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Price Discovery in China's Corporate and Treasury Yield Curves

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Abstract

As financial development progresses, the maturity structure of bond yields plays a rising role not only in the financial system but also as a key transmission channel of monetary policy. China is likely to be no exception. However, specific characteristics in China's bond markets raise two major questions. First do China's Treasury bonds offer the benchmark term structure of yields, or is this role fulfilled by the young but fast expanding corporate bond market? In other words, where does price discovery take place in the Chinese bond market in terms of the different components of the yield curve?

We identify both dynamic and long-run relationships between each of the level, slope and curvature factors of the Treasury and corporate bond markets yield curve in China. We aim at determining which market plays a leading role in the discovery of each factor of the yield curve.

We obtain three main results. First, we document for the first time the presence of a long-run relationship between the corporate and Treasury bond markets in China both for the level and the slope of their yield curve. Second, such a long-run relationship appears to be stable between the slopes over the full sample 2006-2017, but shows a break for the level factor in 2012. Third, the source market for price discovery varies with the parameters of the yield curve. While the corporate bond market is the source of price discovery for the level factor, this function is fulfilled by the government bond market for the slope parameter.

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The finding that the Treasury bond market is not fully dominant in level bond-pricing may not come as a surprise. Although China's corporate bond market has developed rapidly in the past fifteen years, there were few default cases during that period. It is believed investors treat the default risk of corporate bonds as similar to that of Treasury bonds, and benefit from the high corporate spread. Our results for the slope parameter imply that market-oriented reform has progressed enough for the Treasury bond market to already provide a benchmark slope for the yield curve of corporate bonds. When the reform progresses further, we would expect corporate bonds to be priced according to their risk profile which should make the Treasury market lead in price discovery also for the level of the yield curve.

1. **Introduction**

In spite of its rapid growth since the establishment of the interbank market in the mid-1990s, China's bond market is still in the early stage of development relative to the size of its economy. As the People's Bank of China (PBoC) is gradually moving away from regulated interest rates towards more sophisticated tools of liquidity management and lending facilities, one would expect banks to increasingly rely on the sovereign bond yield curve to set medium to long-term loan rates. However, it is not clear that this is the case in China. The more recent, but fast developing corporate bond market may have started to play a non-negligible, possibly leading role, not simply responding to movements in the Treasury bond market. The sharp expansion of the corporate bond market since the Global Financial Crisis (GFC) in China is a feature shared with many emerging economies where firms have increasingly searched for non-bank and non-equity sources of external funding (Ayala et al. 2017).

The corporate and Treasury yield curves have been evolving at a rapid pace over the last decade-and-a-half in China. While recent empirical research has examined the Chinese Treasury bond market yield curve, there has been hardly any focus on the corporate yield curve, and no research on its interaction with the Treasury yield curve. An open issue is thus whether the usual characterization of the yield curve, by its latent level, slope and curvature factors, already accounts in a satisfactory way for both the corporate and the Treasury bond yield movements in China and to what extent these factors of the yield curves interact. It is then important to determine which market plays a leading role in the incorporation into market prices of the information implicit in investor trading (Lehman, 2002), in other words where price discovery takes place.

This research has two objectives. We will aim at extracting the usual three common factors of the yield curve (Litterman and Scheinkman, 1991), using the Nelson-Siegel (1987) approach, for both the sovereign and the corporate bond market in China, with daily data over an eleven-year sample[2] up to 2017. We will also examine the matching of such factors with their empirical counterparts, i.e. the average yield across maturities for the level, the spread between long and short maturity yields for the slope of the yield curve, and the weighted short-medium-and-long-run yields for the curvature, which reflects expectations on changes of interest rates in the long run compared to the medium run. In a second step we will identify changes in the dynamic and long-run relationships between these parameters across the two bond markets so as to determine whether the source-market of adjustment (price discovery) has always been the government bond market for all three parameters, or whether the corporate bond market has been able to play that role for at least one of them.

[2] For the pre-2006 period, see Chen, H and V Yeung (2006).

The development of the Chinese bond market took place over the two decades after the establishment of the interbank bond market in 1997. This bond market has thus emerged very rapidly, becoming the third largest in the world in absolute terms, leading it to be recently included in global emerging bond indices. This rapid development has been notably motivated by financing needs, with the aim to reduce the economy's over-reliance on the banking system for credit, mitigate financial risk as well as enhance market efficiency, and find the additional financing the central government needs to fund infrastructure construction and priority investment projects.

China is undergoing a fast transition in its financial system and putting in place a more market-oriented system. In this process bond markets will increasingly play two major roles. First, they should provide information about the macroeconomic situation and help policy makers to gauge market expectations as well as some of the transmission of their monetary policy impulses. Second, bond markets should reflect liquidity conditions and represent a benchmark for the pricing of financial assets, playing thus an important role in the allocation of resources and risk diversification. Ongoing financial liberalization and financial market development indeed imply that the state of China's financial markets in general, and bond markets in particular today differs sharply from what they were a decade and a half ago. A typical example is the corporate segment where bonds outstanding rose twice by a factor of ten, between 2004 and 2008, and from 2008 to 2015, to reach 80% of government bonds outstanding. It is thus expected that the nature and magnitude of benchmarking exerted by either the Treasury or the corporate bond market in determining the characteristics of yield curves would have experienced structural changes.

The term structure of interest rates, or the yield curve, provides the link between the maturity of a bond and its rate. It is customary in the term-structure literature to decompose, at each moment, yields on bonds with different maturities into a few common factors (Vasicek, 1977; Cox et al, 1985). To understand how the yield curve moves from one moment to the next, one needs to track changes in such factors over time. The level informs us on the average yield, the slope corresponds to the spread between long and short maturity yields, and the curvature indicates whether the rate of change of interest rates is expected to diminish or increase in the long run compared to the medium run.

Existing work on interactions between markets has generally only considered to what extent one market acts as a benchmark or target for the price (or yield) in another market (e.g. Sun, Dunne and Li, 2015). Research has tried to determine in which market price discovery occurs. Price is discovered in the market which does not adjust to movements in the other market (Gonzalo et al. 1995; Baillie et al, 2002; applied by Booth et al. 1999; Chu et al., 1999; and Harris et al, 2002), The current price (or yield) on the responding market is adjusted when it deviated during the previous period from its long-run relationship with the price (or yield) in the benchmark market. If both markets react to each other, then price (yield) discovery is shared between them in proportion to the relative magnitude of this response. We propose to apply this detection of price discovery in turn to each of the three factors of the yield curve: level, slope and curvature (Litterman and Scheinkman, 1991). We thus allow one market to contribute to price discovery for one factor of the yield curve and the other market to do it for another factor. To do that we first have to detect long run relationships between each parameter across markets, and also to assess the stability (or breaks) which characterise this relationship.

We obtain three main results. First, we document for the first time that there exists a long-run relationship between two parameters of the yield curve across the corporate and Treasury bond markets in China. Second, such a relationship is stable for the slope over the full sample 2006-2017 but shows a break for the level in 2012. Third, the market which adjusts to the other varies with the factors of the yield curve. While the corporate bond market is the source of price discovery for the level of the yield curve, this function is fulfilled by the Treasury bond market for the slope parameter.

We contribute to the literature on corporate and Treasury bond markets in China by focusing on the entire yield curves rather than selected yield maturities. Therefore, we estimate empirically the two yield curves in China through a well-known parametric model, powerful for summarizing the term structure into three easily interpretable latent factors at each date. We document both the short-run and long-run interactions between the Treasury and the corporate bond market yield curve parameters, paying particular attention to structural breaks in such relationships and the market responsible for yield-curve parameter discovery.

Our work differs from existing research on the yield curve in China from four viewpoints. First, while previous work, using the Diebold and Li (2006) dynamic Nelson-Siegel model for China, focused on low frequency (i.e. monthly) data (Cassola and Porter, 2011, Yan and Guo, 2015) or on short samples with high frequency (i.e. daily) data (Luo et al. 2012; Löchel et al, 2016), we identify the parameters of China's yield curve both for a long sample (11 years from 2006) and high-frequency (daily) data. Second, while Cassola and Porter (2011) looked at alternative segments only of the Treasury bond market (interbank, exchange traded, and short-run with PBoC bills), we examine both Treasury and corporate bond markets in China. This echoes for China the importance granted to the corporate bond market by recent work on the United States (Krolzig, et al. 2015). Third, while previous work on China focused either on Treasury yield-curve forecasting (Luo et al. 2012), or on the macroeconomic determinants of the parameters of the Treasury yield curve (Cassola and Porter, 2011; Yan and Guo, 2015), we study the short- and long-run interactions between the parameters of the Treasury and corporate yield curves themselves, generalizing the approach of Duffee (1998). An important benefit of this generalization is that it enables us to determine which among the corporate and government bond markets contributes to price discovery (à la Gonzalo-Granger, 1995) for each parameter of the yield curve. Fourth, we propose for the first time in the case of China a structural-break analysis to such yield-curve factor modelling. Our work is thus close in inspiration to Pavlova et al (2015) in the case of the US, except that they have a richer dataset with different ratings of corporate bonds and other financial variables unavailable in the Chinese financial system (see also Davies, 2004; and Chun et al. 2014a and b). Besides, Fan et al (2012) focus on the macroeconomic determinants of government bond's excess returns, while we model the dynamic and long-run relationships between the parameters (themselves) of the term structure of both corporate and government bonds in China. In addition, they consider low frequency data from 1997Q1 to 2009Q4, while we focus on daily data from March 2006 to May 2017.

The rest of the paper is organised as follows. The next section provides an overview of the bond market in China through a presentation of key historical developments and the current functioning of the bond market, as well as the corporate and Treasury yield movements. The third section discusses the methodology of the yield-curve parameter extraction as well of the price-discovery tests while the fourth section presents the estimation results of the yield-curve factor extraction and of the price discovery estimates across parameters among markets. The final section concludes. An appendix compares the estimated yield curve parameters with their empirical counterparts.

2. Chinese bond markets and yields

A broad consensus among economists recognises the development of a well-functioning bond market as a prerequisite in China's economic transition to a more market-oriented system, in order to meet key challenges such as managing and diversifying risks in the banking sector, stimulating sustainable growth and satisfying the increasing need for alternative financing. Therefore, this section reviewsbriefly the historical development of the Chinese bond market and the current structure of the market.

2.1. China's bond markets

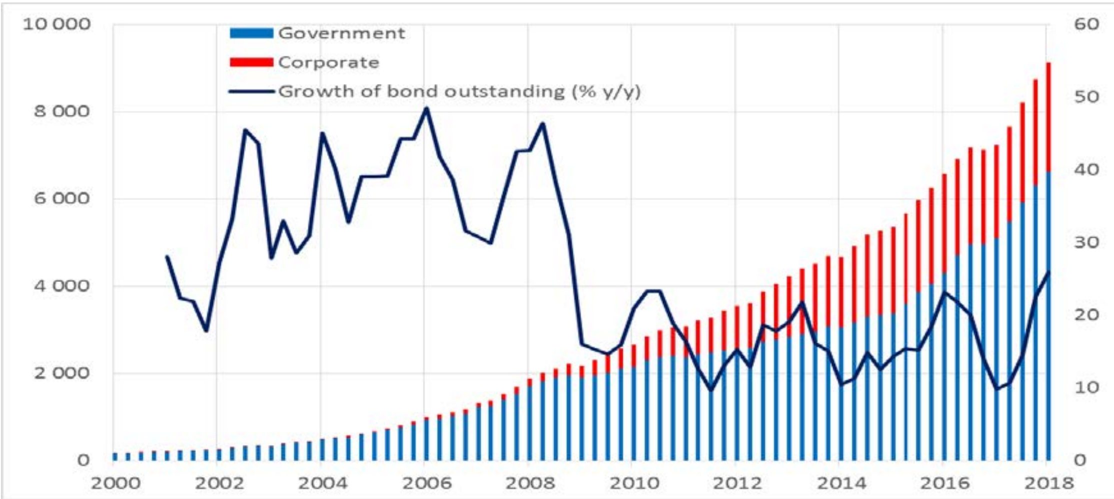
While major development of the Chinese bond market took place over the last two decades, its history dates to the late 19th century, at the end of the Qing dynasty. However, the earlier Chinese bond market differed from its modern version by a heavy reliance on foreign investors (Huang and Zhu, 2007). After the foundation of the People's Republic in 1949, few bonds were issued domestically to assist economic development and the bond market remained anemic under the centrally planned economy until the early 1980s. The Chinese domestic bond market has grown since the 1990s from being almost very marginal to becoming one of the largest in the world. The market has developed gradually, initially opening access to a limited number of healthy companies, while companies in greater need of bond financing remained left out of the market. The state was also especially cautious in keeping control over companies to avoid state-owned assets becoming owned by foreign creditors, as happened with Chinese railway loans a century ago. During the early 1990s, state-owned and local government-owned enterprises obtained permission to issue bonds and took the opportunity to raise capital in an excessive way as they were not financially constrained by bankruptcy prospects. Indeed, most of them were strict subsidiaries of various levels of government agencies. As a consequence, many of the issuers defaulted and caused financial instability, with a significant increase in the balance sheets of the state-owned banks. As a result, the State Economic Planning Commission decided to shut down the corporate bond market.

As pointed out by Huang and Zhu (2007), the legal background played an important role in the development of the bond market over the past two decades. At first, China only had a primary market, issuance was done through administrative allotment and government bonds could not be traded or transferred after issuance (Bai, Fleming and Horan, 2013). Secondary market trading was introduced in selected cities in 1988 and then allowed nationwide in 1990 when stock exchanges were opened in sequence in Shanghai and Shenzhen. Until the creation of a primary dealer system in 1993, Treasury bonds were issued exclusively as physically printed bonds. After 1993, Treasury bonds started being issued as book-entry bonds and certificate bonds which facilitated trading.

The Chinese bond market has emerged very rapidly from early 2000s, becoming the third largest bond market in the world at about RMB 55 trillion at mid-2018 (or US$ 8 trillion, ranked after the US and the Japanese government bond markets), as shown in Figure 1. Indeed, China's Treasury bond market has been growing very fast over the period from early 2000 (from 10% to 45% per year for outstanding bond growth, right-hand scale in Figure1). It has helped promote the development of direct financing, which can reduce the economy's over-reliance on the banking system for credit, mitigate financial risk and enhance market efficiency.

The bond market has developed into a multi-layered market comprised of the national interbank market and the exchange-traded market (Shanghai and Shenzhen Stock Exchanges). The interbank bond market, established in 1997 by the State Council, is an over-the-counter (OTC) wholesale market, where market positioning of institutional investors and one-to-one quote-driven trading takes place. It has become the most active bond market in China (absorbing almost all trading from the second half of the 2000s). The exchange-traded bond market is a retail market, in which individual and small- and medium-size institutional investors carry out trading.

Figure 1: China - bond market size (USD billion)



With such a rapid development, the bond market has deepened. Indeed, the types of bonds have become increasingly diversified, almost equivalently traded between Treasury bonds (34% of the total at end-2013) issued by the Ministry of Finance (MoF), financial bonds issued by government-backed policy banks and financial institutions (33%), and corporate bonds issued by domestic corporations (31%), with a very minor share of central bank (PBoC) bonds (2%). The latter are short-term debt certificates issued to commercial banks, used frequently to regulate the monetary base, in the background of some waves of, at times, sharply increasing foreign exchange reserves.

However, despite this rapid bond market development, many questions remain about the functioning of the Chinese bond market on two issues. First, this market is considered underdeveloped compared to the size of the economy. Indeed, the total amount of bonds outstanding reached in 2014 about 50% of GDP (from around 15% in 2000), which is relatively low compared to other east Asian countries such as South Korea, Malaysia, Singapore and Thailand (respectively at 125%, 100%, 82% and 70% of GDP) and accounts for less than one fourth of the bond-GDP ratio in Japan (225% of GDP). In Asia a less - developed bond market is only present in Indonesia, the Philippines and Vietnam.

Second, an increasing number of investors have been gradually allowed to access the interbank market, enhancing competition and market efficiency. Those participating in the market include banks, insurance companies, agricultural credit institutions, fund management companies, securities firms, non-bank financial institutions and non-financial corporations. In addition, China has progressively relaxed regulations on foreign investors from late 2002, with the launch of the Qualified Foreign Institutional Investors (QFII) scheme, offering foreign capital an opportunity to invest in the Chinese bond market. More recently, China has started allowing local governments to issue bonds to finance urban infrastructure construction projects[3]. The State Council approved in early 2007 a new policy allowing Chinese policy and commercial banks with high credit rating, subject to approval from relevant authorities, to issue Chinese yuan denominated bonds in Hong Kong. Notwithstanding such a rise in the number of participants on the bond market, commercial banks still make up a large majority of market investors, holding 75% of the total at end-2014, followed by special members[4] (9%) and fund institutions (6%). Such rapid development, diversification and opening of the bond market and a more market-oriented system should have allowed it to start fulfilling its function as a benchmark for asset pricing.

2.2. China's bond yields

Our daily data on the "yield curve of interbank fixed-rate treasury bonds", considered as the bond yields benchmark in China, were extracted from Wind Information[5] over the period from March 10 2006 to May 12 2017 with nine maturities ranging from 1 to 30 years. As is usual in aggregate yield curve analysis, we do not separate the credit rating of corporate bonds, but with the corporate default rate very low, credit rating does not matter much, and corporate bond yields can be pooled together to estimate the yield curve.

The pre-2006 period is not examined because the corporate bond market did not exist. Figures 2 and 3 represent respectively the evolution of interbank fixed-rate Treasury and corporate bond rates over our full sample. They illustrate the strong correlation between maturities (on average more than 80%). Moreover, Figure 4 plots the yield differential between the corporate and Treasury markets for maturities from 1 to 30 years.

The dispersion across maturities (i.e. the slope) of Treasury bond yields substantially narrowed (became flatter) from mid-2007 to mid-2008, and subsequently widened very sharply when the short end reached a low, close to 1 percentage point in 2009. A narrow dispersion established itself after late 2013. The extent to which corporate yields behaved in a similar way can be judged from the movement of their spread with Treasury yields.

[3] Until recently, Chinese local and municipal governments were not allowed to issue their own bonds, despite financing need and deficit issues. Local governments used to rely exclusively on fiscal appropriation from the central government, and thus budgeting and financing used to be an important tool that the central government used to keep control on local governments.

[4] Special members comprise the People's Bank of China, Ministry of Finance, policy banks, China Government Securities Depository Trust and Clearing Co., and China Securities Depository and Clearing Corporation.

5 http://www.wind.com.cn/En/Default.aspx

Figure 2: Evolution of China's Treasury bond yields

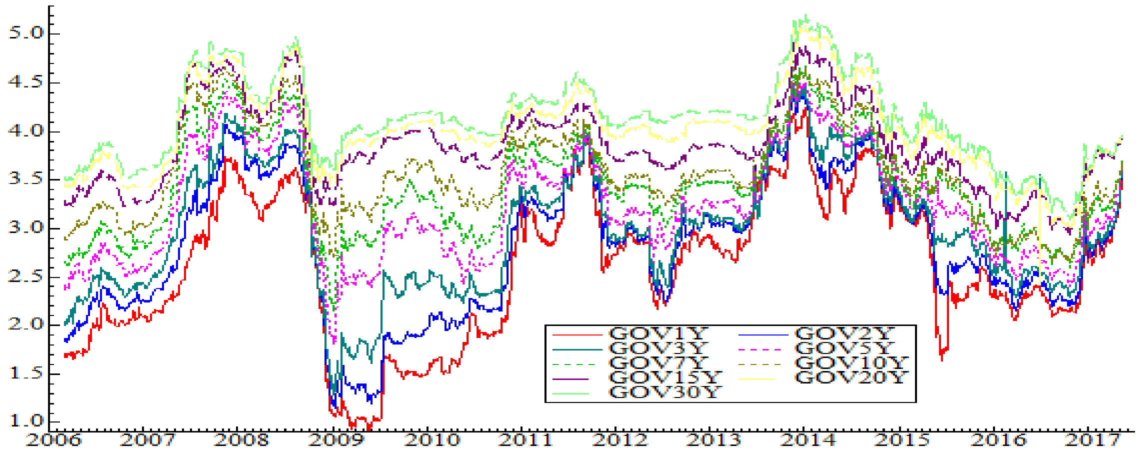


Figure 3: Evolution of China's Corporate bond yields

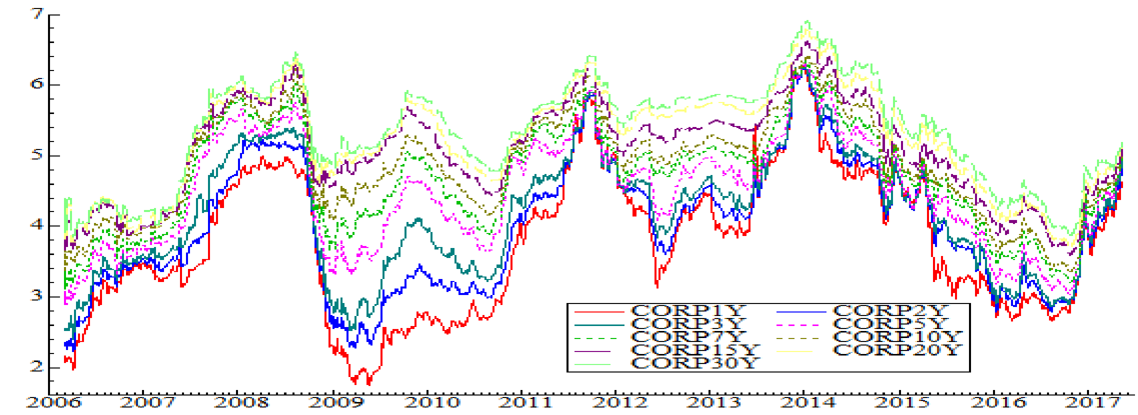
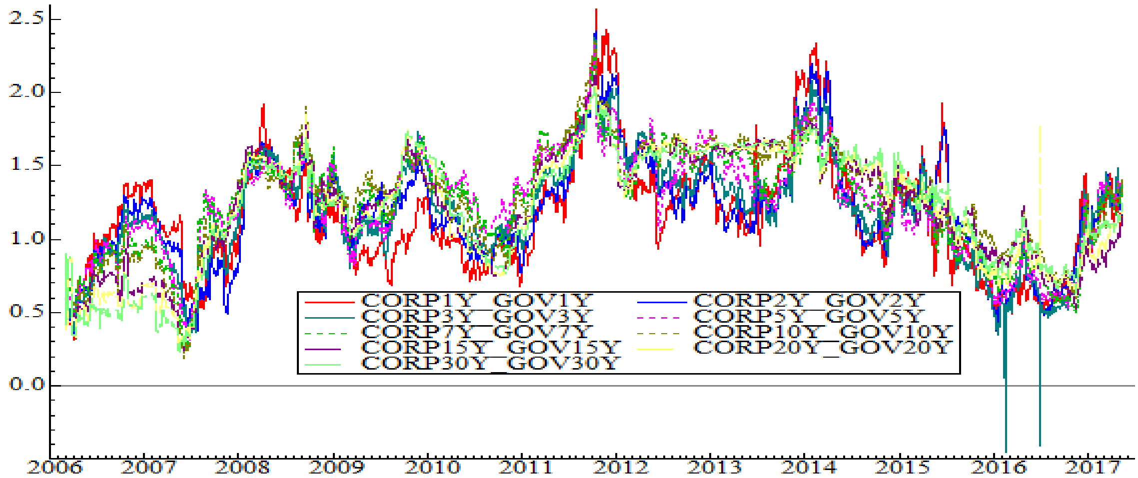


Figure 4: China's yield differentials: Corporate minus Treasury yields



The periods when corporate yields are higher than Treasury yields (Figure 4) by more than average include 2008, late 2009, and early 2011 to late 2014. In contrast the spread is lower than average both at the beginning of the sample, in 2006-2007, and at the end, from mid-2015 to late 2016, as well as more briefly, and less sharply, in the first half of 2009 and the second half of 2010. In order to understand the sources of such yield differentials across markets it is necessary to decompose the yield curve into its major factors.

3. Methodology

We introduce in this section the methodology used first to estimate the three parameters of China's Treasury and corporate bond yield curves on a high-frequency basis and second to try and detect long-run relationships among each of these parameters across the Treasury and corporate bond markets.

3.1. ***Estimation of the Nelson Siegel parameters***

There are plenty of methods to analyze the yield curve accurately in the literature, but the most common approaches used by central banks to estimate the term structure of interest rates are parametric models developed by Nelson and Siegel (1987), their extended version developed by Svensson (1994), and the smoothing spline-based model (Vasicek and Fong, 1982), extended by Fisher, Nychka and Zervos (1995)[6]. De Pooter (2007) provides a good summary of these classes of models. Chen and Yeung (2006) estimated a benchmark treasury yield curve for China, based on Svensson (1994). The different approaches are characterized by a different trade-off between the flexibility to represent shapes generally associated with the yield curve and the smoothness. Moreover, the interpretation of estimated parameters is also important. This is a strong point of the Nelson-Siegel model (1987) which summarizes information contained in the entire yield curve at each date into three easily interpretable latent variables called the level (β_0), the slope (β_1) and the curvature (β_2). The function is expressed as follows:

$$y_t(\tau) = \beta_{0t} + \beta_{1t}\left(\frac{1-e^{-\lambda\,\tau}}{\lambda\,\tau}\right) + \beta_{2t}\left(\frac{1-e^{-\lambda\cdot\tau}}{\lambda\cdot\tau} - e^{-\lambda\,\tau}\right)$$

where $y_t(\tau)$ represents the yield at maturity τ at time t. β_0 denotes the long-run level of yields, β_1 represents the slope factor and the β_2 factor is for the curvature of the yield curve. The lambda (λ) parameter is the exponential decay rate along maturities for each factor, with a larger λ producing a faster decay (Diebold and Li, 2006). Diebold and Li (2006), in the case of the US, set the λ parameter at 0.0609. In the case of China, iterative OLS estimations is required to optimize the λ parameter which minimizes the root mean square error (RMSE) over the whole sample. Therefore, we calculate the

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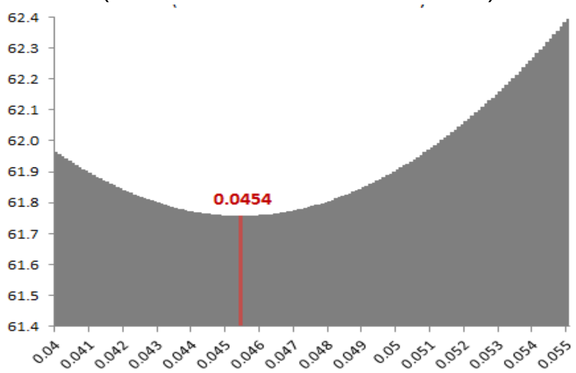
6 For technical documentation, see BIS (2005).

RMSE at each date setting alternative λ parameters ranging from 0.03 to 0.07, based on such OLS estimation.

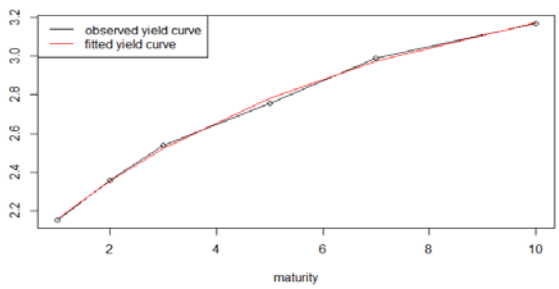
Our λ optimization procedure represented in Figure 5 suggests setting the parameter at 0.0454, which maximizes the impact of the medium-term factor at a maturity of 40 months (against 30 months according to Diebold and Li's results in the US case). Finally, the Nelson-Siegel model is estimated at each date using this fixed λ parameter through OLS regression. Our estimated statistical models of the yield curve capture well the shape of the observed yields, as shown in Figure 6 at mid-January 2017. The detailed estimations (available upon request) illustrate the relatively low estimation errors at each maturity and confirm the accuracy of the Nelson Siegel model.

Figure 5: Lambda parameter optimisation
(minimization of the sum RMSE)



Source: Authors' computation

Figure 6: Fitting the Nelson-Siegel yield curve
(Jan.17, 2017)



Source: Authors' computation

In the Appendix, we check the quality of the yield-curve parameters extracted with the Nelson-Siegel method by comparing their movements with those of simple empirical proxies (as in Diebold, Rudebusch et al. 2006). The proxies for the level factor is the longest-maturity (30 year) bond yield; for the slope factor it is the spread between the longest (30 year) and shortest (one year) maturity yields, and for the curvature twice the three-year yield minus both the one year and the 30 year yields. The match between our Nelson-Siegel factors and the proxies is very close for the level over almost the full sample; it was not good after 2011 (especially for the Treasury market) for the slope, while, as is often the case, the match for the curvature is rather poor, especially in the 2010s.

3.2. Econometric methodology

We adopt a stepwise procedure. In the first step, we estimate three bivariate vector error-correction models [7] (VECM; Johansen, 1995)) in order to extract periods of stable long-run relationships between the levels of each parameter of the yield curve for the government and

[7] The procedure followed in the estimation of the VECM is similar to that used and presented by Sun, Dunne and Li (2015).

corporate bond markets. The detection of periods of stability in the long-run relationship is based on the recursive trace statistic test (Hansen and Johansen, 1993) with a null hypothesis of one cointegration vector. In this test, the estimation starts with an initial window which is extended sequentially by one day at a time and the trace statistic is computed each time.

The VECM framework also enables us to test for weak exogeneity. The results of the weak exogeneity test condition the strategy to be adopted in the second step in order to obtain estimates of the long run and short run parameters. Weak exogeneity of market x for a given term structure parameter i (i= level, slope or curvature factor) corresponds to the lack of significance of the error-correction term in the example of equations (2) or (3) below model. The null hypothesis is thus that the coefficient α is zero. If one variable is weakly exogenous, a single-equation approach becomes appropriate and we should employ an auto-regressive distributed lag (ARDL) approach to cointegration based on the 'bounds-testing' method proposed by Pesaran et al. (2001). The ARDL models, where y denotes the Treasury and x the corporate bond markets, for each of the three term structure parameters i, is such as:

$$y_{it} = \mu_y + \theta_{y1} y_{t-1} + \ldots + \theta_{yj} y_{t-j} + \gamma_{y0} x_t + \gamma_{y1} x_{t-1} + \ldots + \gamma_{yk} x_{t-k} + \zeta_{yt} \quad (1a)$$

$$x_{it} = \mu_x + \theta_{x0} y_t + \theta_{x1} y_{t-1} + \ldots + \theta_{xl} y_{t-l} + \gamma_{x0} x_t + \gamma_{x1} x_{t-1} + \ldots + \gamma_{xf} x_{t-f} + \zeta_{xt} \quad (1b)$$

where y_t and x_t represent respectively the Treasury and the Corporate yield curve parameter, i either the level, the slope or the curvature, and the ζs are white noise. In order to double check the presence of cointegration, after the estimation of the ARDL model, we use the Wald or F-tests for the null of no long-run relationship between the variables, with critical values provided in Pesaran et al. (2001). Model (1a) will be estimated if the corporate yield curve parameter of interest is weakly exogenous, and model (1b) if the weakly exogenous yield curve parameter is associated with the Treasury bond market.

The associated error-correction models in the general case will be as follows:

$$\Delta y_{it} = \mu_1 + \theta_1 \Delta y_{t-1} + \ldots + \theta_n \Delta y_{t-n} + \gamma_0 \Delta x_t + \gamma_1 \Delta x_{t-1} + \ldots + \gamma_p \Delta x_{t-p}$$
$$+ \alpha_{yi} (y_{it-1} - (a_y + b_{yx} x_{it-1})) + \varepsilon_t \quad (2)$$

$$\Delta x_{it} = \psi_1 + \pi_0 \Delta y_t + \pi_1 \Delta y_{t-1} + \ldots + \pi_s \Delta y_{t-s} + \varphi_1 \Delta x_{t-1} + \ldots + \varphi_q \Delta x_{t-q}$$
$$+ \alpha_{xi} (x_{it-1} - (a_x + b_x y_{it-1})) + \varpi_t \quad (3)$$

The a and b parameters are estimated with the ARDL method as in equations (1a) and (1b), and ε like ϖ are white noise. If a given factor (i= level, slope, or curvature) is weakly exogenous for a given market, then the error-correction coefficient α is zero, and a simple dynamic model can be estimated for that factor on this market. The error-correction coefficients obtained for each factor of the two bond yield curves can be used to determine which market contributes to price discovery for that factor, based on a framework proposed by Gonzalo and Granger (1995). If the factor is weakly exogenous in one market, then price discovery takes place fully in that market (Harris et al., 2002) and, for this factor, adjustment takes place in the other market as a response to the first. In addition, to assess the time needed for half the deviation from the long-run relationship to be corrected, the half-life (h), can be computed (Rossi, 2005) from the first-order autoregression (ρ) of the error-correction terms, as expressed in (4) or (5):

$$[(y_{it} - (a_y + b_{yx}x_{it})] = \rho_{iy}\ [(y_{it-1} - (a_y + b_{yx}x_{it-1})] + \xi_{yt} \quad (4)$$

$$[x_{it} - (a_x + b_x\, y_{it})] = \rho_{ix}\ [x_{it-1} - (a_x + b_x\, y_{it-1})] + \xi_{xt} \quad (5)$$

where ξ_y like ξ_x are white noise,

Then h is such that: $h = [\ln(0.5)/ \ln\rho]$ (6)

4. Yield curve parameters: extraction and dynamics

This section presents sequentially the results of the Nelson-Siegel model estimate of the parameters of China's yield curve in the Treasury and corporate bond markets, and the results of the price-discovery tests across markets for each factor of the yield curve based on cointegration tests and error-correction model estimates.

4.1. Estimated yield-curve parameters

The Nelson Siegel model is very useful to summarize information contained in the entire yield curve into three easily interpretable latent variables as the level (β_0), the slope (β_1) and the curvature (β_2) of the yield curve. We extract these three parameters on daily data.

Table 1 provides some descriptive statistics of the yield curve's latent factors over the period March 2006 through May 2017, and highlights, with unit root (Augmented Dickey-Fuller and Phillips-Perron) tests and stationarity (Kwiatkowski et al. 1992) tests, the non-stationarity in the slope and level factors (as well as their stationarity in first difference), but the stationarity of the curvature factors. Figure 8 represents the results of the three estimated latent factors, showing major negative movements in the yield curves in the aftermath of the GFC, with a sharp decline in long-term interest rates on both corporate and Treasury markets (level factor in September 2008, Figure 8A) and a flattening of the yield curve (fall in the slope parameter observed in mid-December 2008); a setting in general typical of a large deterioration of macroeconomic conditions. Note that the slope is here represented as is customary,, with the long minus the short yield. As expected, due to their higher risk level, the level of yields has always been higher for corporate than for Treasury bonds in China, even though the gap became very thin mid-2007.

Table 1: Descriptive statistics of yield curve latent factors (2006-2017)

	Level factor	Slope factor	Curvature factor
Treasury market			
(in level)			
Mean	4.29	1.715	-1.703
St. Dev.	0.42	0.89	0.94
Maximum	5,26	40,04	1,21
Minimum	3,25	0.04	-4,88
Kurtosis	2,91	3,18	3,31
Skewness	-0.086	0.95	0.15
ADF(a)	-3,08	3,1	-4,76***
Phillips-Perron	-2,63	-3,05	-4,31***
KPSS	0.489**	0.164**	0.14
(first difference)			
mean	0.00029	-0.0028	0.0028
Maximum	0.42	0.92	1,34
Minimum	-0.40	-0.84	-1,09
Kurtosis	14,25	10,51	5,7
Skewness	0,04	0,19	0,06
ADF (a)	-8,72***	-16,9***	-16,57***
Corporate market			
Level			
Mean	5.46	1.62	-2.26
St. Dev.	0.72	1.10	1.12
Maximum	6.89	4.98	0.89
Minimum	3.9	-0.74	-5.31
Kurtosis	2.14	3.24	2.65
Skewness	-0.38	0.84	0.028
ADF(a)	-1.98	-2.68	-4.25***
Phillips-Perron	-2.27	-2.73	-3.55***
KPSS	0.46**	0.211**	0.53**
(first difference)			
Mean	0.0014	-0.0018	0.0064
St. Dev.	0.07	0.16	0.31
Maximum	0.36	0.73	01/01/56
Minimum	-0.43	-0.80	-1.62
Kurtosis	8.57	6.99	5.77
Skewness	-0.20	0.15	-0.073
ADF Unit Root Test(a)	-16.27***	-15.53***	-19.5***

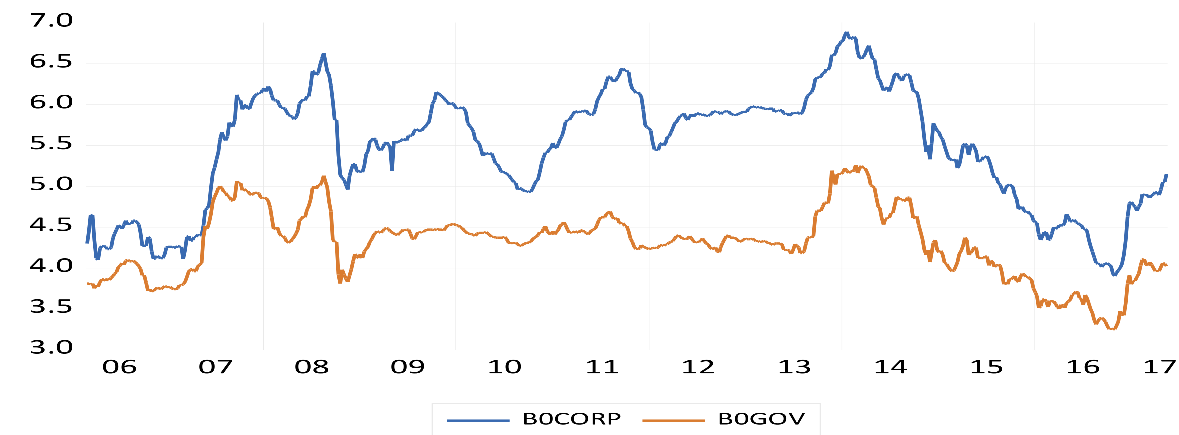
(a) Augmented-Dickey-Fuller Unit Root test. With intercept and trend. Figures indicate t-statistic. Test critical value: 1% level=-3.96, 5% level=-3.41, 10%level=-3.13. The null hypothesis is non-stationarity for the Augmented-Dickey-Fuller (ADF, Dickey and Fuller,1979) and Phillips-Perron (1988) tests (the latter allowing for breaks). The null is stationarity of the Kwiatkowski et al (1992) test. Daily data 03-2006-05-2017. Source: Authors' computations.

As plotted in the Appendix, the usual empirical proxies for the parameters of the yield curve show that our estimates match generally well the slope and level proxies for both the Treasury and corporate bond markets. The match is less good during the period following the GFC, but is better from 2011, when, in the case of the Treasury bond market, the match is almost perfect for the level factor. The difficulty of matching the curvature factor is usual.

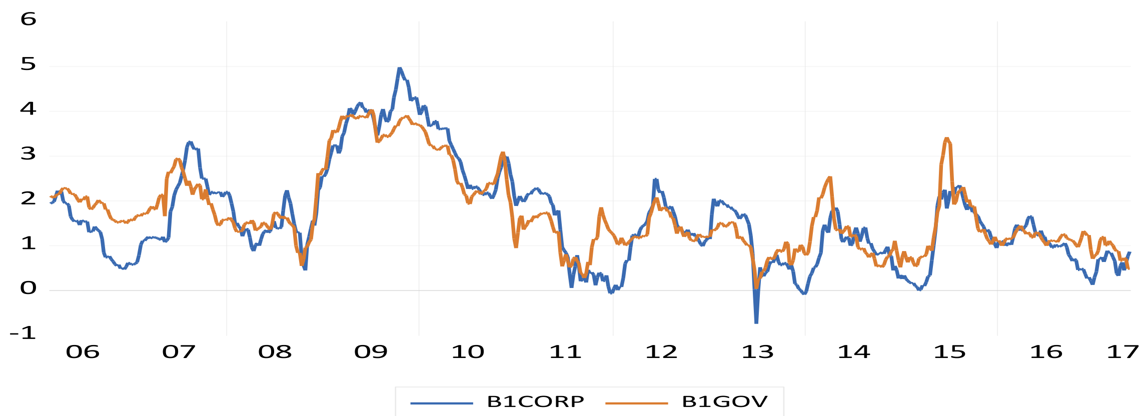
The economic situation underlying the time-series evolution of the three parameters can be described as follows. The pre-GFC period is characterized by continuing robust economic growth under a tightening monetary policy environment, particularly from mid-2007 to mid-2008. Over this period, the term structure of interest rates is upward sloping, concave and on average at a high level. In the background of the GFC and the economic slowdown in China from July 2008 to March 2009, the monetary authorities adopted a substantial easing policy to fight against the slowdown in real GDP growth and inflation. This accommodative policy stance led to a flattening of the yield curve and a strong decline in the level of yields. In addition, there was an increase in the slope, explained by the sharper fall in short-term, as opposed to long-term, interest rates. The post-crisis period, from early-2010 to mid-2011, denotes a progressive shift in monetary policy objectives, allowing weaker economic growth and a more important concern for inflationary pressure. This is revealed by the curvature of the yield curve with expectations of higher future short-term interest rates (an increase in interbank bond rates, particularly over the short-end of the yield curve which results in a flatter yield curve).

Figure 7: Estimated parameters with Nelson Siegel model on the Chinese Treasury and Corporate yield curves

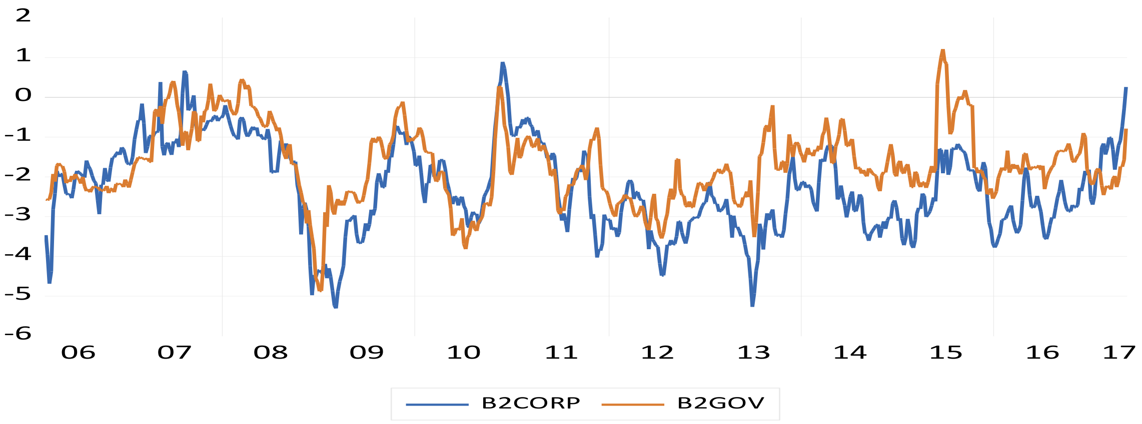
7.A. Level



7.B. Slope



7.C. Curvature



Note: This Figure plots the estimated level, β_0, (7.A), slope, β_1, (7.B), and curvature β_2 ,(7.C), parameters for both the Treasury(Gov) and the corporate(Corp) bond market.

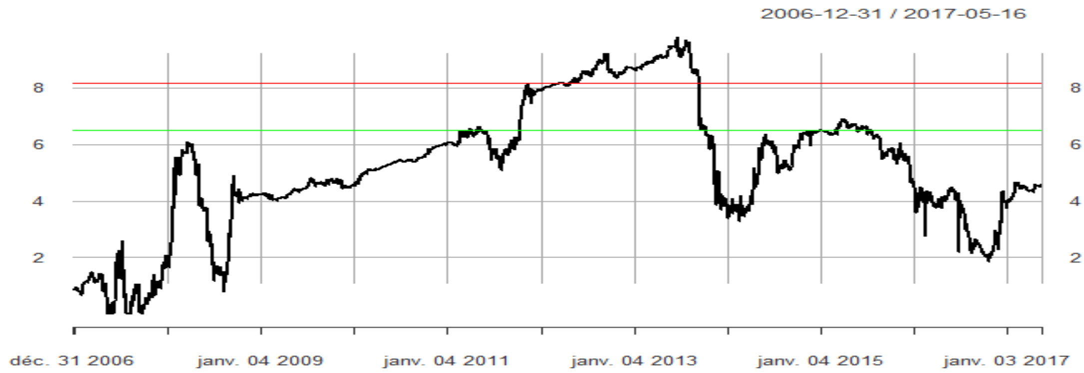
4.2. Modelling and cross-market relationships among yield curve parameters

The dynamic and long-run interactions between the Treasury and corporate yield curves in China are likely to have experienced some breaks either in the late 2000s or early 2010s. However, such breaks may not have occurred at the same time in the VECM characterizing both markets. The curvature factors for both markets being stationary there is no possibility of a long run relationship between them.

Break and cointegration tests

The recursive trace statistic for the two bivariate VECM models (one for each relevant parameter of the yield curves), plotted in Figure 8, indicates (at the 5% level) two breaks for the level (Panel 9A), on the 7 March 2012 and 12 September 2013, and no break for the slope (Panel 9B). The null of one cointegrating relationship is thus accepted for the level of the yield curve both before March 2012 and after mid-September 2013, and over the whole sample for the slope of the yield curve.

Figure 8: Recursive cointegration test between corporate and treasury bond yield curve parameters
8.A. Level



8.B. Slope

Note: This Figure plots the estimated recursive trace statistic for a Vector error-correction model between each of the two pairs of parameters of the yield curve, level (9.A), and slope, (9.B). The 10% significance threshold is in green (lower line); 5% in red (middle line).

Weak Exogeneity Test and Price Discovery

As implied by the methodological presentation in Section 3 above, price discovery is considered to take place in the market which acts as a benchmark or target for a second market. This benchmarking is such that the current price in the responding market is adjusted (error-corrects) when it deviated during the previous period from its long-run relationship with the price in the benchmark market. If both markets react to each other, price discovery is shared between the two markets in proportion to the relative magnitude of this response.

Table 2: Cointegration and Weak exogeneity test within a VECM

Level	**2006/4/07-2012/3/02**	**2013/9/13-2017/5/12**
Trace		
None	19.37	19.50
	[0.01]**	[0.01]**
At most One	5.77	1.48
	[0.49]	[0.22]
Weak exogeneity		
Corporate		
Likelihood ratio	1.36	0.55
[P-value]	[0.24]	[0.45]
Government		
Likelihood ratio	8.51	6.97
	[0.00]***	[0.00]***
Slope	**2006/3/31-2017/5/12**	
Trace		-
None	44.64	
	[0.00]***	
At most One	6.60	
	[0.40]	
Weak exogeneity		
Corporate		-
Likelihood ratio	24.89	
	[0.00]***	
Government		-
Likelihood ratio	1.91	
	[0.16]	

Level: 2006-2012: 4 lags; 2013-17: 3 lags; Slope: 3 lags [P-value]

Within the subsamples of stability of the VECM delimited by these breaks, we test which market error-corrects with respect to the other, in turn for each of the two yield curve parameters. In the absence of such an error correction (this is the null hypothesis) the market of interest would be weakly exogenous with respect to the other and price discovery would take place in the former market. Table 2 provides the value of the trace test as well as of the weak exogeneity test. The weak exogeneity results span opposite possibilities over the first two parameters of the yield curve, with reverse asymmetry in price discovery for the level and slope parameters. The corporate market is weakly exogenous for the level parameter during both the 2006-2012 and 2013-2017 periods. By contrast, for the slope parameter over the full sample the Treasury market is weakly exogenous. Thus, price discovery takes place exclusively in the corporate market for the level and in the Treasury market for the slope.

Long Run Parameter Estimation

The long run parameter of the Treasury yield-curve level factor (b_y), as implied by the cointegrating relationship, fell (by less than one-half) from the first to the second subsample (Table 3). Thus, the level parameter in the Treasury yield curve underreacted sharply (by three-fourths) to long-run movements in the level parameter of the corporate yield curve before March 2012. The underreaction was much milder (one third) after September 2013. The underreaction of the Treasury market may be considered as the result of the higher riskiness of corporate compared to Treasury bonds. By contrast, in the long run over the full sample the corporate bond amplified (b_y larger than unity) movements in the slope of the Treasury yield curve. The time needed for a change in the level of the Treasury yield to correct half the deviation from its long-run relationship (the half-life h_y) with the level of the corporate yield spectacularly dropped six-fold from 24 to 4 days from the 2006-2012 to the 2013-2017 period. The half-life (h_x) stood at an intermediate level for the Corporate bond market slope over the full sample.

Short Run Dynamics

In the dynamics, a 1% change in the corporate bond level parameter immediately translates into a 0.3% change in the Treasury bond level parameter over the 2006-2012 sample, and this short run impact more than doubles, to reach 0.68%, over 2013-17. The coefficient of the error-correction term triples in absolute value between the two periods. The dynamic response of the corporate level to the government level of yields is much weaker than the reverse effect over the first subsample but is not present (and thus not reported) over the second subsample. Over the full sample, the total dynamic response of the slope of the Corporate bond yield curve to the slope of the Treasury yield curve is larger immediately (0.37) than after two days (0.26), while the Treasury yield slope responds much less to the corporate yield slope. For the curvature factor, preliminary tests on the level of this factor (which is stationary) showed that there is no dynamic link between the corporate and Treasury bond markets either way and are thus not reported.

For the change in the level in the Treasury bond market (Table 4), persistence was the same at short lags (first autoregressive coefficient around 0.17) before March 2012 and after September 2013, but longer-lasting and twice larger in the former period after three days. For the change in the slope of the bond yield curve, the persistence is quite low, with about one fourth for both the corporate and Treasury markets.

That we find that the Treasury bond market is not dominant in level bond-pricing is not surprising. Although China's corporate bond market has developed rapidly in the past fifteen years, there were few default cases during our sample period. It is believed investors treat the default risk of corporate bonds as pretty much the same as that of Treasury bonds, and at the same time take advantage of the high corporate spread. The Treasury bonds are mainly bought by big banks for their liquidity management, and both Treasury and corporate bonds are traded in the interbank market[8].

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[8] Given that the market structure is the same for both corporate and Treasury bonds, it is unlikely that microstructure noise would bias (Yan and Zivot, 2010; and Putnins, 2013) the price discovery measure a la Gonzalo-Granger (1995) used here. At any rate whenever one market contributes 100% to price discovery, as is the case for the level and the slope, attempting to correct for such possible bias would not alter the conclusion.

Table 3: Long run parameters

Level β_0 (ARDL)	**2006/3/10-2012/3/02**	**2013/9/12-2017/5/12**
Treasury bond		
Intercept (a_y)	3.08 (7.36)***	0.73 (5.20)***
Corporate Bond (b_y)	0.236 (3.09)***	0.644 (24.6)***
Bounds test	8.42***	7.07***
ρ **h_y= Half-life (days)**	0.972 (73.3)*** 24.40	0.860 (25.6)*** 4.59
Slope β_1 (ARDL)	**2006/3/31-2017/5/12**	-
Corporate Bond		
Intercept (a_x)	0.516 (2.77)***	-
Treasury bond yield (b_x)	1.239 (12.8)***	-
Bounds test	12.96***	-
ρ **h_y= Half-life (days)**	0.938 (64.3)*** 11.55	- -

*** significant at 1%. This corresponds to the cointegrating or long-run parameters estimated with the ARDL model (equations 1a and 1b) for the Level and Slope. The bounds test of cointegration has a null of no cointegration. This Table reports the long-run solution associated with the estimation of the corresponding ARDL equations (1) and (2).

Table 4: Dynamics ($\Delta\beta_0$), Level

	2006/3/10-2012/3/02	**2013/9/12-2017/5/12**	**2006/3/10-2012/3/02**
	$\Delta\beta_0{}^{Gov}{}_t$	$\Delta\beta_0{}^{Gov}{}_t$	$\Delta\beta_0{}^{Corp}{}_t$
$\Delta\beta_0{}^{Gov}{}_{t-1}$	0.177 (3.63)***	0.168 (2.38)**	0.076 (0.21)
$\Delta\beta_0{}^{Gov}{}_{t-2}$	-0.006 (0.12)	-	0.134 (2.12)**
$\Delta\beta_0{}^{Gov}{}_{t-3}$	0.209 (4.37)***	-	-
$\Delta\beta_0{}^{Corp}{}_t$	0.367 (10.8)***	0.688 (12.4)***	-
$\Delta\beta_0{}^{Corp}{}_{t-1}$	-	-0.132 (1.82)*	0.38 (6.18)***
$\Delta\beta_0{}^{Corp}{}_{t-2}$	-	-	-0.123 (2.01)**
C	-	-	0.002 (0.31)
ECT_{t-1}	-0.057 (5.04)***	-0.157 (4.63)***	-
R2 adj: SC: AR(10)	0.423 -3.41 7.64 [0.66]	0.503 -3.11 8.99 [0.53]	0.171 -1.037 13.3 [0.20]

The first two columns report the estimation of equation (3) in the text for the level of the Treasury yield curve where the error correction term comes from the ARDL estimation in equation 1b). The last column reports the estimation of equation (2) for the level of the corporate yield curve, without the error correction term. For parsimony, higher-order lags were not reported when excluded on the basis of the Schwartz Information criterion. * significant at 10%; ** 5%; ***1%. P-Value between square brackets.

Table 5: Dynamics ($\Delta\beta_1$), Slope: 2006/3/31-2017/5/12

$\Delta\beta_1^{Corp}{}_t$	$\Delta\beta_1^{Corp}{}_{t-1}$	$\Delta\beta_1^{Corp}{}_{t-2}$	$\Delta\beta_1^{Gov}{}_t$	$\Delta\beta_1^{Gov}{}_{t-1}$	ECT $_{t-1}$		
	0.363 (9.09)***	-0.137 (3.64)***	0.372 (9.16***)	-0.095 (2.16)**	-0.067 (6.24)***		
	R2 adj: 0.287	SC: -1.15	AR(10): 7.26 [0.70]				
$\Delta\beta_1^{Gov}{}_t$	$\Delta\beta_1^{Gov}{}_{t-1}$	$\Delta\beta_1^{Gov}{}_{t-2}$	$\Delta\beta_1^{Gov}{}_{t-3}$	$\Delta\beta_1^{Corp}{}_{t-1}$	$\Delta\beta_1^{Corp}{}_{t-2}$	$\Delta\beta_1^{Corp}{}_{t-3}$	C
	0.332 (7.55)***	-0.103 (2.24)**	0.019 (0.65)	0.084 (2.03)**	-0.012 (0.29)	0.113 (2.73)***	0.001 (0.29)
	R2 adj: 0.133	SC: -1.09	AR(10): 7.58 [0.67]				

This is the estimation of equation (3) in the text for the corporate market change in the slope factor with the error correction term from the ARDL estimate in equation (1a), and of equation (2) without the error-correction term for the Treasury market change in the slope factor. * significant at 10%; ** 5%; ***1%. P-Value between square brackets.

Our results for the slope parameter imply that market-oriented reform in the corporate bond market has progressed enough for the Treasury bond market to provide a benchmark slope for the yield curve of corporate bonds. When the reform progresses further we would expect corporate bonds to be priced according to their risk profile which could translate into price discovery in the Treasury market also for the level of the yield curve.

We found that the structural break of the cointegration or long-run relationship between markets mainly happens in the level, not the slope, parameter. This shows the maturity-spreads of the yield curve move together without interruption, which proves the point mentioned above that maturity premiums are highly correlated. The relationship between the level parameter has two breaks in the 2010s. This is because there was a huge credit expansion during that period, which not only generated volatility but also drove down the long-term yields and disrupted the previous pattern of the cointegration relationship.

5. Conclusion

With the gradual liberalization of the Chinese financial system, the interbank bond market is playing an increasing role in macroeconomic management, fund allocation and risk management. The sharp expansion in the corporate segment, from an initial very low level of development, has been a major feature of the last fifteen years in China; a feature shared with many emerging markets. The object of this paper was to extract the factors of the interbank bond yield curve in China for both the Treasury and corporate segments and assess the nature of price discovery across the parameters of the yield curves, taking into account structural breaks, over the period 2006-2017 at a daily frequency.

While price discovery between the Treasury and corporate bond market yield curves in China had previously not been studied, our estimation of the three key parameters of the yield curve in both markets has enabled us to document that the Treasury bond has in no way a uniform leading role in providing a benchmark for all factors of the yield curve for China. Indeed, our study of long and short run relationships shows that the dominant role of the government bond market only appears in the discovery of the slope of the yield curve. By contrast, the leadership is reversed for the level since discovery is done by the corporate bond market over the full 2006-2017 sample, though with breaks.

For future research, one direction is to study how monetary policy affects the yield-curve factors in both Treasury and corporate bond markets, particularly how monetary policy transmits through the yield curve and the corporate-treasury yield spread, which could be an indicator for risk taking. Another direction is to study how both Treasury and corporate yield curves are related to the interest rate on bank loans. Given that the People’s Bank of China is trying to build an effective monetary transmission mechanism through the interest rate channel, these are important topics for both theoretical and empirical research.

Appendix:

The parameters of the term structure of bond yields and their empirical proxies

It is customary to check the quality of the yield curve parameters extracted with the Nelson-Siegel method by comparing their movements with those of simple empirical proxies (Diebold, Rudebusch et al. 2006). The level factor is usually proxied by the longest-maturity (30 year) bond yield. For both the corporate and the Treasury bond market in China the match between the two series for the level is very close, with the exception of the mismatch lasting one year and two years from 2009 respectively (Figures A1 and A2).

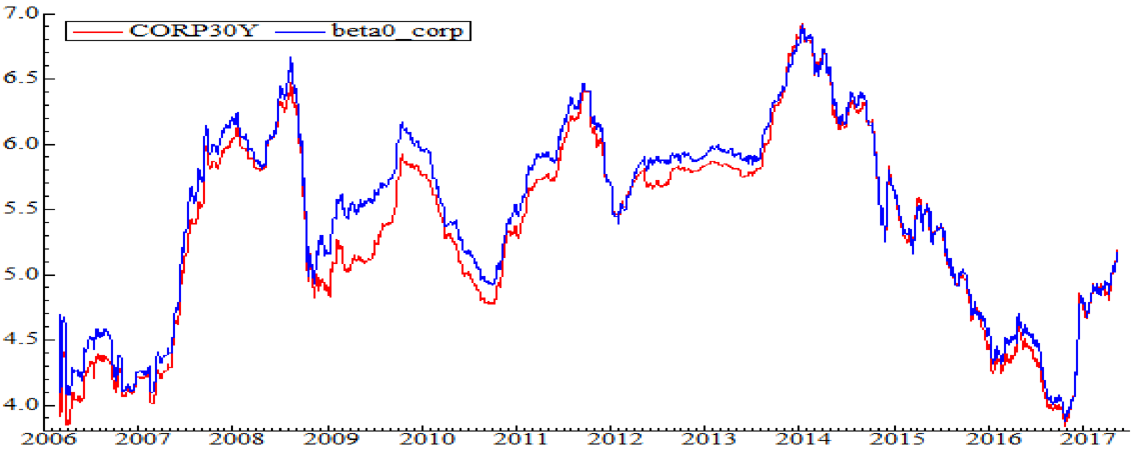
The slope factor is usually proxied by the spread between the longest- and shortest-maturity yields, which in our case are respectively 30 years and 1 year. The match with the extracted slope factor improved from 2011 onwards, and more so in the Treasury than in the corporate bond market (Figures A3 and A4). Previously the gap between the two series was especially large in 2007 and 2009, when the empirical proxy implies a less steep yield curve than the estimated β_1 for both types of bonds.

The proxy for the curvature is computed as twice the three-year yield minus both the one year and the 30 year yields, i.e. as $[(2^*y_{3year})-y_{1year}-y_{30year}]$ and $[(2^*x_{3year})-(x_{1year})-(x_{30year})]$, for the Treasury (y) and the corporate (x) bond market (yield) respectively. As usual, and shown in Figures A5 and A6, it is not an easy task to proxy the curvature factor, and especially so from 2010.

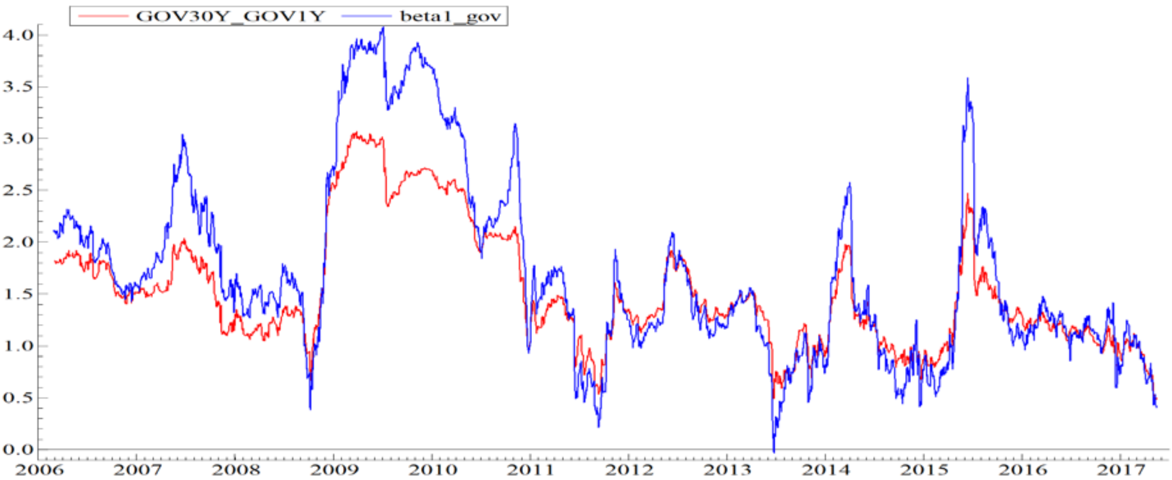
Figure A: The factors of China's yield curves and their empirical proxies

A1: Level Treasury

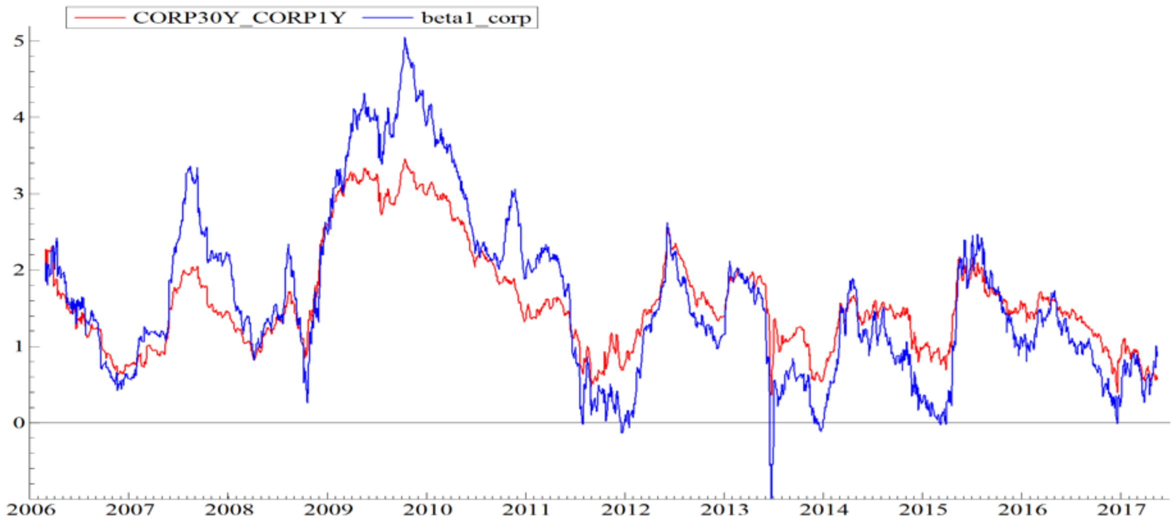
A2: Level Corporate



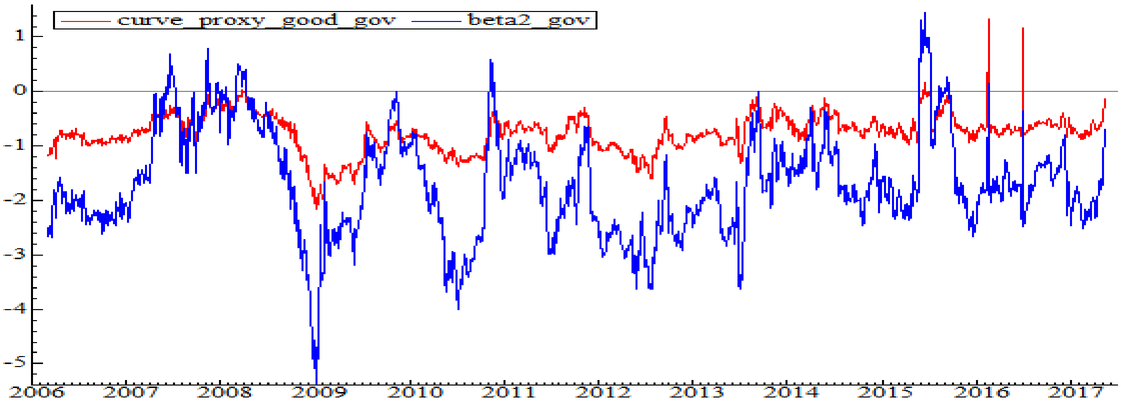
A3: Slope Treasury



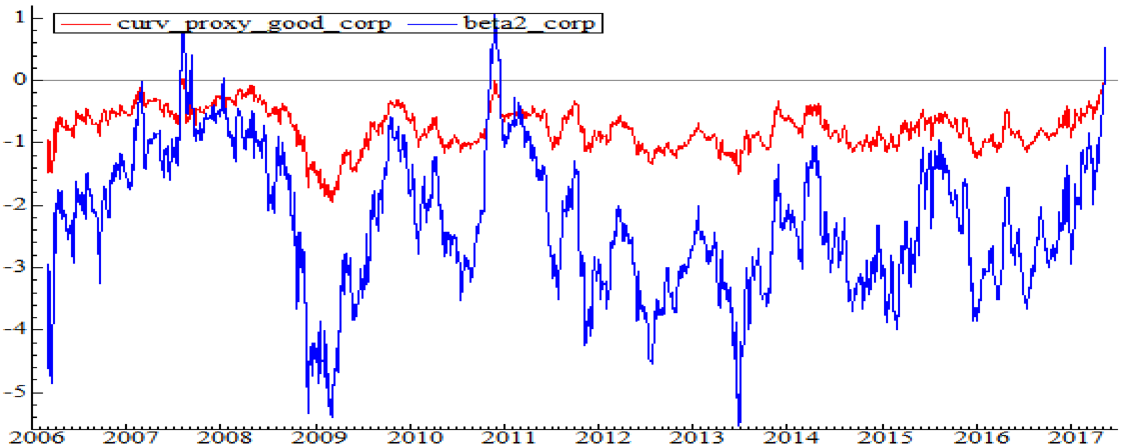
A4: Slope Corporate



A5: Curvature Treasury



A6: Curvature Corporate



Note: Figures A 1 to A6 plot the estimated level (β_0), slope (β_1) and curvature (β_2) parameters, as reported in the text for both the Treasury and corporate bond market, as well as the corresponding empirical proxies.

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