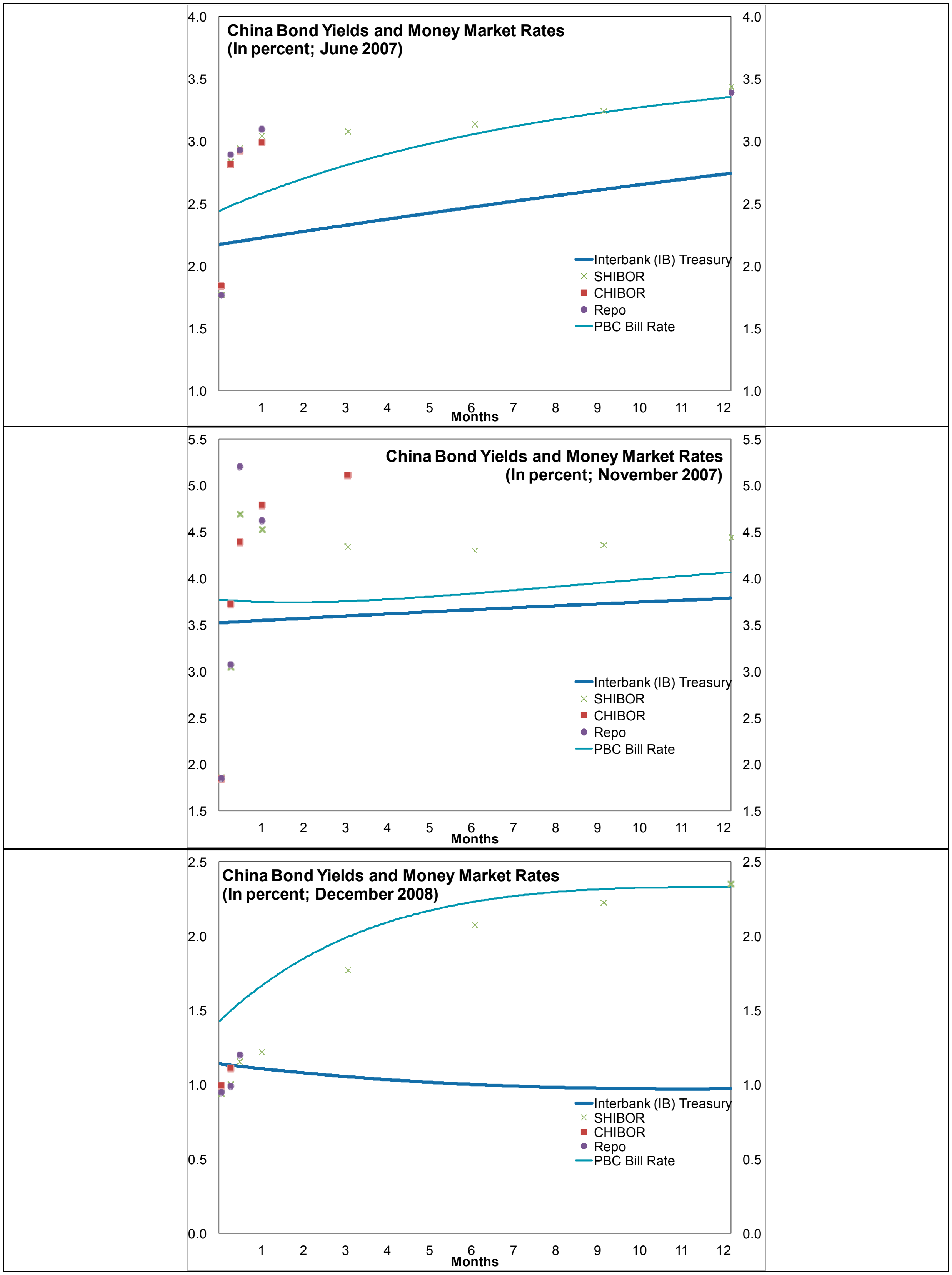


Figure 11. Yield Curve Factors: Estimated Level, Slope, and Curvature

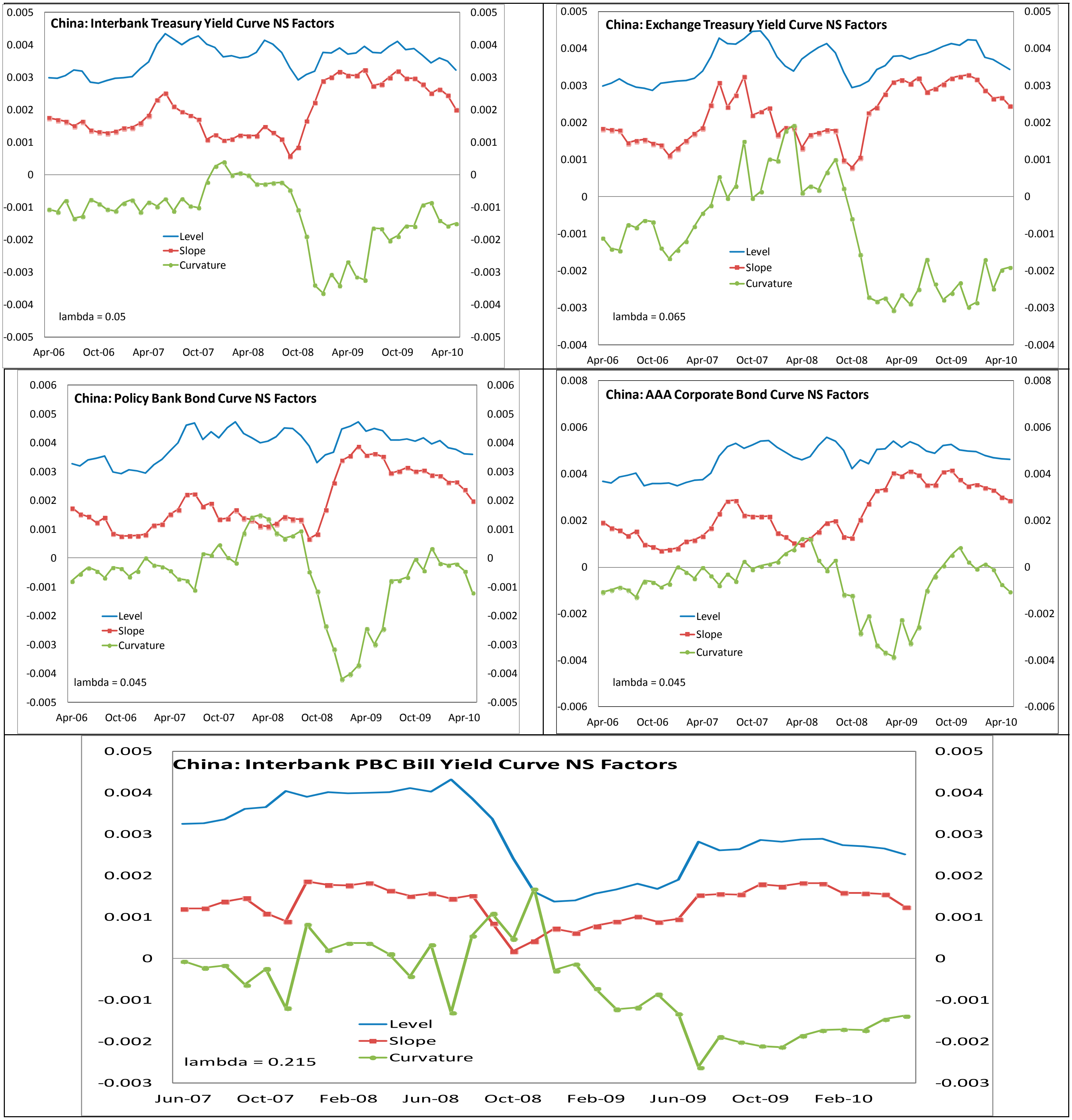
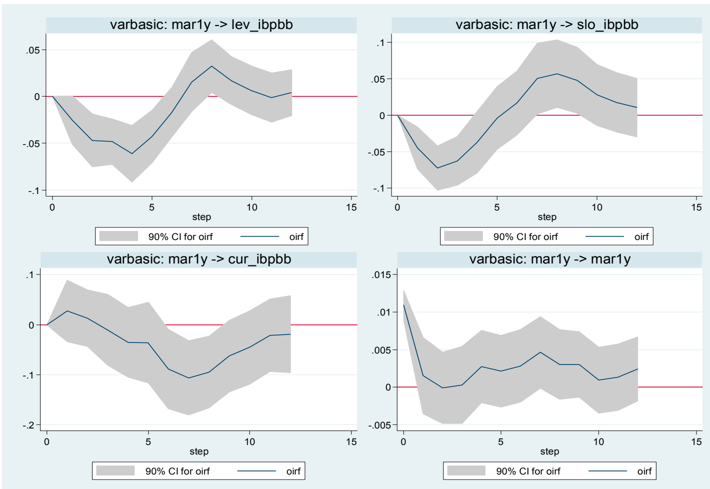


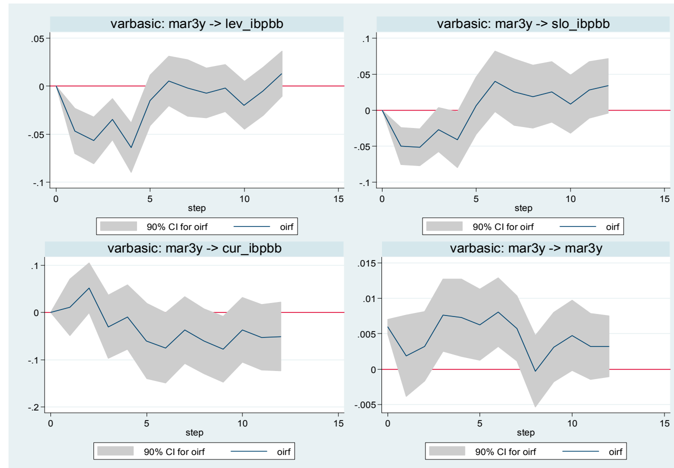
Figure 12. The Impact of Administered Benchmark Interest Rates on Bond Yields

LINKAGES FROM MARGINS TO FACTORS

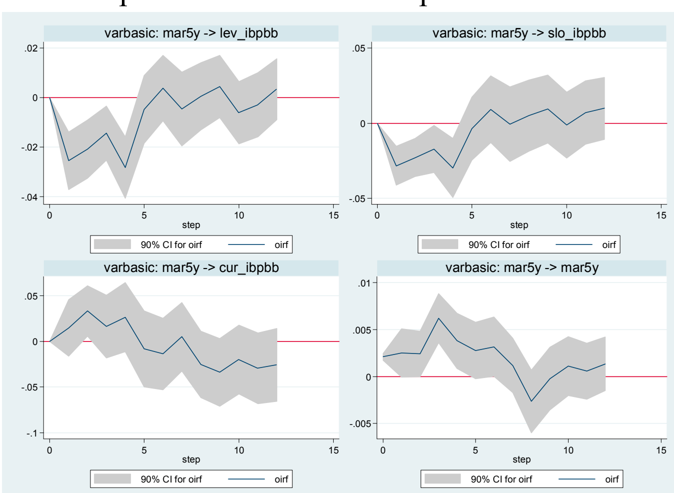
Responses of Factors to Impulse to MAR1Y



Responses of Factors to Impulse to MAR3Y

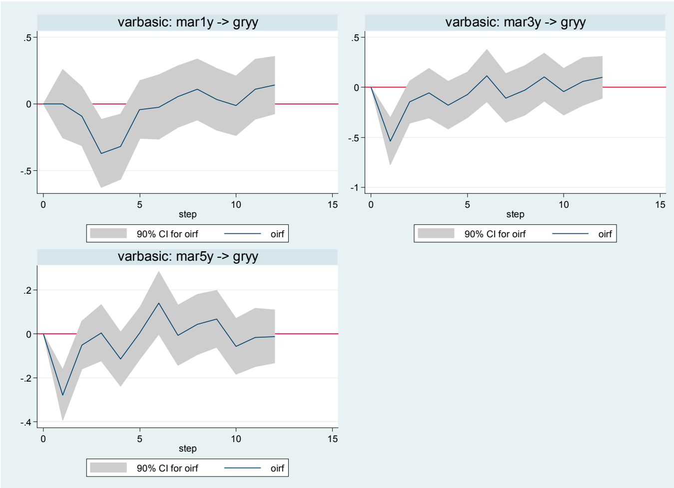


Responses of Factors to Impulse to MAR5Y



LINKAGES FROM MARGINS TO MACRO

Responses of growth to impulses to MAR1Y-3Y-5Y



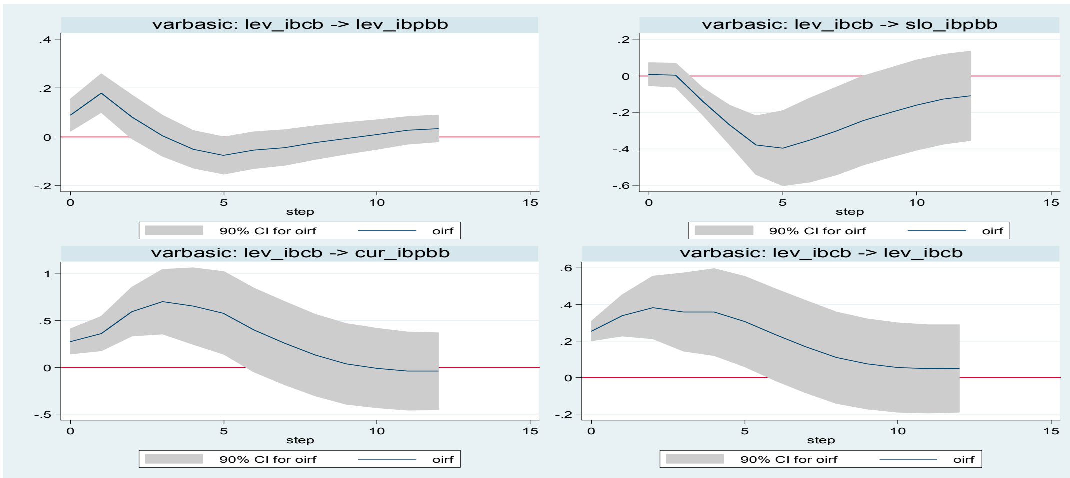
Response of inflation to impulses to MAR1Y-3Y-5Y

Notes: 1. Displayed for Policy Financial Bonds (IBPBB)

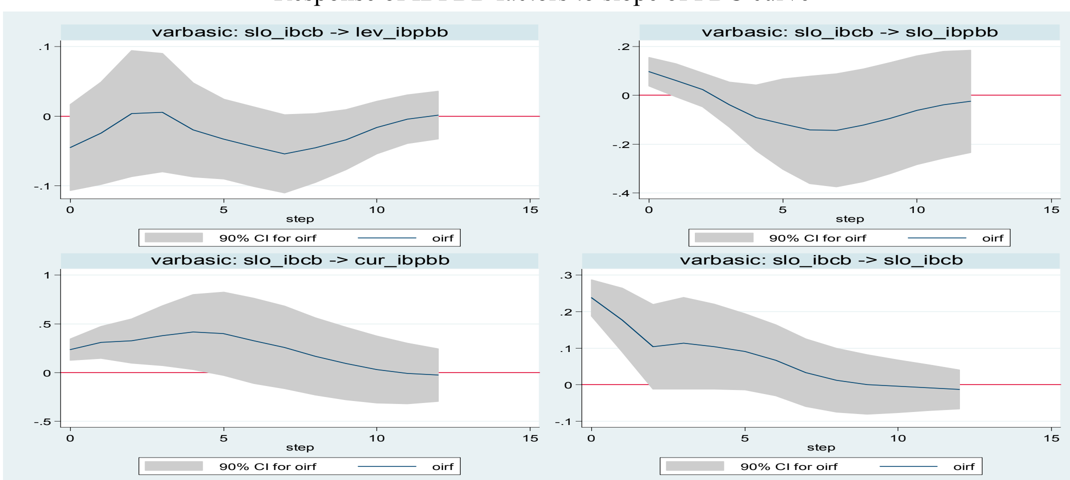
2. VAR with 4 lags and the following variables: 3 yield curve factors, monthly industrial value added growth (year-on-year), and CPI inflation (year-on-year), and regulated margins (benchmark lending – deposit rate) at 1, 3 and 5 years.

Figure 13. Interaction Between Policy Bank and PBC Yield Curves

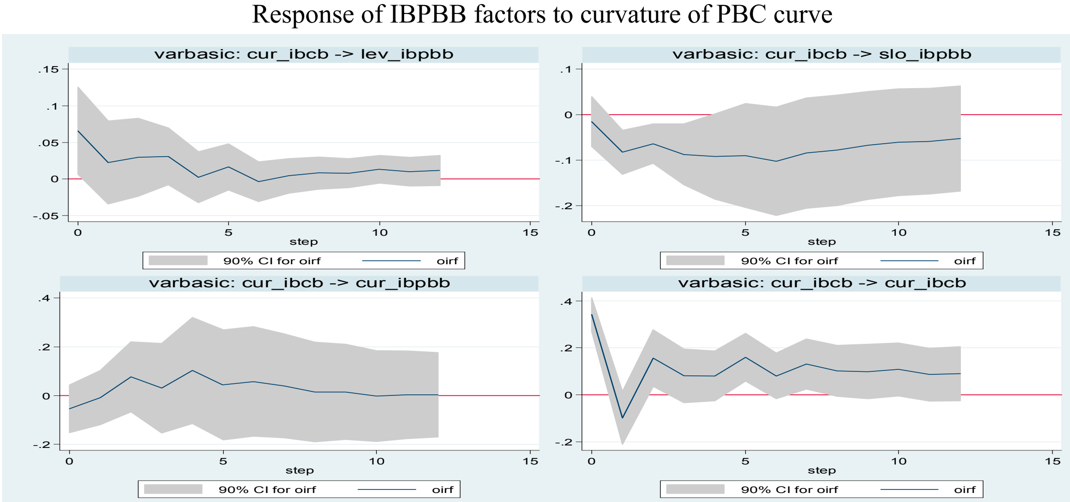
Response of IBPBB factors to level of PBC curve



Response of IBPBB factors to slope of PBC curve



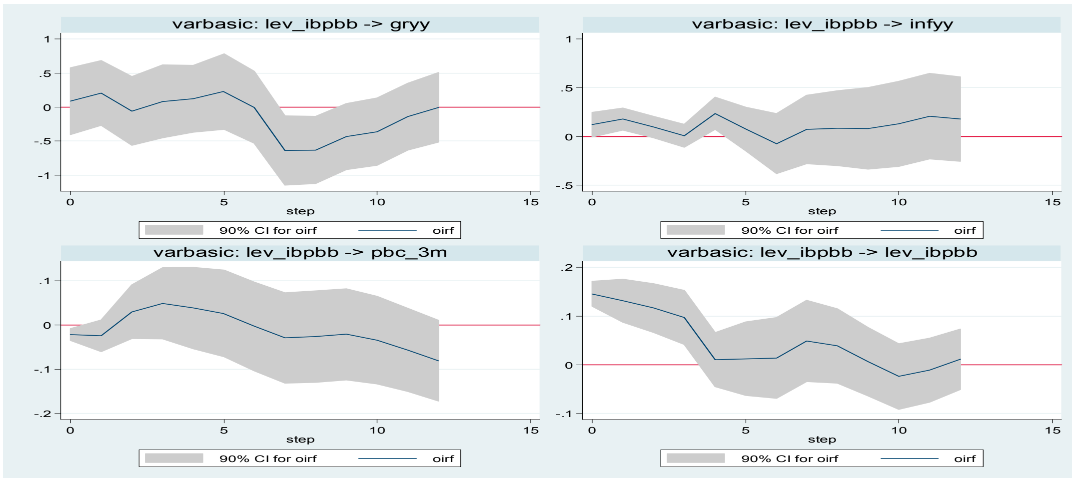
Response of IBPBB factors to curvature of PBC curve



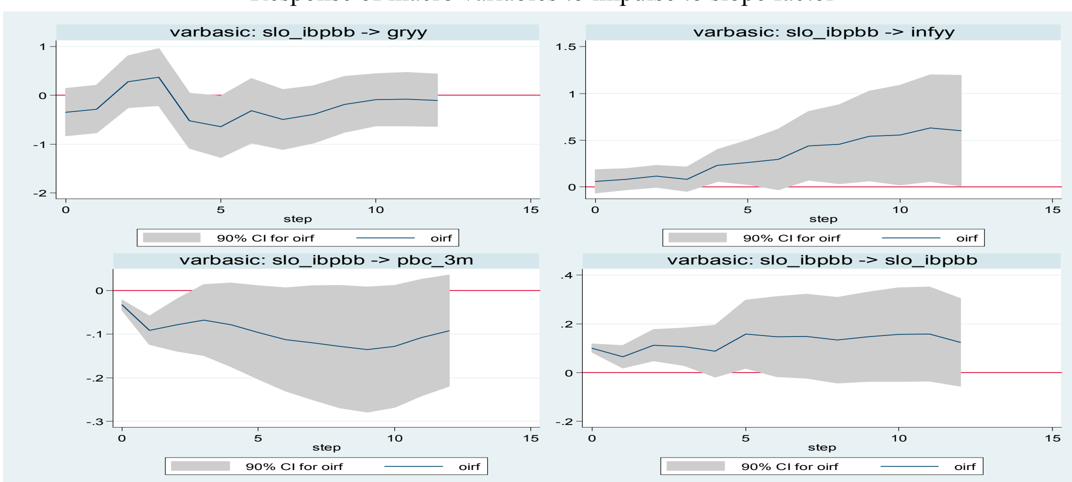
Note: VAR with two lags and six variables which are three IBCB factors and three IBPBB factors. The factors refer to the level, curvature and slope factors in the Nelson-Siegel model.

Figure 14. Yield Curve Factors and Macroeconomic Variables

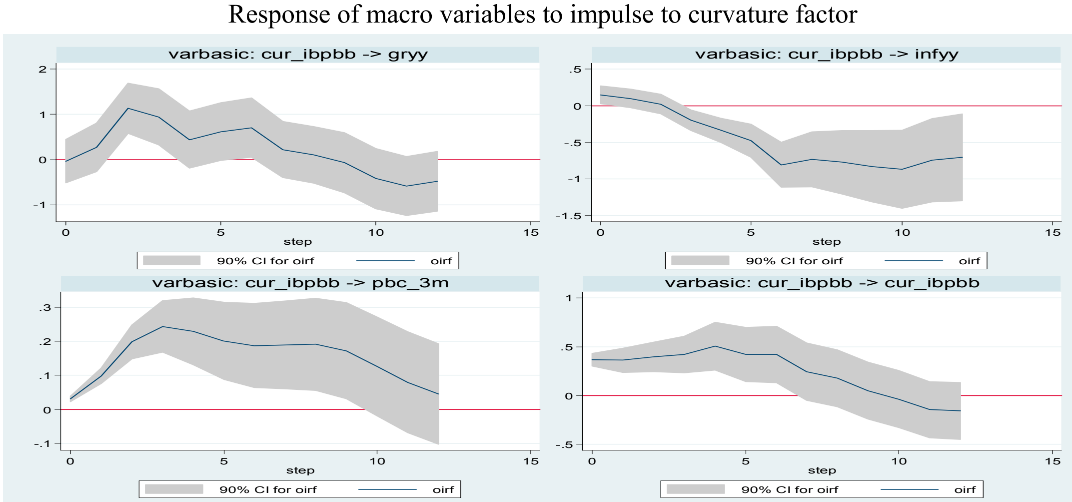
Response of macro variables to impulse to level factor



Response of macro variables to impulse to slope factor

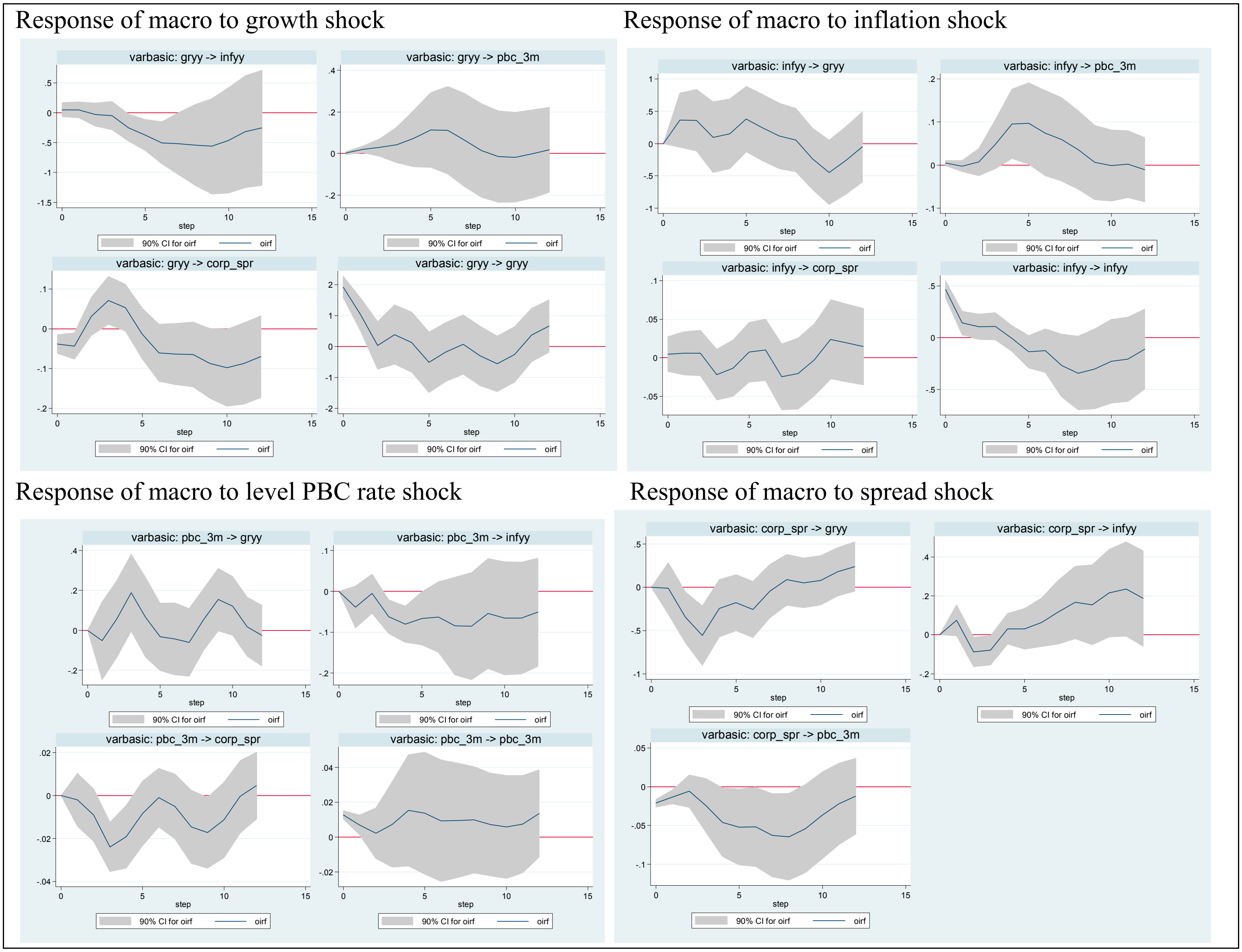


Response of macro variables to impulse to curvature factor



Note: VAR with two 2 lags and seven variables as follows: three factors of the IBPBB curve, 3-mth PBC bill rate, real growth of industrial value added, CPI inflation and corporate bond spreads.

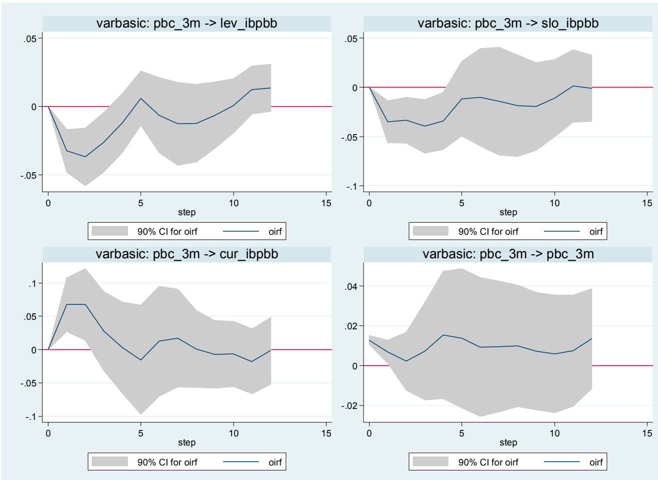
Figure 15. Growth, Inflation, Corporate Spreads and 3-month PBC Rate



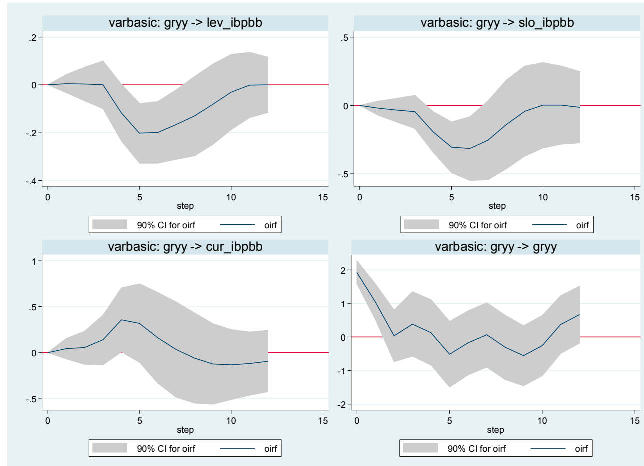
Note: VAR with two 2 lags and seven variables as follows: three factors of the IBPBB curve, 3-mth PBC bill rate, real growth of industrial value added, CPI inflation and corporate bond spreads.

Figure 16. Macroeconomic and Yield Curve Factors

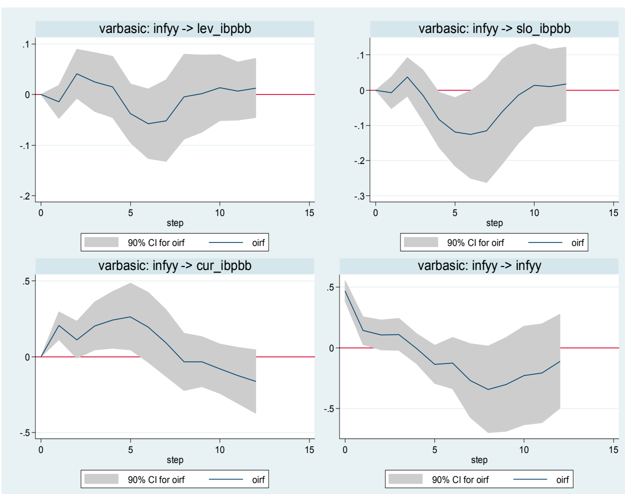
Response of factors to impulse to PBC 3mth rate



Response of factors to impulse to growth



Response of factors to impulse to inflation

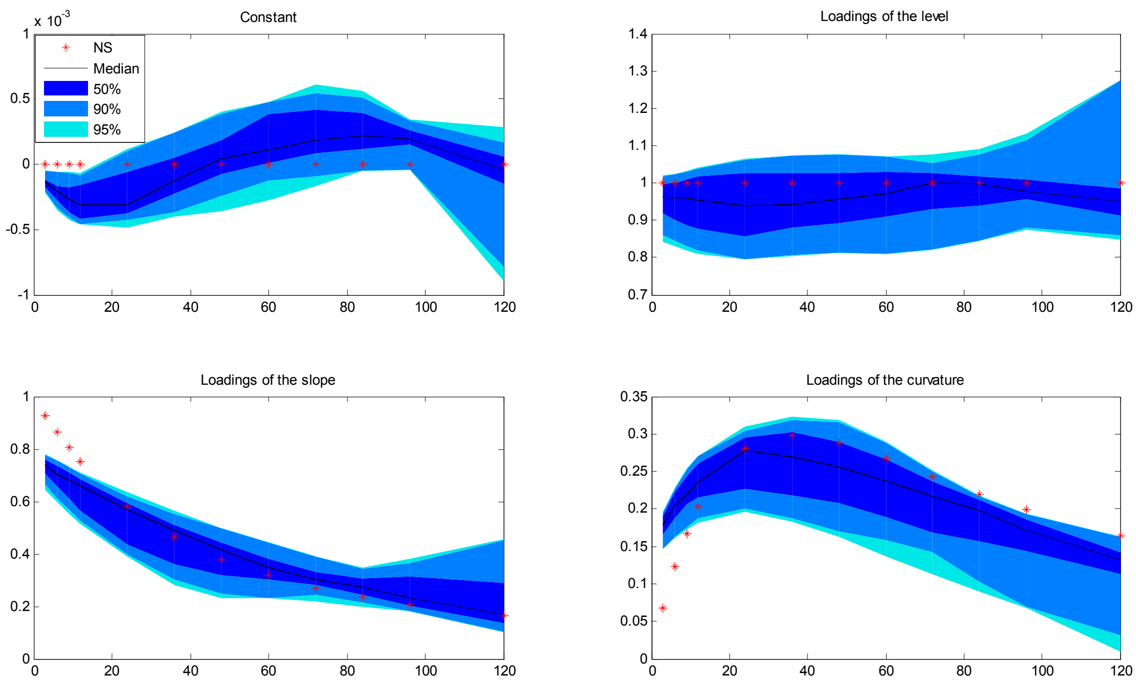


Response of factors to corporate spread shock

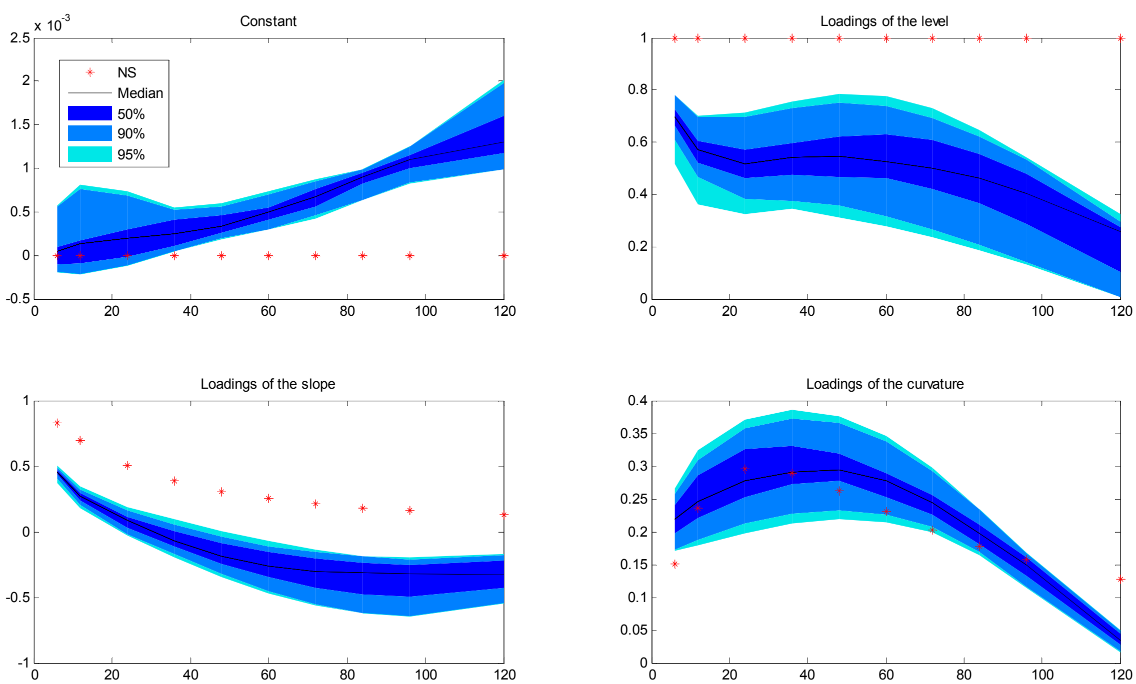
Note: VAR with two 2 lags and seven variables as follows: three factors of the IBPBB curve, 3-mth PBC bill rate, real growth of industrial value added, CPI inflation and corporate bond spreads.

Figure 17. No-Arbitrage Tests for Chinese Bond Yields

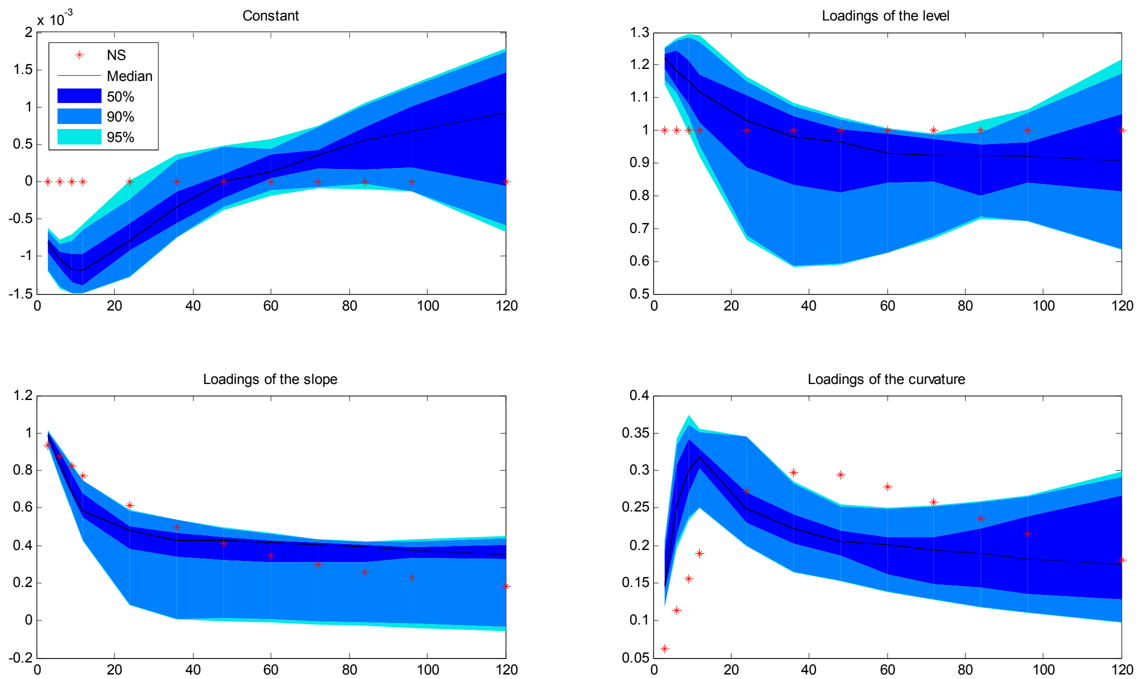
(a) Interbank Treasury Bond



(b) Exchange Treasury Bond



(c) Interbank Policy Bank Bond



(d) Central Bank Bill

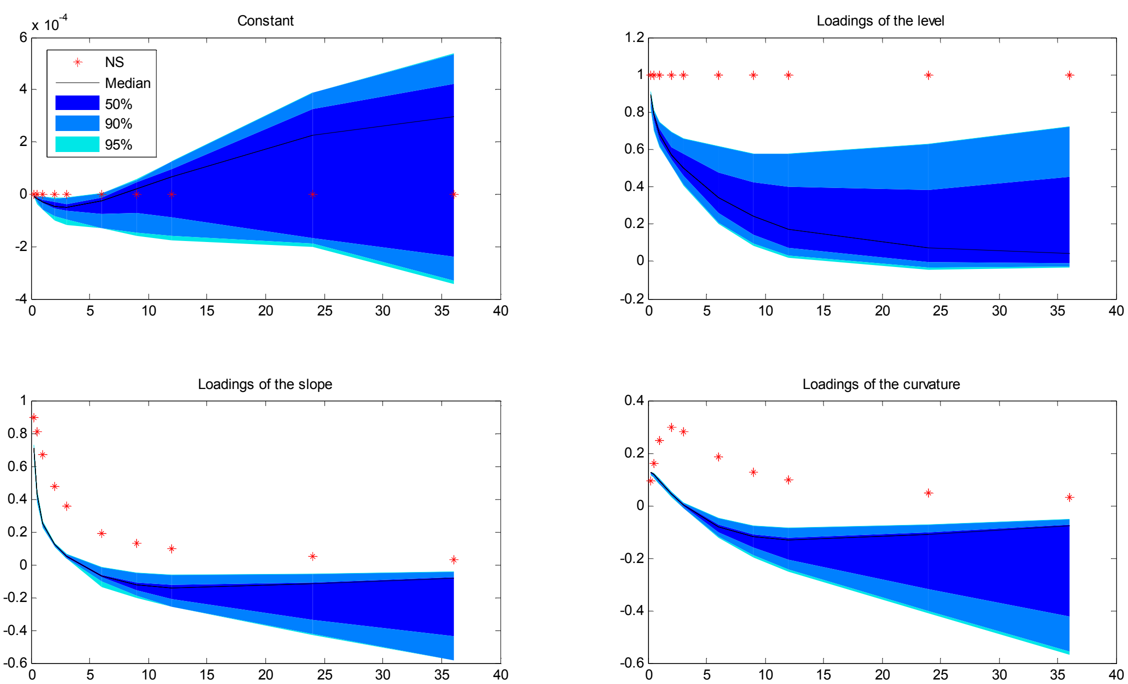
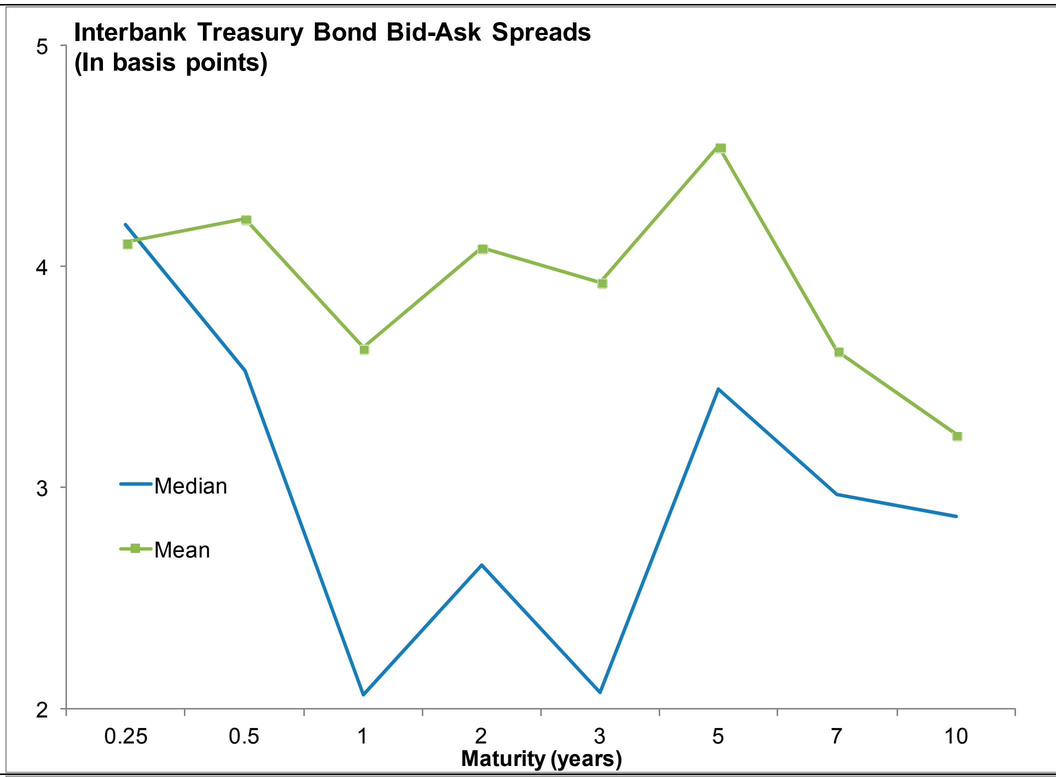
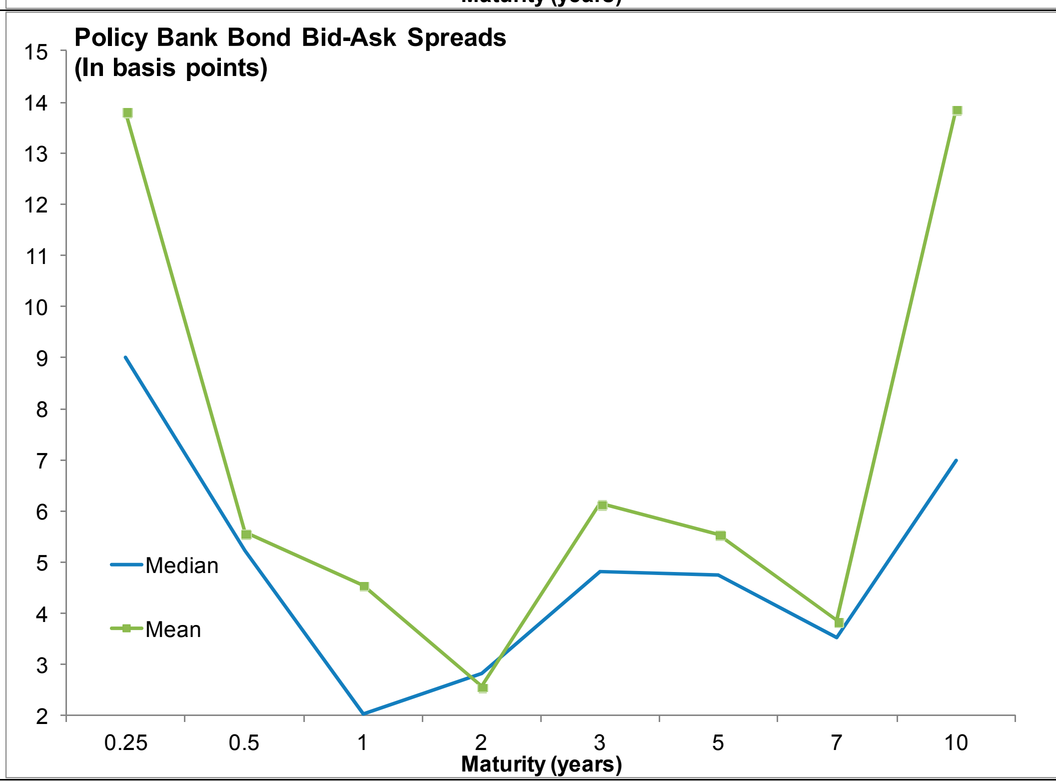


Figure 18. Interbank Bond Market Bid-Ask Spreads





Source: Bloomberg LP and authors' estimates.

TABLES

Table 1. Properties of the Yield Data

Maturity	Mean	Median	std	min	max	Autocorrelation Functon 1/ 1	3	6	12	24
Interbank Treasury										
3	2.0	1.9	0.8	0.8	3.6	**0.95**	**0.75**	**0.43**	-0.15	**-0.30**
6	2.1	2.0	0.8	0.9	3.6	**0.95**	**0.75**	**0.42**	-0.15	**-0.28**
9	2.2	2.0	0.9	0.9	3.7	**0.95**	**0.75**	**0.42**	-0.16	-0.28
12	2.2	2.1	0.9	1.0	3.8	**0.95**	**0.75**	**0.41**	-0.16	**-0.28**
24	2.5	2.3	0.9	1.2	4.1	**0.95**	**0.76**	**0.42**	-0.22	-0.26
36	2.8	2.5	0.8	1.3	4.1	**0.94**	**0.70**	**0.33**	-0.26	-0.20
48	3.0	2.8	0.7	1.6	4.2	**0.93**	**0.66**	0.28	**-0.29**	-0.14
60	3.1	2.9	0.7	1.8	4.3	**0.91**	**0.63**	**0.28**	**-0.29**	-0.13
72	3.3	3.1	0.6	2.0	4.4	**0.91**	**0.62**	0.27	**-0.32**	-0.11
84	3.4	3.2	0.6	2.2	4.5	**0.90**	**0.60**	0.26	**-0.32**	-0.10
96	3.5	3.3	0.6	2.4	4.5	**0.91**	**0.60**	0.25	**-0.32**	-0.09
120	3.7	3.6	0.6	2.9	4.6	**0.91**	**0.61**	0.24	**-0.32**	-0.06
Exchange Treasury										
6	2.0	2.0	0.7	0.9	3.3	**0.89**	**0.71**	**0.38**	-0.09	**-0.29**
12	2.3	2.2	0.8	1.1	3.7	**0.92**	**0.73**	**0.42**	-0.08	**-0.34**
24	2.7	2.5	0.8	1.4	4.1	**0.93**	**0.75**	**0.43**	-0.13	**-0.30**
36	3.0	2.6	0.8	1.7	4.4	**0.94**	**0.72**	**0.37**	-0.17	-0.26
48	3.2	3.0	0.7	2.0	4.6	**0.93**	**0.67**	**0.30**	-0.23	-0.19
60	3.4	3.2	0.7	2.3	4.7	**0.92**	**0.64**	0.28	**-0.30**	-0.14
72	3.5	3.4	0.7	2.5	4.8	**0.92**	**0.62**	0.26	**-0.32**	-0.11
84	3.7	3.5	0.6	2.7	5.0	**0.91**	**0.60**	0.24	**-0.33**	-0.08
96	3.8	3.6	0.6	2.8	5.0	**0.90**	**0.59**	0.21	**-0.34**	-0.05
120	3.9	3.8	0.6	3.0	5.0	**0.89**	**0.57**	0.17	**-0.35**	0.00
PBC Bills										
0.25	1.9	1.6	0.8	0.7	3.5	**0.90**	**0.65**	0.27	-0.03	-0.20
0.5	2.0	1.5	1.0	0.8	4.7	**0.83**	**0.63**	0.33	-0.09	-0.22
1	2.1	1.6	1.0	0.8	3.8	**0.92**	**0.73**	**0.42**	-0.10	-0.26
2	2.2	1.9	1.0	0.9	3.6	**0.95**	**0.78**	**0.45**	-0.11	-0.28
3	2.3	1.9	1.0	1.0	3.7	**0.95**	**0.78**	**0.46**	-0.11	-0.28
6	2.4	2.0	1.1	1.0	3.9	**0.95**	**0.76**	**0.43**	-0.14	-0.25
9	2.6	2.0	1.1	1.1	4.1	**0.95**	**0.76**	**0.41**	-0.16	-0.23
12	2.7	2.1	1.2	1.1	4.2	**0.96**	**0.76**	**0.40**	-0.19	-0.22
24	3.1	2.6	1.1	1.5	4.5	**0.95**	**0.74**	**0.34**	-0.23	-0.18
36	3.3	2.9	1.1	1.5	4.7	**0.95**	**0.73**	0.32	-0.25	-0.16
Interbank Policy Financial Bonds										
3	2.4	2.6	0.9	1.1	3.9	**0.95**	**0.77**	**0.46**	-0.10	**-0.32**
6	2.6	2.7	0.9	1.1	4.1	**0.95**	**0.76**	**0.44**	-0.11	**-0.29**
9	2.7	2.7	1.0	1.1	4.2	**0.95**	**0.76**	**0.42**	-0.13	-0.28
12	2.8	2.8	1.0	1.1	4.4	**0.95**	**0.76**	**0.40**	-0.16	-0.27
24	3.1	2.9	0.9	1.6	4.6	**0.95**	**0.74**	**0.35**	-0.23	-0.24
36	3.3	3.1	0.9	1.7	4.9	**0.95**	**0.71**	**0.30**	-0.27	-0.20
48	3.5	3.2	0.8	2.0	5.0	**0.94**	**0.68**	0.26	**-0.31**	-0.16
60	3.7	3.5	0.8	2.2	5.1	**0.93**	**0.66**	0.26	**-0.33**	-0.13
72	3.8	3.6	0.7	2.4	5.1	**0.92**	**0.64**	0.26	**-0.34**	-0.12
84	3.9	3.7	0.7	2.6	5.2	**0.91**	**0.61**	0.26	**-0.33**	-0.11
96	4.0	3.8	0.7	2.8	5.2	**0.91**	**0.61**	0.27	**-0.33**	-0.11
120	4.2	4.0	0.6	3.3	5.3	**0.91**	**0.60**	**0.28**	**-0.30**	-0.12
Interbank Corporate AAA										
6	3.0	3.0	0.9	1.7	4.6	**0.95**	**0.78**	**0.44**	-0.15	**-0.32**
12	3.3	3.2	1.0	1.8	5.0	**0.95**	**0.76**	**0.37**	-0.22	**-0.29**
24	3.7	3.4	0.9	2.4	5.3	**0.95**	**0.74**	**0.31**	**-0.29**	-0.26
36	4.0	3.7	0.9	2.7	5.5	**0.93**	**0.69**	0.23	**-0.33**	-0.18
48	4.2	3.9	0.8	3.1	5.7	**0.93**	**0.67**	0.23	**-0.35**	-0.13
60	4.4	4.2	0.8	3.2	5.8	**0.93**	**0.66**	0.23	**-0.35**	-0.08
72	4.5	4.3	0.8	3.4	6.0	**0.92**	**0.65**	0.24	**-0.35**	-0.05
84	4.7	4.4	0.8	3.5	6.1	**0.92**	**0.64**	0.27	**-0.34**	-0.05
96	4.8	4.6	0.7	3.6	6.1	**0.91**	**0.63**	**0.28**	**-0.31**	-0.06
120	4.9	4.9	0.7	3.7	6.2	**0.91**	**0.63**	**0.31**	-0.26	-0.08

1/ Bold entries indicate significance at 5 percent using asymtotic standard errors.

Table 2. Properties of the Estimated Errors

Maturity	Mean	Median	std	min	max	rmse	Autocorrelation Functon 1/				
							1	3	6	12	24
Interbank Treasury											
3	-0.03	-0.02	0.05	-0.14	0.10	0.06	**0.50**	0.05	-0.21	-0.02	-0.04
6	0.00	0.00	0.03	-0.05	0.08	0.03	**0.31**	-0.10	0.25	-0.02	-0.09
9	0.01	0.01	0.03	-0.05	0.08	0.03	**0.43**	-0.03	-0.21	-0.07	0.01
12	0.02	0.01	0.05	-0.09	0.16	0.06	**0.56**	0.18	-0.08	-0.12	-0.07
24	0.00	0.02	0.08	-0.23	0.14	0.08	**0.80**	**0.65**	**0.29**	-0.13	-0.21
36	0.00	0.01	0.04	-0.14	0.06	0.04	**0.31**	0.24	-0.03	-0.05	-0.15
48	0.00	-0.01	0.06	-0.12	0.12	0.06	**0.78**	**0.56**	0.09	-0.20	-0.22
60	-0.01	-0.02	0.06	-0.20	0.13	0.06	**0.55**	**0.37**	0.15	-0.14	-0.13
72	-0.02	-0.02	0.04	-0.10	0.08	0.04	**0.28**	0.25	0.23	0.07	-0.23
84	-0.01	-0.01	0.03	-0.08	0.06	0.03	**0.28**	0.04	0.00	0.05	-0.14
96	0.00	0.00	0.03	-0.08	0.07	0.03	0.15	0.08	-0.10	0.15	-0.05
120	0.03	0.04	0.07	-0.13	0.17	0.07	**0.62**	**0.33**	0.12	-0.09	-0.17
Exchange Treasury											
6	-0.01	-0.01	0.05	-0.23	0.08	0.05	0.16	0.02	0.13	-0.14	0.12
12	0.02	0.01	0.06	-0.12	0.31	0.06	0.10	0.00	0.10	-0.09	0.05
24	0.02	0.02	0.09	-0.19	0.24	0.09	**0.51**	**0.30**	-0.02	-0.17	-0.01
36	-0.01	0.00	0.04	-0.13	0.09	0.05	**0.42**	0.19	0.06	-0.09	0.06
48	-0.01	-0.02	0.07	-0.28	0.12	0.07	**0.35**	0.19	-0.12	-0.08	-0.06
60	-0.01	-0.03	0.08	-0.22	0.27	0.08	**0.60**	0.15	0.13	-0.09	0.05
72	0.00	-0.01	0.06	-0.20	0.13	0.06	**0.61**	0.12	0.14	-0.10	0.06
84	0.00	0.00	0.03	-0.11	0.08	0.03	0.20	-0.25	0.00	0.07	-0.04
96	0.01	0.01	0.04	-0.08	0.11	0.04	**0.35**	0.15	-0.07	0.12	0.04
120	0.01	0.00	0.07	-0.16	0.26	0.07	**0.52**	-0.01	0.20	-0.25	0.08
PBC Bills											
0.25	-0.10	-0.07	0.15	-0.80	0.18	0.18	**0.34**	0.27	0.09	0.06	-0.11
0.5	0.01	-0.01	0.17	-0.19	0.92	0.17	-0.01	0.02	0.00	-0.20	-0.02
1	0.03	0.02	0.08	-0.22	0.24	0.09	0.29	-0.03	-0.12	0.26	-0.03
2	0.06	0.05	0.09	-0.15	0.32	0.11	0.17	0.09	-0.09	-0.12	-0.09
3	0.04	0.05	0.07	-0.10	0.25	0.08	0.33	0.04	-0.14	-0.11	-0.15
6	0.00	0.00	0.05	-0.13	0.14	0.05	**0.60**	0.17	0.16	0.02	-0.23
9	-0.03	-0.03	0.05	-0.15	0.07	0.06	**0.41**	0.06	-0.16	0.06	-0.19
12	-0.04	-0.04	0.05	-0.17	0.04	0.07	**0.42**	0.29	0.03	**-0.35**	0.02
24	-0.01	-0.02	0.03	-0.07	0.08	0.04	**0.51**	0.32	0.16	-0.02	-0.11
36	0.04	0.04	0.04	-0.04	0.13	0.05	0.21	0.26	0.09	-0.04	-0.17
Interbank Policy Financial Bonds											
3	-0.04	-0.04	0.06	-0.17	0.11	0.07	**0.59**	0.24	0.19	-0.09	0.13
6	-0.01	-0.01	0.03	-0.09	0.09	0.03	**0.59**	0.18	0.03	-0.06	0.10
9	0.02	0.02	0.04	-0.08	0.11	0.05	**0.53**	0.16	0.17	-0.10	0.14
12	0.05	0.05	0.06	-0.11	0.16	0.07	**0.55**	**0.30**	0.18	-0.04	-0.14
24	0.02	0.01	0.04	-0.08	0.14	0.05	0.14	0.14	-0.22	-0.14	-0.05
36	-0.02	-0.02	0.04	-0.19	0.03	0.05	**0.35**	0.15	-0.05	-0.12	-0.10
48	-0.01	-0.03	0.05	-0.11	0.12	0.05	**0.44**	0.06	0.14	0.02	-0.07
60	-0.01	-0.02	0.05	-0.13	0.14	0.05	**0.54**	0.16	0.02	-0.12	-0.04
72	-0.01	-0.02	0.04	-0.10	0.11	0.04	0.21	**0.36**	0.03	-0.18	0.06
84	-0.01	-0.01	0.03	-0.09	0.05	0.03	0.08	0.03	**0.30**	-0.15	-0.13
96	0.00	0.00	0.02	-0.05	0.04	0.02	0.11	**-0.29**	0.01	-0.02	-0.09
120	0.03	0.04	0.06	-0.11	0.18	0.07	0.26	**0.36**	0.23	-0.22	-0.07
Interbank Corporate AAA											
6	0.0	0.0	0.1	-0.1	0.1	0.1	**0.63**	**0.43**	0.09	-0.26	-0.04
12	0.0	0.0	0.1	-0.1	0.2	0.1	**0.57**	**0.44**	0.16	-0.11	-0.10
24	0.0	0.0	0.1	-0.2	0.1	0.1	**0.57**	0.26	-0.26	-0.18	0.22
36	0.0	0.0	0.0	-0.1	0.1	0.0	0.27	0.09	**-0.30**	-0.01	-0.07
48	0.0	0.0	0.0	-0.1	0.1	0.0	**0.32**	0.04	-0.12	-0.09	0.02
60	0.0	0.0	0.1	-0.1	0.2	0.1	**0.49**	0.18	-0.12	-0.25	-0.01
72	0.0	0.0	0.0	-0.1	0.2	0.0	**0.52**	0.24	-0.16	-0.25	0.00
84	0.0	0.0	0.0	-0.1	0.1	0.0	0.27	0.09	-0.07	-0.17	-0.03
96	0.0	0.0	0.0	0.0	0.1	0.0	0.21	-0.07	0.08	-0.17	-0.03
120	0.0	0.0	0.1	-0.2	0.1	0.1	**0.57**	**0.31**	-0.17	-0.26	0.04

1/ Bold entries indicate significance at 5 percent using asymtotic standard errors.

Table 3. Properties of the Estimated Factors

						Autocorrelation Functon 1/				
Maturity	Mean	Median	std	min	max	1	3	6	12	24
Interbank Treasury										
Level (Factor 1)	4.3	4.4	0.5	3.4	5.2	**0.84**	**0.43**	0.09	**-0.33**	0.17
Slope (Factor 2)	-2.4	-2.1	0.9	-3.9	-0.7	**0.93**	**0.68**	**0.33**	-0.14	-0.07
Curvature (Factor 3)	-1.5	-1.3	1.2	-4.4	0.5	**0.88**	**0.64**	0.26	**-0.31**	-0.10
Exchange Treasury										
Level (Factor 1)	4.4	4.5	0.6	3.4	5.4	**0.88**	**0.46**	0.11	**-0.42**	0.22
Slope (Factor 2)	-2.6	-2.7	0.9	-3.9	-0.9	**0.86**	**0.62**	0.21	**-0.30**	0.16
Curvature (Factor 3)	-1.2	-1.4	1.7	-3.7	2.3	**0.89**	**0.73**	**0.50**	-0.07	**-0.29**
PBC Bills										
Level (Factor 1)	3.5	3.4	1.1	1.7	5.2	**0.93**	**0.67**	0.19	-0.31	-0.08
Slope (Factor 2)	-1.6	-1.8	0.5	-2.2	-0.2	**0.78**	**0.45**	-0.06	**-0.41**	0.09
Curvature (Factor 3)	-0.8	-0.8	1.3	-3.1	2.0	**0.70**	**0.58**	**0.36**	-0.21	-0.20
Interbank Policy Financial Bonds										
Level (Factor 1)	4.7	4.9	0.6	3.5	5.7	**0.85**	**0.46**	0.24	-0.19	-0.05
Slope (Factor 2)	-2.3	-2.0	1.1	-4.7	-0.8	**0.93**	**0.70**	**0.36**	-0.04	-0.11
Curvature (Factor 3)	-0.7	-0.5	1.6	-5.0	1.8	**0.89**	**0.59**	0.01	**-0.38**	-0.03
Interbank Corporate AAA										
Level (Factor 1)	5.6	5.7	0.8	4.2	6.7	**0.88**	**0.59**	**0.39**	-0.06	-0.11
Slope (Factor 2)	-2.7	-2.6	1.3	-5.0	-0.9	**0.94**	**0.75**	**0.45**	-0.03	-0.11
Curvature (Factor 3)	-0.8	-0.6	1.4	-4.6	1.5	**0.86**	**0.60**	-0.05	**-0.44**	-0.04

1/ Bold entries indicate significance at 5 percent using asymtotic standard errors.

Table 4. Estimated lambda by type of curve

Bond	Estimated Lambda	Maturity of maximum curvature (months)	Estimation Sample	Number of Maturities	Minimum Maturity	Maximum Maturity
Interbank Treasury	0.050	36	Apr-06 - May-10	12	3	120
Exchange Treasury	0.065	28	Apr-06 - May-10	10	6	120
Interbank PBC	0.215	8	Jun-07 - May-10	10	0.25	36
Interbank Policy Bank	0.045	40	Apr-06 - May-10	12	3	120
Interbank Corporate (AAA)	0.045	40	Apr-06 - May-10	10	6	120

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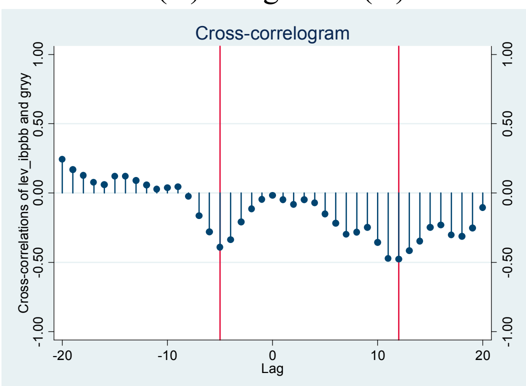
APPENDIX: CROSS-CORRELOGRAMS OF IBPBB FACTORS AND MACRO VARIABLES

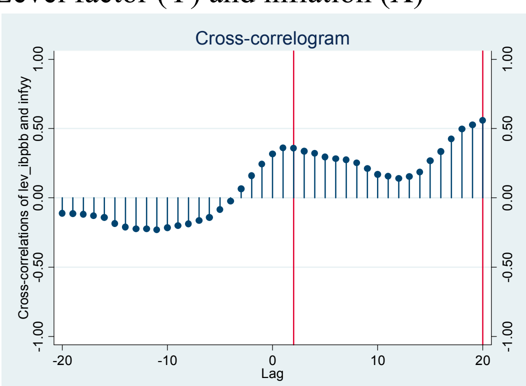
Cross-correlation between Factor Y(t) and Macro variable X(t+k)
Vertical bars show highest and second highest correlations in absolute value

Level factor (Y) and growth (X)



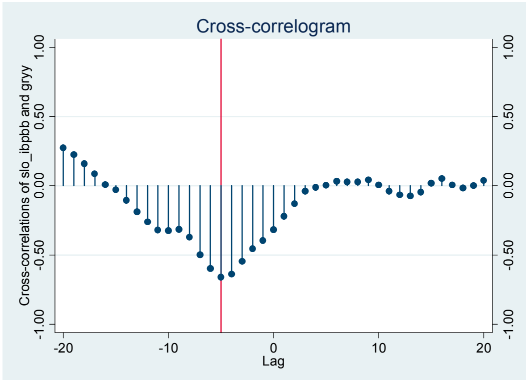
Note: cross-correlation is highest (in abs. value) at around +12 months suggesting that growth lags the level factor by around one year; there is also some evidence of growth leading the level factor by about half-year (-5). Correlation is mainly negative meaning higher factor level indicating slowdown in growth rate.

Level factor (Y) and inflation (X)



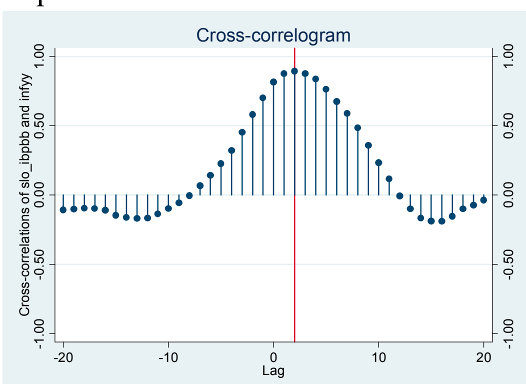
Note: cross-correlation is highest at around +20 months suggesting that inflation lags the level factor by around two years; there is also some evidence of inflation lagging the level factor by about one- two-months (+2). Correlation is positive meaning higher factor level indicating acceleration in inflation rate.

Slope factor and growth



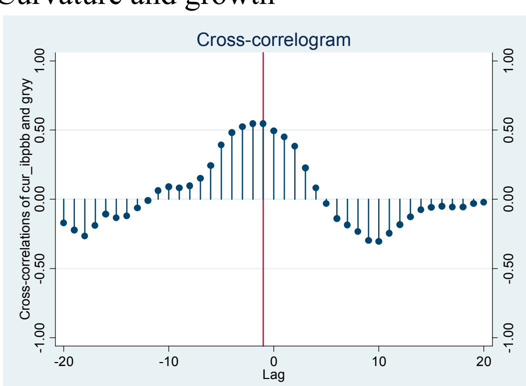
Note: cross-correlation is highest (in abs. value) at around -5 months suggesting that growth leads the slope factor by around five months. Correlation is negative meaning that higher growth leads a flattening of the yield curve.

Slope factor and inflation



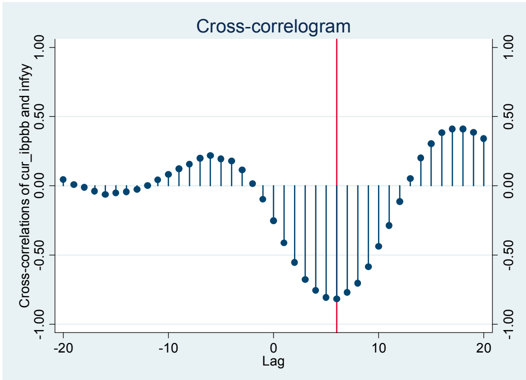
Note: cross-correlation is highest at around +2 months suggesting that inflation slightly lags the slope factor by around two months. Correlation is positive meaning that higher inflation lags a steepening of the yield curve.

Curvature and growth



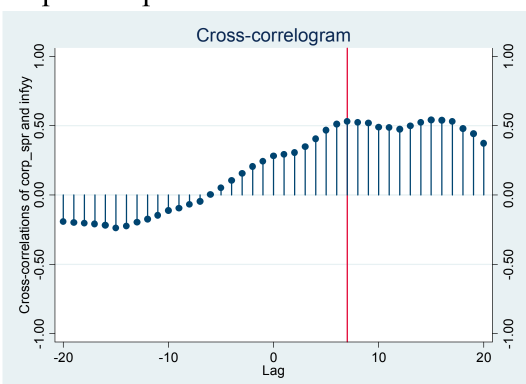
Note: cross-correlation is highest at around -1/-2 months suggesting that growth leads the curvature factor by around two months. At these lags cross-correlation is positive meaning that higher inflation (slightly) lags a steepening of the yield curve.

Curvature and inflation



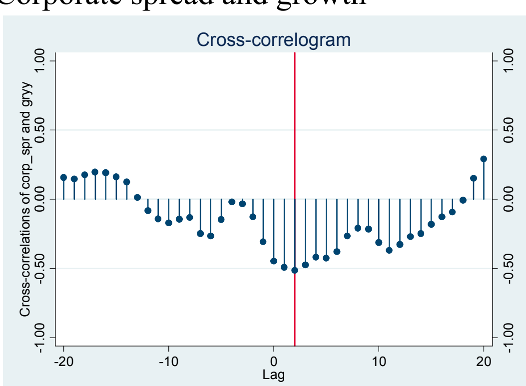
Note: cross-correlation is highest (in abs. value) at around 6 months suggesting that inflation lags the curvature factor by around half year. Correlation is negative meaning that lower inflation lags an increase in curvature.

Corporate spread and inflation



Note: cross-correlation peaks at around 7 months suggesting that inflation lags the corporate spread factor by around half year. Correlation is positive meaning that higher inflation lags an increase in spreads.

Corporate spread and growth



Note: cross-correlation peaks (in absolute value) at around 2 months suggesting that growth lags the corporate spread factor by around 2 months. Correlation is negative meaning that higher growth lags an increase in spreads.