Preferred-habitat and demand factors in the term structure: Evidence from the Chinese bond market

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Abstract

Recently, demand and supply are found to have effects on bond market. While some studies use the evidence to support the preferred-habitat hypothesis, others employ the assumption of market segmentation to explain the phenomena. By introducing a simple preferred-habitat model, we show that preferred-habitat investors are the only cause for the effect of their alternative opportunities on bond market, and both preferred-habitat investors and arbitrageurs may cause demand or supply effect. Taking advantage of data in Chinese bond market, which have the term structure of official rates to measure yields of preferred-habitat investors' alternative investment opportunities and demand of major investors, we find sound evidence to support the preferred-habitat hypothesis. Finally, using an affine-type preferred-habitat interest rate model, we demonstrate that the preferred-habitat and demand factors should be included as state variables to make bond pricing more accurate.

JEL classification: E0; E4; G12; G10

Keywords: The preferred-habitat hypothesis; Market segmentation; Official interest rates; Demand of bonds; affine model

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1 Introduction

Recently, the evidence about the effect of demand and supply on bond yields and returns challenges researchers to rethink about the determinants of term structure of interest rates. The well-known observation is the Federal Reserve's buyback program of 2000-2001. The program intended to spur spending and economic growth by reducing the long-term bond yields via decreasing their supplies. Greenwood and Vayanos (2010) find that after the purchase plan of 2000-2001 was announced, the spread between the 20 and 5 year spot rates decreased from 26 bps to -39 bps in three weeks (a total decrease by 65bps). Other observations include the influence on bonds of the UK pension reform of 2004 (Greenwood and Vayanous, 2010), and effect of international capital flows on U.S. interest rates and bond returns (Warnock and Warnock, 2009; Sierra, 2010).

There are two potential theories to meet the phenomena. The first one is market segmentation or incompleteness. In an incomplete market, financial assets cannot be replicated by other assets perfectly, therefore they have their unique risk and return profiles to satisfy investors. With limited supplies and downward demand curves of assets, asset prices or yields are affected by their demands or supplies. Prices of many types of financial assets, such as stocks, options, CDS, are found being affected by demand or supply factors. For example, Chordia and Subramanyam (2004), Coval and Stafford (2007), Sarkar and Schwartz (2009) find that order imbalance and price pressure affect stock market. Greenwood (2005) documents that demand shocks have effect on stock prices. Gabaix, Krishnamurthy, and Vigneron (2007) reveal demand effect in mortgage-backed securities markets. More recently, Garleanu, Pedersen, Poteshman(2009) expose that demand-pressure has effect on option prices. Tang and Yan (2010) report that net buying interest predicts CDS price changes. Ivashina and Sun (2010) show that demand pressure affects corporate loans. With so many evidences of demand and supply effect, it is not surprising that bond demand and supply are documented to affect bond yields and excess returns on bonds. Cochrane (2008) comments on early version of Greenwood and Vayanos (2010) by emphasizing market incompleteness is a possible reason. D'Amico and King (2010) study the effects of the Federal Reserve's program to purchase $300 billion of Treasury bonds during 2009 and conclude that the evidence supports a view of segmentation or imperfect substitution within Treasury market.

The second interpretation is the preferred-habitat hypothesis for term structure of interest rates. According to the hypothesis, investors prefer for assets with specific maturities. They would like to trade off bonds with other assets or investment opportunities with the same maturities (Vayanos and Vila, 2009). Because of market power of preferred-habitat investors, yields of alternative investment opportunities with similar maturities become factors to determine bond yields and returns. Speculators or arbitrageurs cannot eliminate their influences because of the nature of their risk aversion. Greenwood and Vayanous (2010) take the outcomes of the UK pension reform of 2004 and the buyback program of US Treasury bonds in 2000-2001 as examples to support the preferred habitat hypothesis. Vayanos and Vila (2009) propose a preferred-habitat model of market yield curves in continuous-time setting. Greenwood and Vayanos (2010) find that when the average maturity of bonds increases, the expected excess returns on bonds go high by examing the relationship between excess returns on bonds and maturity structure of government bonds in the U.S. They argue this as evidence to support the preferred-habitat hypothesis. Hamilton and Wu (2011) develop an affine-type preferred-habitat interest rate model to measure the effects of treasury supplies. Kaminska, Vaysnos, and Zinna (2011) estimate the term structure of interest rates of the U.S. by introducing a demand factor of preferred-habitat investors. Greenwood, Hanson, and Stein (2010) find that firms absorb the supply shocks associated with the changes in the maturities of government debts when issuing corporate bonds. Their theoretical model assumes four types of investors, and one-type of them is preferred-habitat investors.

In this paper, we introduce a simple preferred-habitat model to distinguish roles of demand and supply with that of alternative investment opportunities of bonds in bond pricing. Following Vayanos and Vila (2009), we assume that there are two kinds of investors in the market: preferred-habitat investors and arbitrageurs. We also assume there are assets with similar maturities as bonds and their yields are benchmarks to measure returns of alternative investment opportunities of bonds. Thus bond demand by preferred-habitat investors is inversely determined by the yields of alternative opportunities. Arbitrageurs seek maximal expected return with given risk by holding bonds. With these assumptions, we conclude that yields on alternative opportunities have positive effect on bond yields and returns. Given the supply of bonds, total demand of both the arbitrageurs and preferred-habitat investors has effect on bond yields and returns. Our model exposes that, without preferred-habitat investors in the market, the demand of arbitrageurs still have influence on bond returns, but yields on alternative investment opportunities do not. Effects of yields on alternative opportunities attribute to preferred-habitat investors and can be used to test preferred-habitat hypothesis. Furthermore, we question pricing accuracy of classical interest rate model without preferred-habitat and demand factors. Therefore we introduce an affine-type preferred-habitat interest rate model to infer contributions in bond pricing of preferred-habitat and demand factors with the existence of the latent state variables.

With only data of supply or demand of bonds, we cannot distinguish the effects of preferred-habitat investors and arbitrageurs from each other. This is why many studies mentioned above use either market incompleteness or preferred-habitat hypothesis to explain the demand or supply effects. Fortunately, we can observe the yields of alternative investment opportunities of bonds of different maturities in China bond market. This makes the test of the preferred-habitat hypothesis feasible. In China, the central bank sets a term structure of interest rates with different maturities for commercial banks to lend loans. The term structure of lending rates, hereafter called the official rates, is changed with a relatively low frequency, and the long-term rates are always a little bit higher than the short-term interest rates. As intermediaries of lending loans and accepting deposits, commercial banks are the biggest players in the bond market in China. They hold up to 60% of total bonds outstanding. Because commercial banks are not allowed to hold stocks, they take loans and bonds as their main compositions of assets. The commercial banks hold bonds mainly for two reasons. First, they take bonds as one part of portfolios instead of loans to reduce credit risk of their assets. Second, they use bonds for fund liquidity management. Bonds are traded with high liquidity, whereas loans are not tradable. So when they have extra fund, they take bonds to make profits; otherwise when fund is tense, they sell bonds to meet the liquidity demand. In this sense, commercial banks play double roles in the bond market. When they use bonds as the substitutes of loans, they will compare bond yields with lending rates of loans with the similar maturities. They are behaving as typical preferred-habitat investors. On the other hand, when they buy or sell bonds to make use of trading opportunities for the purpose of liquidity management, they are arbitrageurs. Of course, there are many other investors in the bond markets, such as securities companies, insurance companies, and individuals. Aggregating all the investors, we can categorize them into two types: preferred-habitat investors who always compare bond yields with those of alternative investment opportunities of the same maturities, represented by the official rates; the arbitrageurs who trade bonds to make use of arbitrage opportunities. Hence, Chinese bond market provides us with unique data to do the test, because it has the term structure of the official rates to measure the returns of alternative investment opportunities.

There have been several studies examining the effect of bond supply on bond markets, but few researches are about effect of demand of bonds. Chinese bond market data make examining effect of bond demand possible. Another advantage of Chinese bond market data is that we have the observations of the spread between values of deposits and loans of all Chinese commercial banks. The spread can be used to measure demand for bonds by the commercial banks. Chinese central bank, the People Bank of China (PBC), claims that money supply is its main monetary policy target, and it monitors and regulates the growth of M1 and M2 closely. Deposits in commercial banks are closely related to Chinese central bank's money supply policy. But as we know from macroeconomic theory, loan demand depends on the lending interest rates set by the central bank and other real and nominal economy conditions. Thus, loan demand is closely related to the central bank's interest rate policy. We conclude that the spread between values of deposits and loans is partially out of control of commercial banks and affected by the monetary policy. When the spreads widen, the commercial banks may actively hold more bonds as substitute of loans or passively have to buy more bonds to hold because of more fund. When fund liquidity becomes tense, the commercial banks might have to reduce their holdings of bonds since reducing loans is not easy, then the spread becomes smaller. Given that supply of bonds is stable, the demand of bonds, measured as the spread, might have an effect on bond market.

With monthly data from 2000 to 2010, we regress market interest rates on the preferred-habitat factor (the average of lending interest rates) and the demand factor constructed with the spread between values of deposits and loans. We confirm that the official rate affects market interest rates positively and that demand factor has negative effect. We also use the two variables to explain annual excess returns on bonds. Excess returns on bonds are highly predicted by these variables, and signs of the estimated coefficients are consistent with the prediction of the theoretical model. These evidences support the preferred-habitat hypothesis.

With the evidences of effects of the preferred-habitat and demand factors on market yields, we believe if we don't adopt them as state factors in interest rate models, we would lose pricing accuracy for bonds. In classical interest rate models, such as affine models, state factors are assumed to be latent factors. In this paper, following Vayanos and Vila (2009), Dai and Singleton (2000), Ang, etc (2011), Hamilton and Wu (2011), we present an affine-type preferred-habitat interest rate model with 4 state variables, consisting of two latent factors, the preferred-habitat rate and demand factors. Like Joslin, Priebsch, Singleton (2010), the choice of number of latent factors is based on principal component analysis of bond yields. Using the model to fit the data, we get the estimates of parameters in the model. Comparing the model with the two observed factors to that without the two observed factors, we find that the preferred-habitat model has significant improvements in fitting yields and predicting bond yields and returns. The mean absolute errors of bond yield fitting are reduced by up to 5 basis points (BPs) for 2, 3 year market yields, and around 2 BPs for 4 year market yield. Furthermore, the preferred-habitat model forecasts market yields and returns on bonds with different terms more accurately at various forecasting horizons. In the preferred-habitat model, although the latent factors explain most volatility of market yields, the preferred-habitat factor (the official rate) still has important contribution to change of market yields. When we predict market yields one-month ahead with the model, around 11 to 22% of variances of market yields come from shock of the factor. If we predict market yields one-year ahead, around 16% to 22% forecasting variances of the different market yields are attributed to the factor. For long-term (60 months) forecasting, the influence of the factor is a little smaller, but it still results in about 11 to 16% of the forecasting variances. The demand factor contributes a little for the forecasting variances but still affects market interest rates significantly. So the preferred-habitat and demand factors should be included as a state variables in interest rate model.

The rest of this paper is organized as follows. Section 2 uses framework of affine-type model to illustrate how the official rates and demand for bonds affect bond yields and returns, when both preferred-habitat investors and arbitrageurs are present in the market. An affine-type preferred-habitat interest rate model with two latent variables and two observed variables (one preferred-habitat factor and one demand factor) is introduced as follows. Section 3 introduces background of Chinese bond market and the data, including monetary policy system which sets the official rates, bond market and its main participants: commercial banks. Section 4 documents the empirical evidence. We uses the preferred-habitat and demand factors to explain bond yields and returns and test the role of the two factors in bond pricing through estimating the affine-type preferred-habitat interest rate model. The results support the preferred-habitat hypothesis and show important contribution of the preferred-habitat and demand factors in interest rate modeling. Finally there is a brief conclusion in Section 5.

2 A theoretical analysis using affine framework

2.1 Bond yield and expected excess returns

Following Vayanos and Vila (2009), we use the framework of affine model to show how bond yields and excess returns behave in equilibrium. There are two types of investors in the bond markets: preferred-habitat investors and arbitrageurs. Preferred-habitat investors seek to hold assets with time to maturities the same as their investment horizons. As we have discussed, we assume that the preferred-habitat investors behave somehow like the commercial banks. There are two major assets for them to hold: taking bonds and lending fund to some others as loans. The returns on loans are determined by the official yield curve set by the central bank. Specifically, for the n-period preferred-habitat investors, they can buy a bond with time to maturity n, or lending their fund to others as n-period bank loan, which is with the return of the n-period official lending rate. The official lending rates of different terms are always changed at the same time and with similar sizes by the central bank, so they are highly correlated. To make it simple, we use r_t to indicate the official lending interest rates of different terms at time t. Similar but different to Vayanos and Vila (2009), we assume that demand for bonds by preferred-habitat investors inversely depends on the lending rate because of the imperfect substitution of the two main instruments. That is [1]

$$D_t^{(n)} = \alpha_{0t}^{(n)} - \alpha_{1t}^{(n)} r_t, \tag{1}$$

where $\alpha_{1t}^{(n)}$ measures the sensitivity of their demand to the official interest rate. When the level of official lending rates is raised, preferred-habitat investors, finding holding bank loans are preferable, will reduce their holds of bonds. Therefore, we assume that $\alpha_{0t}^{(n)} > 0$, $\alpha_{1t}^{(n)} > 0$.

The other type of investors is arbitrageurs in the bond market. Arbitrageurs choose portfolio of bonds with mean-variance preference.[2] We assume their investment horizon is one-period and hence myopic. They invest in bonds of different terms to maximize their expected utility at the end of the period. Given their total endowment of wealth W_t to invest, the value weighted ratio in zero-coupon bond with maturity n is denoted as ω_n. Following Vayanos and Vila (2009), Hamilton and Wu (2010), we use the framework of affine models and assume bond yields are affine functions of state vectors, X_t, but we do not need to specify what the state variables are now. We use $P_t^{(n)}$ to denote the price of the zero-coupon bond with maturity n and face value of 1 at time t. Log bond price has the form

$$\ln P_t^{(n)} = -A_n - B_n' X_t, \tag{2}$$

[1] It is more reasonable to assume that $D_t^{(n)} = \alpha_{0t}^{(n)} - \alpha_{1t}^{(n)} r_t + \alpha_{2t}^{(n)} y_t^{(n)}$, where $y_t^{(n)}$ is bond yield with maturity n. This assumption will make market interest rates affect bond return in a complicated way without changing the effect of official rate. We omit the market yield term for simplicity and focus on the effects of official rates and demand for bonds.

[2] Assuming arbitrageurs' portfolio only consists of bonds is assuming that market is segmented. Vayanos and Vila (2009) make the same assumption. We can consider arbitrageurs as commercial banks when they make liquid management in Chinese bond market.

where the state vector follows the first-order Markov dynamics

$$X_{t+1} = \mu + \Phi(\mu - X_t) + \Sigma\varepsilon_t, \qquad \varepsilon_t \sim N(0, I). \tag{3}$$

For the bond with maturity n, its one-period log return is

$$\begin{aligned} r_{t+1}^{(n)} &= \ln P_{t+1}^{(n-1)} - \ln P_t^{(n)} \\ &= -A_{n-1} - B'_{n-1}X_{t+1} + A_n + B'_n X_t. \end{aligned} \tag{4}$$

The gross return on arbitrageurs' portfolio is

$$\begin{aligned} R_{t+1}^{(p)} &= \sum_{n=2}^{N} \omega_n \exp(-A_{n-1} - B'_{n-1}X_{t+1} + A_n + B'_n X_t) \\ &\quad + (1 - \sum_{n=2}^{N} \omega_n)\exp(A_1 + B'_1 X_t), \end{aligned} \tag{5}$$

with expected mean

$$\begin{aligned} E_t R_{t+1}^{(p)} &\approx 1 + \sum_{n=2}^{N} \omega_n [-A_{n-1} - B'_{n-1}E_t X_{t+1} + \frac{1}{2}B'_{n-1}\Sigma\Sigma' B_{n-1} + A_n + B'_n X_t] \\ &\quad + (1 - \sum_{n=2}^{N} \omega_n)(A_1 + B'_1 X_t), \end{aligned} \tag{6}$$

and variance[3]

$$\text{var}_t(R_{t+1}^{(p)}) \approx \sum_{n=2}^{N} (\omega_n B'_{n-1})\text{var}(X_{t+1}) \sum_{n=2}^{N} (\omega_n B_{n-1}). \tag{7}$$

The arbitrageurs' optimization problem is to choose optimal weights $\{\omega_n\}$ to maximize mean-variance form utility function

$$\max_{\{\omega_n\}} [E_t(R_{t+1}^{(p)}) - \frac{1}{2}\gamma \, \text{var}_t(R_{t+1}^{(p)})], \tag{8}$$

where γ indicates the risk-aversion degree of arbitrageurs. Optimized weights should satisfy the first-order condition. After simple mathematical deviation of the first-order condition, we have the following equation for the optimal weight ω_n to satisfy

$$\begin{aligned} -A_{n-1} - B'_{n-1}E_t X_{t+1} + \frac{1}{2}B'_{n-1}\Sigma\Sigma' + A_n + B'_n X_t - A_1 - B'_1 X_t \\ -\gamma \sum_{m=2}^{N} (\omega_m B'_{m-1}) \, \text{var}(X_{t+1}) B_{n-1} = 0. \end{aligned} \tag{9}$$

[3]See Himilton and Wu (2011) for the deviations of Equations (6,7)

From Equation (2), we know bond yield and state vector have the relation

$$y_t^{(n)} = \frac{1}{n}A_n + \frac{1}{n}B_n'X_t, \tag{10}$$

Rewriting Equation (9) using Equation (10), we get

$$\begin{aligned} y_t^{(n)} &= \frac{n-1}{n}E_t y_{t+1}^{(n-1)} + \frac{1}{n}y_t^{(1)} - \frac{1}{n}\frac{1}{2}B_{n-1}'\Sigma\Sigma' B_{n-1} \\ &\quad + \frac{1}{n}\gamma B_{n-1}' \mathrm{var}(X_{t+1})\sum_{m=2}^{N}(B_{m-1}\omega_m). \end{aligned} \tag{11}$$

When market is in equilibrium, the sum of demands for the bond of m periods by the two types of investors is equal to its supply, which is assumed to be given exogenously with the market value, S_m. We have

$$S_m = \alpha_{0t}^{(m)} - \alpha_{1t}^{(m)} r_t + W_t\omega_m,$$

or equivalently

$$\omega_m = \frac{S_m - \alpha_{0t}^{(m)}}{W_t} + \frac{\alpha_{1t}^{(m)}}{W_t} r_t. \tag{12}$$

Substituting ω_m with Equation (12) in Equation (11), we get

$$\begin{aligned} y_t^{(n)} &= \frac{n-1}{n}E_t y_{t+1}^{(n-1)} + \frac{1}{n}y_t^{(1)} - \frac{1}{n}\frac{1}{2}B_{n-1}'\Sigma\Sigma' B_{n-1} \\ &\quad + \frac{1}{n}\gamma B_{n-1}' \mathrm{var}(X_{t+1})\sum_{m=2}^{N}[B_{m-1}(\frac{S_m - \alpha_{0t}^{(m)}}{W_t} + \frac{\alpha_{1t}^{(m)}}{W_t} r_t)] \\ &= \frac{n-1}{n}E_t y_{t+1}^{(n-1)} + \frac{1}{n}y_t^{(1)} - \frac{1}{n}\frac{1}{2}B_{n-1}'\Sigma\Sigma' B_{n-1} \\ &\quad + \frac{1}{n}\gamma B_{n-1}' \mathrm{var}(X_{t+1})\sum_{m=2}^{N}(B_{m-1}\frac{S_m - \alpha_{0t}^{(m)}}{W_t}) \\ &\quad + \frac{1}{n}\gamma B_{n-1}' \mathrm{var}(X_{t+1})\sum_{m=2}^{N}(B_{m-1}\frac{\alpha_{1t}^{(m)}}{W_t}) r_t. \end{aligned} \tag{13}$$

In the empirical study, we use a variable d_t to measure the demand for bonds by the commercial banks as the representative of investors of the two types. When d_t increases, possibly W_t, $\alpha_{0t}^{(m)}$, $\alpha_{1t}^{(m)}$ get large. To make it simple, we assume that $\beta_m \triangleq \alpha_{1t}^{(m)}/W_t > 0$ is a constant and consider $(S_m - \alpha_{0t}^{(m)})/W_t$ as a linear function d_t, $c_{m0} - c_{1m}d_t$, where c_{0m},

c_{1m} are positive constants. Equation (13) can be written using β_m, d_t as

$$
\begin{aligned}
y_t^{(n)} &= \frac{n-1}{n} E_t y_{t+1}^{(n-1)} + \frac{1}{n} y_t^{(1)} - \frac{1}{n}\frac{1}{2} B'_{n-1} \Sigma\Sigma' B_{n-1} \\
&+ \frac{1}{n} \gamma B'_{n-1} \text{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} c_{0m}) \\
&- \frac{1}{n} \gamma B'_{n-1} \text{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} c_{1m}) d_t \\
&+ \frac{1}{n} \gamma B'_{n-1} \text{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} \beta_m) r_t. \qquad (14)
\end{aligned}
$$

In the equation, the first three terms on the right hand determine long-term interest rate according to local expectations hypothesis, while the third term is the convexity effect. The fifth term is demand effect, and the last term is the effect of the official rate. Given the supply, when demand increases, market interest rate deviates from the expectations hypothesis and going down if $B'_{n-1}\text{var}(X_{t+1}) \sum_{m=2}^{N}(B_{m-1}c_{1m}) > 0$. Similarly, if the official rate goes up, market interest rate deviates from the expectations hypothesis and goes up if $B'_{n-1}\text{var}(X_{t+1}) \sum_{m=2}^{N}(B_{m-1}\beta_m) > 0$. Preferred-habitat investors are the only cause for the existence of the last term. Without preferred-habitat investors, Equation (12) becomes $\omega_m = S_m/W_t$, and then β_m in Equation (14) becomes zero. In this situation, the official rate has no effect on the market yields. But the fifth term is still there because S_m/W_t is inversely related to d_t, and thus demand or supply influences bond yields. This confirms Cochrane (2008) and many other studies, which attribute the demand or supply effect to the market incomplete or segmentation. We get to know that the evidence of effect of demand and supply is not sufficient to test the preferred-habitat hypothesis. But according to the model, the effect of the official rate can be used to judge the effect of preferred-habitat investors and therefore verify if the preferred-habitat hypothesis holds on not.

With Equation (14), we can easily get expected excess returns on bonds. Expected excess return on bond with maturity n is

$$
\begin{aligned}
E_t(ex_{t+1}^{(n)}) &= -(n-1)E_t y_{t+1}^{(n-1)} + n y_t^{(n)} - y_t^{(1)} \\
&= \gamma B_{n-1}' \mathrm{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} c_{0m}) \\
&\quad -\gamma B_{n-1}' \mathrm{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} c_{1m}) d_t \\
&\quad +\gamma B_{n-1}' \mathrm{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} \beta_m) r_t \\
&\quad -\frac{1}{2} B_{n-1}' \Sigma\Sigma' B_{n-1}.
\end{aligned} \tag{15}
$$

The equation shows that expected excess return on bond is related to four terms on the right side of the equation. The first term is a constant. The second term is demand effect. Given the supply of bonds, an increase in demand of the bonds from both types of investors causes bond prices go up and expected returns on bonds go down (if $B_{n-1}' \mathrm{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} c_{1m}) > 0$). The third term is the effect of preferred-habitat investors. When official rates go up, preferred-habitat investors will decrease their demand for bonds and lend their fund as loans, bond prices goes down and yields goes up, causing bonds to have high expected returns (if $B_{n-1}' \mathrm{var}(X_{t+1}) \sum_{m=2}^{N} (B_{m-1} \beta_m) > 0$). last term is convexity effect, because we use log excess return (continuously compounded return) here.

All our discussion is in the framework of affine model. Do the assumptions we make above contradict to affine model? If we assume that official rate r_t and demand of investors d_t change but can be perfectly forecasted, then the above assumptions are harmonious with assumptions that make the affine model hold. More reasonably, official rate r_t and demand variable d_t are allowed to change randomly. But if they are state factors or linear functions of state factors, all above are still consistent with affine model.

Another problem is that because we don't have a closed form solutions for $\{B_n\}$ in the above, therefore we have to discuss the effects of demand and official rates on the bond yields and excess returns based on guessing the signs of coefficients of d_t, r_t in Equations (14, 15). In the following, we show a one-factor model as special case of the model above. We can obtain closed-form solutions with the simple model, so the effects can be seen clearly.

We assume official rates and the demand or supply of bonds can be perfectly forecasted, therefore they have no relation with state variables. In the affine framework, there is only one state factor which follows zero-mean mean-reverting process

$$x_{t+1} = -\kappa x_t + \sigma_x \epsilon_{xt}.$$

Short rate is assumed to be

$$y_t^{(1)} = \delta_0 + x_t.$$

In affine model, bond price has the affine form

$$\ln P_t^{(n)} = -A_n - B_n x_t,$$

with similar derivation of Equation (9), we find A_n , B_n satisfy the following equation

$$(B_{n-1}\kappa + B_n - 1)x_t - A_{n-1} + A_n - \delta_0 - \gamma\sigma_x^2 \sum_{m=2}^{N} (\omega_m B_{m-1}) B_{n-1} = 0.$$

In the equation, the coefficient of x_t should be zero, then we get the equation that B_n satisfies

$$B_{n-1}\kappa + B_n - 1 = 0,$$

B_n also satisfies the initial condition

$$B_1 = 1,$$

because of

$$\ln P_t^{(1)} = -A_1 - B_1 x_t = -(\delta_0 + x_t).$$

Solving the equation with the initial condition, we have the solution for B_n as

$$B_n = 1 - \kappa + \kappa^2 - \kappa^3 + ... + +\kappa^{n-1} = \frac{1-\kappa^n}{1-\kappa} > 0,$$

because of $-1 < \kappa < 1$. With the solutions for $\{B_n\}$, we know the coefficients of d_t, r_t in Equations (14) satisfy

$$\frac{1}{n}\{\gamma \frac{1-\kappa^n}{1-\kappa} \text{var}(x_{t+1}) \sum_{n=2}^{N} (\frac{1-\kappa^n}{1-\kappa} c_{1n})\} > 0,$$

$$\frac{1}{n}\{\gamma \frac{1-\kappa^n}{1-\kappa} \text{var}(x_{t+1}) \sum_{n=2}^{N} (\frac{1-\kappa^n}{1-\kappa} \beta_n)\} > 0.$$

Therefore using this model, we find official rates definitely have positive effect on bond yields and returns, while the demand factor has negative effects.

2.2 An preferred-habitat affine interest rate model

In the preceding subsection, we have illustrated how bond yields and excess returns behave with the existence of preferred-habitat investors, using a general affine framework. But we don't assume what the state variables are and how exactly they change dynamically. To analyze the role of the preferred-habitat and demand factors on bond pricing quantitatively in an interest rate model, we have to specify the state vector and its dynamic movement. Recently, there are several studies addressing bond yields using affine models. Duffee (2010) finds unconstrained model with more than 3 factors produces a too high Sharpe ratio and implies overfit using Treasury yield data of the U.S.[4] Furthermore, he compares different Gaussian affine models with more than (including) 3 factors and concludes that they show no big difference in fitting the cross section and forecasting. Duffee (2011) exposes that bond premia cannot be detected using yield data themselves. Ang and Piazzesi (2003) use affine model including macroeconomic variables as state variables and report that the model forecast bond yields better and that macro factors explain much variation in bond yields. Joslin, Priebsch, Singleton (2010) focus on market prices of risks from macroeconomic variables. They assume that macroeconomic variables impact bond investment separately from the information in the bond yields. With these studies in mind, we think it might happen that the effect of the preferred-habitat and demand factors cannot be replaced by the latent variables in the traditional interest rate models. And without them in the state vector we may loss pricing accuracy. To attack this issue, we introduce an affine-type model that includes two latent factors , and one preferred-habitat factor and one bond demand factor, and then estimate it using data in section 4.[5] The model helps us evaluate the marginal contribution of the preferred habitat and demand factors to bond pricing. Our model follows Vaynos and Greenwood (2009), Hamilton and Wu (2011), Dai and Singleton (2000), Ang, etc (2011), Ang and Piazzesi (2003). The state vector is

$$X_t = (z_{1t}, z_{2t}, r_t, d_t)',$$

in which z_{1t}, z_{2t} are two latent factors. Effect of r_t is caused by the existence of preferred habitat investors, and so it is also called the preferred-habitat factor. Similarly, we called d_t the demand factor. We assume that X_t follows VAR(1) process

$$X_{t+1} - \mu = \Phi(X_t - \mu) + \Sigma\varepsilon_t, \qquad \varepsilon_t \sim N(0, I), \tag{16}$$

[4]Principle component analysis suggests 3 factors for the interest rate models.

[5]Principal component analysis exposes that 2 factors can explain 99.7% of the variance of the 5 market yields in our sample.

where the vectors of parameters have the following form

$$\mu = \begin{pmatrix} 0 \\ 0 \\ \mu_3 \\ 0 \end{pmatrix}, \quad \Phi = \begin{pmatrix} \phi_{11} & 0 & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & \phi_{42} & \phi_{43} & \phi_{44} \end{pmatrix}, \quad \Sigma = \begin{pmatrix} \sigma_{11} & 0 & 0 & 0 \\ 0 & \sigma_{22} & 0 & 0 \\ 0 & 0 & \sigma_{33} & 0 \\ 0 & 0 & \sigma_{43} & \sigma_{44} \end{pmatrix}.$$

The restrictions on parameters, $\mu_1 = \mu_2 = 0$, $\phi_{12} = 0$, $\sigma_{12} = \sigma_{21} = 0$, follow Dai and Singleton (2000). $\mu_4 = 0$ is because the detrended demand factor is used in estimation. We further assume that latent and observed factors may mutually Granger cause each other, but they are conditionally independent. This follows Ang, etc (2011). With this assumption, the vector of the observed factors needs not to follow a VAR(1) process itself and can be a more general VARMA process. Also, following the tradition of affine models, we assume that annualized one-period short rate is a linear function of the state variables

$$y_t^{(1)} = \delta_0 + z_{1t} + z_{2t} + \delta_r r_t + \delta_d d_t, \tag{17}$$

the assumption of coefficients of 1 in the equation for latent factors is to make the parameters of the model well identified, which follows Dai and Singleton (2000). The affine assumption allows us to write the log price of n-period zero coupon bond with face value of 1 as a linear function of the state factors as Equation (2). From Equation (16), we get

$$E_t(X_{t+1}) = (I - \Phi)\mu + \Phi X_t,$$
$$\text{var}_t(X_{t+1}) = \Sigma\Sigma',$$

substitute them into Equation (9), we have

$$-A_{n-1} - B'_{n-1}[(I - \Phi)\mu + \Phi X_t] + \frac{1}{2}B'_{n-1}\Sigma\Sigma' B_{n-1} + A_n + B'_n X_t$$
$$-A_1 - B'_1 X_t - \gamma \sum_{m=2}^{N} (\omega_m B'_{m-1})\, \Sigma\Sigma' B_{n-1} = 0. \tag{18}$$

From subsection 2.1, we know in equilibrium, arbitrageur's portfolio depends on the level of official rates and demand for bonds. We have assumed that $(S_m - \alpha_{0t}^{(m)})/W_t$ is a linear form of d_t , and $\alpha_{1t}^{(m)}/W_t$ is a constant. So Equation (12) can be written in the form

$$\omega_m = e_{m,0} - e_{1,m} d_t + e_{2,m} r_t \tag{19}$$

Using Equation (19) to substitute bond weight in Equation (18), we get the equation

$$\begin{aligned}
& A_n - A_{n-1} - A_1 - B'_{n-1}(I-\Phi)\mu \\
& +(B'_n - B'_{n-1}\Phi - B'_1)X_t + \frac{1}{2}B'_{n-1}\Sigma\Sigma B_{n-1} \\
= \ & \gamma \sum_{m=2}^{N}[(e_{m,0} - e_{m,1}d_t + e_{m,2}r_t)B'_{m-1}]\Sigma\Sigma' B_{n-1} \\
= \ & \gamma B'_{n-1}\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,0} - B_{m-1}e_{m,1}d_t + B_{m-1}e_{m,2}r_t) \\
= \ & \gamma B'_{n-1}\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,0}) - \gamma B'_{n-1}\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,1})d_t \\
& +\gamma B'_{n-1}\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,2})r_t \\
\equiv \ & B'_{n-1}\theta_0 - B'_{n-1}\theta_d d_t + B'_{n-1}\theta_r r_t,
\end{aligned} \tag{20}$$

where

$$\begin{aligned}
\theta_0 &\triangleq \gamma\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,0}), \\
\theta_d &\triangleq \gamma\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,1}), \\
\theta_r &\triangleq \gamma\Sigma\Sigma' \sum_{m=2}^{N}(B_{m-1}e_{m,2}).
\end{aligned}$$

The terms without state variables should be equal on the both sides of Equation (20), and the same is for coefficients of the state vector, thus we have

$$A_n = A_{n-1} + A_1 + B'_{n-1}[(I-\Phi)\mu + \lambda_0] - \frac{1}{2}B'_{n-1}\Sigma\Sigma' B_{n-1}, \tag{21}$$

$$B_n = B'_{n-1}(\Phi + \lambda_1) + B_1, \tag{22}$$

the new parameters λ_0, λ_1, are determined by θ_0, θ_d ,θ_r as

$$\lambda_0 = \theta_0, \qquad \lambda_1 = \begin{pmatrix} 0 & 0 & \theta_{r,1} & \theta_{d,1} \\ 0 & 0 & \theta_{r,2} & \theta_{d,2} \\ 0 & 0 & \theta_{r,3} & \theta_{d,3} \\ 0 & 0 & \theta_{r,4} & \theta_{d,4} \end{pmatrix}.$$

Although λ_1 involves 8 possible non-zero parameters theoretically, in model estimation we estimate a simplified form with only two non-zero parameters: $\theta_{r,3}$, $\theta_{d,4}$. This means only risk associated with each of observed factors get compensated with a time-varying risk premium determined by the factor. This is a common assumption in empirical examination, such as Ang and Piazzesi (2003). Usually the time-varying risk premium parameters in interest rate model are difficult to estimate. Furthermore, our model involves four state variables, which makes the estimation more challenging. Making such a simplification doesn't harm our purpose. If two observable variables are proved to have significant contribution in bond pricing in this simplified model, they must be useful in the general form. So we assume λ_1 has the following form in model estimation

$$\lambda_1 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \theta_{r,3} & 0 \\ 0 & 0 & 0 & \theta_{d,4} \end{pmatrix}.$$

The equations of (21, 22) can be used to get $\{A_n, B_n\}$ recursively with the following initial condition gotten using Equation (17)

$$\begin{aligned} A_1 &= \delta_0 h, \\ B_1 &= (1, 1, \delta_r, \delta_d)' \times h, \end{aligned}$$

where h is the length in years of one period. For monthly data, $h = 1/12$. For zero coupon bond with maturity of n years, its annualized yield is

$$\begin{aligned} y_t^{(n/h)} &= -\frac{1}{n}\ln P_t^{(n/h)} \\ &= \frac{1}{n}A_{n/h} + \frac{1}{n}B'_{n/h}X_t \\ &\equiv a_n + b'_n X_t, \end{aligned} \tag{23}$$

where $a_n \triangleq \frac{1}{n}A_{n/h}$, $b_n \triangleq \frac{1}{n}B_{n/h}$.

3 Background of Chinese bond market and data

3.1 Bond market

Compared to the stock market, Chinese bond market became prosperous relatively late. In 1997, there were 23 bonds being traded in Shanghai Stock Exchange, including Treasury bonds, financial institutional bonds and corporate bonds, with a total market value of RMB 240.5 billions. 1997 was also a milestone in Chinese bond market with the introduction of the interbank bond market, which made more debt instruments available and ensured greater trading volumes. The interbank market is designed for financial institutions to trade for fixed income instruments. The commercial banks are allowed to trade only in the market since it started. So commercial banks cannot hold stocks and hence their assets are mainly restricted to loans and bonds. To have a glance of rapid development of Chinese bond market, Figure 1 shows the values of outstanding tradable bonds from 2001 to 2010.[6] In 2001, the total value of tradable bonds outstanding was RMB 1.68 trillions, and amounted to only 15% of GDP of that year. The bond market expanded every year with a quick step. At the end of 2010, the value of tradable bonds outstanding grew to RMB 17.29 trillions. The ratio of the value of bonds outstanding to GDP also increased gradually. In 2005, the ratio was 31%, and finally in 2010, it reached to 45%. The fast expansion indicates that the bond market has been playing an increasingly important role in the booming China economy.

(Insert Figure 1 here)

3.2 A glimpse of Chinese monetary policy

During the past three decades, banking system and monetary policy have experienced great changes. In 1994, the People Bank of China (PBC), the central bank, started to use classical monetary instruments, such as open market operations, interest rates setting, and reserve requirements to fine tune the economy. In 1998, the PBC lifted its control over the scale of loans issued by state-owned commercial banks and declared that monetary policy would be mainly conducted by adjusting the money supply, with the immediate targets being the growth of M1 and M2. At the same time, the PBC continued to set deposit and lending interest rates of different maturities with which commercial banks could accept deposits and lend loans.

The PBC sets official rates for three objectives: 1) to ensure a stable and reasonable growth of deposits and to deliver reasonable incomes for depositors; 2) to minimize the financing costs of business, especially state-owned companies; and 3) to make due allowance for commercial banks' expenses and profits. Figure 2 exhibits the term structure of the lending interest rates from January 2001 to December 2010. This figure draws 5 official rates including the short-terms and long-terms. The official rates are changed in

[6]There are also some Treasury bonds called saving Treasury bonds, most of which are held by individual investors. They are usually held to maturities.

a low frequency and are always changed at the same time. Long-term official rates are always larger than short-term official rates. Because they are highly correlated, we use their average to indicate these lending interest rates of different terms in the following. The average is defined as [7]

$$r_t = (r_t^{(6-)} + r_t^{(12-)} + r_t^{(36-)} + r_t^{(60-)})/4,$$

where $r_t^{(6-)}$ is the lending interest rate for loans with maturities less than or equal to 6 months; $r_t^{(12-)}$ is the lending interest rate for loans with maturities less than or equal to 12 months but longer than 6 months; $r_t^{(36-)}$ is the lending interest rate with maturities less than or equal to 36 months but longer than 12 months; $r_t^{(60-)}$ is the lending interest rate with maturities less than or equal to 60 months but longer than 36 months.

(Insert Figure 2 here)

3.3 Bond trading of the commercial banks

The commercial banks system in China was formally established in 1994 when the PBC decided to split its functions of accepting deposits and lending loans to commercial banks. In the early period, the commercial banks lent loans to state owned firms and did not worry about possible defaults. After Asia financial crisis in 1997, many loans defaulted, causing high risk for many commercial banks. Since then, the commercial banks started to pay attention to credit risk when lending their funds. Because of low default risk of bonds, especially Treasury bonds, the commercial banks take a proportion of bonds to be instead of loans to reduce their asset portfolio risk. In addition to low default risk, bonds are tradable and high liquid whereas loans cannot be traded. In this sense, bonds are ideal instruments for the commercial banks to manage their fund liquidity. That is, when the commercial banks have extra funds after lending their loans or buying bonds which tend to be held to maturities, they buy bonds with the funds; when their funds are tense, they can sell bonds to meet the demand of liquidity. In this way, they use portfolio of bonds to seek short-term return while satisfying the requirements of fund liquidity. Because the commercial banks are the biggest players in the bond markets (holding more than 60% of bonds outstanding at the end of 2010), their trading behaviors have important effect on the bond yields. When they take bonds as substitutes of bank loans, they compare

[7] Because our market rates in the sample are with maturities from 1 to 5 years, the average of official rates don't involve the interest rate with maturity longer than 60 months (5 years). Actually, either the long-term rate is included or not does't change empirical results materially.

bond yields to the lending rates of loans. This makes the commercial banks behave like preferred-habitat investors. When the commercial banks make liquid management, they balance their bond portfolios with the tradeoff of short term return and risk. This is exactly what arbitrageurs do.

We should also mention the influence of the PBC on bond trading behavior of the commercial banks. Because the lending rates have been specified by the central bank and economic background is exogenous for the commercial banks, the commercial banks have no much things to do with loan demand. Funds of the commercial banks are mainly from deposits, which closely relate to the central bank's money supply policy. For example, when the central bank decided to stimulate the economy after Asian financial crisis started in 1997 and worldwide financial crisis after 2007, money supply grew faster than usual, and the commercial banks found that they had large deposits, which make them have large funds to invest. In these situations, while demand of loans was stable, spread between deposits and loans widened, and thus the commercial banks had to hold more bonds. In other situations, when the central bank found that it was necessary to reduce money supply for fighting against inflation or hotness of economy, such as in the ends of 2004 and 2010, the deposits of the commercial banks decreased. Because of illiquidity of loans, the commercial banks had to reduce their holding of marketable bonds. Therefore, change in the difference between values of deposits and loans was determined by the monetary policy to some degree, and thus partially out of control of the commercial banks. Without other choices, they have to spend (get) the extra funds by taking (selling) bonds. Of course, even if the monetary policy keeps unchanged, when the commercial banks decide to takes more bonds as the substitutes of bank loans, the difference becomes larger also. So the difference in values of deposits and loans of all the commercial banks can be used as a measure of commercial banks' demand for bonds to represent demand of both preferred-habitat investors and arbitrageurs.

Figure 1 shows the difference in values of deposits and loans of all the commercial banks in the past ten years. It grew fast and steadily. There were two main reasons for the growth. The first is due to the growing scale of economy. Deposits and loans grew every year because the GDP and price level kept positive growth rates usually, and the money supply was even with a larger growth rate than the sum of that of the GDP and price level. The second reason is that the commercial banks needed bonds in a growing proportion in their asset portfolios because of low risk and tradability of bonds. This growing trend of demand was somehow met by the growing bond market. We have mentioned that bond supplies increased with a high speed. Also, there are two possible main reasons for the growth of bond market: (1) high growth of Chinese economy needed more fund financing through bond issuance; and (2) Strict policy restrictions loosen with time, and financing by issuing bonds was available to more institutions and companies with more instruments introduced in the market.

To construct a factor to measure demand for bonds by the commercial banks, We use the difference in log values of deposits and loans

$$d_t = \ln(\text{deposits}_t) - \ln(\text{loans}_t).$$

The upper-left panel of Figure 3 shows the monthly observations of the demand factor, d_t, from the beginning of 2001 to the end of 2010. The factor was about 20% at the start of the sample. It is obvious that there was a positive trend in the demand factor. Its maximal value was about 38%, which happened at the end of 2008. To have a view of influence of the demand factor on market interest rates, we draw the 5-year market interest rate, $y_t^{(60)}$, in the lower-left panel to compare with the factor. We find that during most of time of the sample, when the factor rose (fell) locally, the market interest rate went down (up). The market interest rate had no obvious trend, so its variation was mainly related to local change of the demand factor rather than its trend. To make it clear, in the lower-left panel, we also draw the detrended demand factor, dd_t.[8] We see an apparently negative correlation between dd_t and the market interest rate. Why was there no obvious effect of the trend of the demand factor on market interest rates? It is possible that the demand trend was met by the growth trend of the supply of bonds as we have mentioned in the last paragraph. In the upper-right panel of the figure, we show annually changes of the demand factor, $d_{t+12} - d_t$, and in the lower-right panel we draw annually change of the 5-year market interest rate, $y_{t+12}^{(60)} - y_t^{(60)}$. As expected, they were negatively correlated. The figure further suggests that change in the demand factor led to change of the market interest rate to some degree. In short, we have a rough impression that the demand for bonds of the commercial banks, measured by the demand factor, negatively affected the market interest rates.

(Insert Figure 3 here)

3.4 Market interest rates and bond excess returns

To make our results comparable to others, such as Fama and Bliss (1987), Cochrane and Piazassi (2005), and Ludvigson and Ng (2009), we focus on yields and excess returns on

[8] dd_t is the residual of the OLS regression, $d_t = a + b \times t + dd_t$.

zero coupon bonds with maturities ranging from one to five years. Because most traded Treasury bonds pay interests before maturity, we use a polynomial spine to fit trading prices of Treasury bonds and obtain zero-coupon bond yields for maturities from one year to five years. Figure 4 shows one-year, three-year, and five-year market interest rates in the upper panel and annually excess returns on zero-coupon bonds with maturities of two, three, and five years in lower panel. The market interest rates went up and down several times in the sample. Combining with the information from Figures 2 and 3, we see that the market interest rates went down from 2001 to 2002, which was accompanied by the decrease of official rates. Market interest rates went up from the start of 2003 and picked at 2005. This corresponded to the tense of funds measured by the detrended demand factor. The market interest rates picked at the second half of 2007 and the second half of 2008 accompanied by high official rates and tightness of fund. The market interest rates went downward after 2008 with the fall of the official rates and loose of fund. Bond excess returns were positive most of time during the sample period, but there were three subperiods with slight negative excess returns on bonds. Therefore, the averages of excess returns on bonds were positive.

(Insert Figure 4 here)

Finally, Table 1 presents the basic statistics of the variables that will be used for empirical study. On average, like in most developed markets, the term structure of market interest rates has a positive slope. But long-term market interest rates have slightly larger standard deviations than short-term market rates. This is different from that in most developed markets. Market interest rates do not have significant skewness and kurtosis. Furthermore, the autocorrelations of market interest rates are high with lag of one, but the autocorrelations decrease quickly with increase of lag and are almost zero when lag is 9 months. The second panel of Table 1 is for the official interest rates and the demand factor. It reports statistics for short-term, long-term, and the level of official rates of different terms. Their averages are higher than that of market interest rates with the similar maturities. This is because of credit and liquidity differences between Treasury bonds and bank loans. Their standard deviations have similar values as that of market interest rates of the same terms. Similar to market interest rates, the long-term official rates have slight larger volatilities than the official rates of short-terms. This suggests that the unique term structure of volatilities of market yields is caused by the unique term structure of volatilities of official rates. The third panel is for annually excess returns on bonds. The average excess returns on bonds are positive. Long-term bonds have larger average returns than short-term bonds. Standard deviations are also larger for excess returns on longer term bonds. Autocorrelations of excess returns are high with lag of one month because the samples are overlapped, but the autocorrelations decrease quickly with increase of lag and are almost zero when time lag is 9 months.

(Insert Table 1 here)

4 Empirical evidence

4.1 Effects on bond yields and excess returns

From Section 2, we know from the theoretical model, when official rates go up, arbitrageurs are compensated with a high risk premium for their risky portfolio in equilibrium. Similarly, when demand for bonds becomes higher, arbitrageurs require only a low risk premium. Hence the market yields may be affected positively by official rates and negatively by demand for bonds through their effect on risk premia. Maybe there are other channels through which official rates and demand for bonds affect market yields. These variables may affect current short-term rate and the expectations of future interest rates and eventually affect current long-term rates. If that is true, the net effects on market yields of the two kinds of variables are still not clear. To test the theoretical model, we do regression analysis using both market yields and excess returns on bonds. For market yields, we construct the following regression equation to examine Equation (14) for determining market interest rates

$$y_t^{(n)} = \psi_0 + \psi_1 r_t + \psi_2 d_t + \zeta_t^{(n)} \tag{24}$$

From Figure 2, we find that change of d_t leads to change of $y_t^{(n)}$ to some degree. Thus in the regression, we use current detrended demand factor dd_t, its three-month lag dd_{t-3}, or the average of its values of past six months $\bar{d}_t = (\sum_{q=0}^{5} dd_{t-q})/6$ as the representative of demand factor. Suggested by Equation (14), we may have $\psi_1 > 0$, $\psi_2 < 0$. The regression results are presented in table 2.

(Insert Table 2 here)

Table 2 exhibits the estimates of the regression equation. The Newey-West t ratios are adjusted for a lag of 9 months as suggested in Table 1. From the first panel, we see that the level of official rates have significantly positive effects on market interest rates of all terms. The demand factor has significantly negative effect on market interest rates.

The Adj. R^2's range from 0.27 to 0.42. The different measures of demand for bonds have similar effects, and the averaged demand factor has largest effect. The results are consistent with Equation (14).

From Equation (15) in the theoretical model, expected excess returns on bonds mainly consist of two parts: positive effect of official rate; negative effects of demand factor. Actually, many studies use slope of market yield curve to predict bond excess returns (Fama, Bliss, 1987; Campbell, Shiller, 1991). It is also true that, as a mathematical equation, the slope of yields contains either the information about the expectation of future short rates or the deviation from the expectations hypothesis. In the late case, it can be used to predict bond excess returns. Thus, we include the slope of market rates as an explaining variable. Finally, we construct the following regression equation.

$$ex_{t+12}^{(n)} = \varsigma_0 + \varsigma_1 r_t + \varsigma_2 d_t + \varsigma_3 (y_t^{(60)} - y_t^{(12)}) + \nu_{t+12}, \tag{25}$$

where $ex_{t+12}^{(n)}$ are one-year excess returns on bonds with maturities of 24, 36, 48, 60 months and computed as

$$ex_{t+12}^{(n)} = \frac{n}{12} y_t^{(n)} - \frac{n-12}{12} y_{t+12}^{(n-12)} - y_t^{(12)}.$$

When talking about predictability of excess returns on bonds, people are used to using annual returns although the data are monthly observed. We also use annual returns to do the regression. So our empirical results can be compared conveniently with that in other papers. Empirical results with annual returns also cause no trouble to be compared with what are predicted by theoretical model, because one time period can be one-year or any other length in the theoretical model introduced in Section 2.

The regression results are presented in Table 3. The Newey-West t ratios are also adjusted for a lag of 9 months suggested in Table 1. The first three panels expose that official rate and demand factor are useful to predict bond excess returns. Higher the level of official rates are, higher bond excess returns on average would be; when the demand of bonds is higher, bonds have a lower expected returns. About the three different measures of demand for bonds, Lagged demeaned demand factor dd_{t-3} shows higher predictability than current demeaned demand factor dd_t, while the average demand factor $\bar{d}_t$ shows the highest marginal predictability among them. Panel 4 confirms the worldwide evidence that the slope of market rates can predict bond excess returns. With all the three variables as predictable variables, bond excess returns are highly predicted and the Adj R^2's are from 40% to 44%. The effects of the official rate and demand factor are still significant when the slope of market rates is an explaining variable. The results are all consistent with the preferred habitat model.

(Insert Table 3 here)

4.2 Pricing rule of preferred-habitat and demand factors

In this subsection, we estimate the interest rate model developed in subsection 2.2. Our purpose is to examine if the observable factors are still useful and what their marginal contributions to bond pricing are when the latent factors are present.We still use the level of official rates r_t as the preferred-habitat factor. Base on the evidence in subsection 4.1, we use the six-month average of demeaned demand factor $\bar{d}_t$ as the demand factor. To estimate parameters in the model, we use the similar methodology of Ang and Piazzesi (2003) to maximize the likelihood function of the observed factors and market yields. We assume one-year and five-year market interest rates are observed without error, using Equation (23) to get the two unobservable latent factors. With the same method of Ang and Piazzesi (2003), we obtain the likelihood for the five market yields and the observable factors. Different from Ang and Piazzesi (2003), however, we estimate the model by dividing the parameters into different blocks. We maximize the likelihood with each block iteratively until the maximum value don't change. We finally estimate the t-values of estimated parameters using simulation by bootstrap sampling. Specially, diagonal elements of Φ are usually large and are put into one block; non-diagonal parameters in Φ are usually small and are put into another block; parameters in Σ are formed into one block; parameters in λ_0 are in one block, and parameters of λ_1 are in another block; parameters determining short rate in Equation (17) is in one block; one block is for standard deviations of observing errors of 2, 3, 4 year market rates; μ_3 itself is in one block.

Table 4 shows the estimates of parameters in the preferred-habitat pricing model. The first panel gives the estimates of μ and the companion matrix Φ. The level of official rates has an unconditional mean 4.4 percent, which is reasonable. Latent and observed variables are highly persistent. It is in line with other studies that latent variables are persistent (Ang and Piazzesi, 2003; Duffee, 2011). The average of official rates is highly persistent, and this is consistent with Table 1 and Fig. 2. The demand factor shows high persistence because of the average is used. The first latent factor shows predicting ability for the official rate and demand factor because the estimated values of ϕ_{31}, ϕ_{41} are significant. The second latent factor has predicting ability for the demand factor because ϕ_{42} is significantly negative. On the contrary, the two observed variables show a little predictability for the two latent factors because only ϕ_{23} is significantly different from zero in upper triangular part of the matrix. The second panel is for volatility parameters of the four state variables. Small values of these parameters indicate the four factors are highly predicated by their lagged values. The third panel tells that the official rate and the demand factor have effect on current short-term interest rate. The fourth and fifth panels give the estimated risk premium parameters. We find that the time-varying risk premium parameters are very small. This seems inconsistent with the regression results in Table 3 in which we find official rates and demand factor have obvious effects on bond excess returns. The intuition is as follows. The difference is mainly that the annually returns are used in the regression. Whereas in Table 4, the parameters are used to explain monthly excess returns.[9] Take the demand factor as an example, we have found that the demand factor leads to change of market rates. When demand factor is high, bond prices of current time and next month are positively affected to be high. This makes returns next month be not obviously affected by current demand factor. For annually returns, the demand factor affects current bond prices but not the bond prices one year later, therefore the demand factor can explain annually bond returns significantly. The last panel is the estimated standard deviation parameters of the fitting errors of yields with maturities of 2, 3, 4 years. The small estimated values show that the preferred-habitat interest rate model fits the data sample very well. Overall, the model parameters are estimated with high accuracy indicated by large t values. This is because of small estimated values for residuals in the VAR model (Equation (16)), and small fitting errors of the 2, 3, 4 year market yields.

(Insert Table 4 here)

Table 5 shows the performance of the model for fitting bond yields and predicting future yields and bond returns 1, 3, 6, 12 month ahead in the sample period. Without the two observed factors, the preferred-habitat interest rate model reduces to a standard two-factor Vasicek model. To show the improvement of the preferred-habitat model, we also report the corresponding performance of the two-factor Vasicek model to make a comparison. We assume that the 1 and 5 year yields are observed without errors to get the likelihood of market yields and two observed variables in the two-factor Vasicek model, and then estimate the parameters through maximizing the likelihood. The method for making the estimation is standard, and the estimated parameters are not reported for saving space. We predict bond yields and annualized returns on bonds p-month ahead

[9] With the bond yield data in the US, it is also found the expected monthly and annually returns are quite different. See Duffee (2011).

using the following equation

$$E_t(y^{(n)}_{t+p}) = a_n + b'_n E_t(X_{t+p}) \qquad (p = 1, 3, 6, 12),$$

$$E_t(r^{(n)}_{t+p}) = [-A_{n-p} - B'_{n-p} E_t(X_{t+p}) + A_n + B'_n X_t] \times \frac{12}{p} \qquad (p = 1, 3, 6, 12).$$

The preferred-habitat model shows a significant improvement over two-factor Vasicek model in bond pricing through reducing mean absolute errors (MAEs) in fitting by around 5 BPs for 2, 3 year market yields and around 2 BPs for 5 year market yield. It also makes more accurate predictions for various yields and bond excess returns at different forecasting horizons with smaller MAEs than the Vasicek models. Possibly there is a concern why not comparing the preferred-habitat model with essential affine models which allow the risk premium to change with the state variables. Duffee (2010) has found the essential affine model may over-fit bond yields and returns. Duffee (2011), Joslin, Priebsch, Singleton (2010) only allow the level factor risk to be priced with time-varying character based on preceding papers studying on bond excess returns. So far few studies give clues to how the latent factors enter the risk premium for China bond market,.

(Insert Table 5 here)

To make further analysis, Table 6 reports the variance decompositions of the 5 market interest rates. They are computed through the preferred-habitat model with the estimated parameters. The official rate shows big contributions to the variations of all the 5 market rates. For the 1, 2 and 3 year rates, the proportions accounted for by the official rate have a hump-shaped pattern. Specifically, for one-month ahead forecast, it makes contributions of around 11, 17, 21 percent of the variances for 1, 2 and 3 year interest rates. The proportions increase to around 16, 21, 22 percent for 1, 2, 3 year interest rates at 12-month horizon, and then declines to around 16, 15, 14 percent respectively at 60-month forecasting horizon. For longer term interest rates with maturities of 4, 5 years, above 22 percent of the variances are attributed to the official rate for one-month ahead forecast, and then the contributions decrease with the increase of forecasting horizon. For demand factor, its contributions are a little. This is because the demand factor affects different market interest rates with a small coefficients and its effect is absorbed by two latent factors to some degree.[10]

[10]Estimated values of the fourth elements of b_n in Equation (23), $b_{n,4} (n = 1, 2, 3, 4, 5)$, are -0.23, -0.21, -0.20, -0.18, -0.16 respectively. From values of Φ in Table 4, two latent factors can predict the demand factor, but demand factor show no predicability for latent factors. So in the variance decomposition, latent factors are attributed to the variations that move latent and the demand factors.

(Insert Table 6 here)

5 Conclusion

With the events happened recently in bond markets, it is realized that not only fundamentals but also other factors, such as demand or supply factors, have influences on bond yields. Some studies use preferred-habitat hypothesis to explain, while others consider market segmentation as the cause. Using an affine-type preferred-habitat model, we find that, in incomplete markets, demands of both the preferred-habitat investors and arbitrageurs have effects on bond market. Moreover, the model also shows that the preferred-habitat investors' alternative investment opportunities of bonds have effect on market yields and excess returns on bonds. An increase in demand by investors of all the two types results in low market yields and expected returns on bonds, and the rise in yields of the alternative investment opportunities causes high market yields and expected returns on bonds.

To test the preferred-habitat hypothesis, it is critical to find the effect that it is only relevant to preferred-habitat investors. Thus evidence of demand effect cannot help, but the evidence of effect of alternative investment opportunities can be used to support the preferred-habitat hypothesis. Chinese bond market data have the unique yield curve of official rates for measuring the alternative opportunities of bonds and demand of the major investors. This makes it possible to check the effects of both alternative investment opportunities and demand.

Using Chinese bond market data from 2001 to 2010, we find that, as the preferred-habitat model suggested, market rates and excess returns on bonds are positively affected by the preferred-habitat factor. Excess returns on bonds are highly predicted by predetermined factors including the preferred-habitat factor. So our evidence supports preferred-habitat hypothesis. We also supplement the literature by showing evidence of effects of demand for bonds on market yields and bond returns. The demand factor, constructed with deposits and loans of commercial banks, negatively affects bond yields and returns.

We further discuss whether the preferred-habitat and demand factors should be included or not in state variables in the affine interest rate model. We examine an affine model consisting of two latent and the two observed variables. The preferred-habitat and demand factors still affect market yield significantly when the latent factors are present. They improve bond pricing by reducing the fitting errors and predicting future bond returns and market yield more accurately. Variance decomposition analysis tells that the preferred-habitat factor explains a part of the variation of bond yields, but the demand factor contributes a little.

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Table 1: Summary statistics

	Moment				Autocorrelation			
	Mean	Std	Skew	Kurt	1	3	6	9
				Bond yield				
$y_t^{(12)}$	2.09	0.54	0.39	2.42	0.85	0.60	0.24	0.00
$y_t^{(24)}$	2.42	0.54	0.52	2.48	0.89	0.64	0.25	0.03
$y_t^{(36)}$	2.73	0.57	0.60	2.45	0.92	0.68	0.31	-0.01
$y_t^{(48)}$	3.00	0.62	0.64	2.43	0.93	0.72	0.37	0.04
$y_t^{(60)}$	3.22	0.65	0.66	2.46	0.94	0.74	0.42	0.09
				Official rate and demand factor				
$r_t^{(6-)}$	5.35	0.50	1.28	3.68	0.97	0.85	0.63	0.40
$r_t^{(60-)}$	6.02	0.66	1.55	4.09	0.98	0.88	0.70	0.51
$\bar{r}_t$	5.79	0.63	1.50	4.04	0.98	0.87	0.68	0.47
d_t	28.73	5.03	-0.40	1.52	0.97	0.93	0.86	0.79
dd_t	0.00	1.89	0.37	2.17	0.93	0.82	0.66	0.50
				Excess return				
$ex_t^{(24)}$	0.76	0.87	0.33	2.20	0.93	0.72	0.31	-0.10
$ex_t^{(36)}$	1.41	1.89	0.34	2.25	0.95	0.75	0.36	-0.04
$ex_t^{(48)}$	1.89	3.08	0.29	2.25	0.95	0.77	0.39	-0.00
$ex_t^{(60)}$	2.17	4.34	0.22	2.26	0.95	0.77	0.41	0.02

This table reports statistics include mean (Mean), standard deviation (Std), skewness (Skew), kurtosis (Kurt) and autocorrelation coefficients ρ_i of lag i months, where $i = 1, 3, 6, 9$. $y_t^{(n)}$ is the market interest rate with maturity of n months ($n = 12, 24, 36, 48, 60$); $r_t^{(6-)}$ is the lending interest rate with maturity less than or equal to 6 months, $r_t^{(60-)}$ is the lending interest rate with maturity less than or equal to 60 months but more than 36 months. The average of official interest rates, r_t, is defined as $r_t = (r_t^{(6-)} + r_t^{(12-)} + r_t^{(36-)} + r_t^{(60-)})/4$. d_t is the demand factor; dd_t is the detrended demand factor. $ex_t^{(n)}$ is annually excess return from $t-12$ to t ($n = 24, 36, 48, 60$). The sample period is January 2001 to December 2011. All figures in this table are in percent and are annualized.

Table 2: Effects of the official rate and demand on the market interest rates

Maturity (years)	Constant	Official rate	Demand for bond	Adj. R^2
		Demand for bonds is measured by dd_t		
1	-0.96	0.53	-0.09	0.30
	(-1.15)	(3.63)	(-2.47)	
2	-0.91	0.58	-0.10	0.38
	(-1.26)	(4.72)	(-4.11)	
3	-0.81	0.62	-0.12	0.38
	(-1.17)	(5.53)	(-5.89)	
4	-0.66	0.64	-0.13	0.36
	(-0.91)	(5.74)	(-6.34)	
5	-0.48	0.64	-0.14	0.32
	(-0.62)	(5.53)	(-5.87)	
		Demand for bonds is measured by dd_{t-3}		
1	-0.82	0.51	-0.08	0.28
	(-0.94)	(3.28)	(-2.23)	
2	-0.82	0.57	-0.10	0.37
	(-1.09)	(4.29)	(-3.64)	
3	-0.76	0.61	-0.13	0.40
	(-1.10)	(5.23)	(-4.69)	
4	-0.64	0.64	-0.15	0.38
	(-0.95)	(5.77)	(-4.83)	
5	-0.48	0.65	-0.15	0.35
	(-0.69)	(5.85)	(-4.49)	
		Demand for bonds is measured by $\bar{d}_t$		
1	-0.93	0.53	-0.09	0.30
	(-1.04)	(3.34)	(-2.32)	
2	-0.93	0.59	-0.12	0.39
	(-1.23)	(4.41)	(-3.73)	
3	-0.88	0.63	-0.15	0.42
	(-1.28)	(5.42)	(-4.87)	
4	-0.76	0.66	-0.16	0.40
	(-1.14)	(6.02)	(-5.10)	
5	-0.60	0.67	-0.17	0.37
	(-0.87)	(6.10)	(-4.78)	

This table reports the results of regressing market interest rates on official rate and demand factor. Three different measures of bond demand are used: demeaned demand factor dd_t at current time t, demeaned demand factor with lag of 3 months, dd_{t-3}, and the average of demeaned demand factors of the last six months $\bar{d}_t$. Numbers in the parentheses are Newey-West t statistics, which are are adjusted for a lag of 9 months. The sample period is from January of 2001 to December of 2010.

Table 3: Predicting excess returns on bonds

Maturity (years)	Constant	Official rate	Demand factor	Slope of market rates	Adj. R^2
			Official rate, and demand factor dd_t		
2	-3.49	0.75	-0.19		0.28
	(-4.37)	(6.58)	(-2.51)		
3	-7.35	1.54	-0.39		0.25
	(-3.74)	(5.40)	(-2.17)		
4	-11.38	2.33	-0.57		0.21
	(-3.26)	(4.54)	(-1.85)		
5	-15.43	3.08	-0.73		0.18
	(-2.97)	(4.01)	(-1.60)		
			Official rate, and demand factor dd_{t-3}		
2	-3.51	0.75	-0.22		0.33
	(-5.14)	(8.15)	(-3.13)		
3	-7.59	1.58	-0.50		0.32
	(-4.55)	(6.88)	(-2.99)		
4	-12.00	2.45	-0.78		0.29
	(-3.94)	(5.69)	(-2.75)		
5	-16.48	3.28	-1.05		0.26
	(-3.52)	(4.88)	(-2.52)		
			Official rate, and demand factor $\bar{d}_t$		
2	-3.69	0.79	-0.25		0.36
	(-5.69)	(9.15)	(-3.16)		
3	-7.95	1.65	-0.56		0.34
	(-4.86)	(7.36)	(-2.92)		
4	-12.51	2.54	-0.87		0.30
	(-4.13)	(5.94)	(-2.63)		
5	-17.12	3.40	-1.15		0.27
	(-3.65)	(5.05)	(-2.38)		
			Slope of market rates		
2	0.12			0.58	0.12
	(0.35)			(2.04)	
3	-0.33			1.57	0.19
	(-0.42)			(2.50)	
4	-1.26			2.83	0.24
	(-0.94)			(2.76)	
5	-2.54			4.22	0.27
	(-1.31)			(2.93)	

Table 3 Continued

Maturity (years)	Constant	Official rate	Demand factor	Slope of market rates	Adj. R^2
		Official rate, demand factor $\bar{d}_t$, slope of market rates			
2	-3.80	0.73	-0.22	0.38	0.40
	(-6.98)	(7.06)	(-3.03)	(1.62)	
3	-8.29	1.48	-0.46	1.15	0.44
	(-6.83)	(6.28)	(-2.58)	(2.23)	
4	-13.16	2.21	-0.68	2.22	0.44
	(-6.14)	(5.40)	(-2.16)	(2.53)	
5	-18.12	2.89	-0.86	3.43	0.44
	(-5.50)	(4.73)	(-1.83)	(2.69)	

This table reports the results of predicting annually excess returns on Treasury bonds with maturities of one to five years from month t to month $t+12$. The explaining variables are official rate r_t, demand factor, and slope of market interest rates, $y_t^{(60)} - y_t^{(12)}$. Different measures of demand for bonds are used. They are demeaned demand factor, dd_t, at current time t, demeaned demand factor with lag of 3 months, dd_{t-3}, and average of demeaned demand factors of the last six months, $\bar{d}_t$. Numbers in the parentheses are Newey-West t statistics, which are are adjusted for a lag of 9 months. The sample period is from January of 2001 to December of 2010.

Table 4: Estimated parameters of the preferred habitat interest rate model

$\mu(\times 100)$	Φ			
0	0.939	0	-0.004	0.001
(–)	(59.2)	(–)	(-0.3)	(0.2)
0	0.082	0.964	0.048	-0.004
(–)	(2.7)	(155.1)	(3.7)	(-0.6)
4.40	-0.326	-0.018	0.978	0.008
(43.5)	(-8.4)	(-0.6)	(164.0)	(0.6)
0	-0.154	-0.094	0.043	1.004
(–)	(-2.6)	(-3.5)	(1.2)	(107.7)
		$\Sigma(\times 100)$		
σ_{11}	σ_{22}	σ_{33}	σ_{44}	σ_{43}
0.086	0.307	0.144	0.235	-0.019
(2.8)	(8.4)	(4.9)	(13.4)	(-1.1)
δ_0	δ_{z1}	δ_{z2}	δ_r	δ_d
-0.022	1	1	0.538	-0.236
(-3.9)	(–)	(–)	(4.7)	(-6.9)
			$\lambda_0(\times 100)$	
	latent 1	latent 2	official rate	demand factor
	0.020	-0.06	0.137	0.049
	(3.4)	(-4.5)	(9.1)	(4.1)
			$\lambda_1(\times 100)$	
			$\theta_{r,3}$	$\theta_{d,4}$
			0.018	-0.054
			(1.3)	(-0.7)
		$\sigma_\varepsilon(\times 100)$		
1-year	2-year	3-year	4-year	5-year
0	0.019	0.026	0.021	0
(–)	(9.7)	(10.5)	(12.2)	(–)

This table reports estimated parameters and their t values of the preferred-habitat interest rate model. The model is described in Subsection 2.2. Yields on bonds with maturities of 1 and 5 years are assumed to be observed without any error. But yields of 3, 4, 5 years are assumed have independent observation errors. The monthly sample data is from January 2001 to December 2010. The t values are computed from Monte Carlo simulations. In the simulation, we first generate randomly 120 monthly data using bootstrap sampling through the model with estimated parameters, and then re-estimate the parameters. The procedure is repeated 1000 times.

Table 5: Fitting and predicting performance of the preferred-habitat interest rate model

Maturity	Fitting		Predicting							
			1-month		3-month		6-month		12-month	
	MAE		MAE of yield							
	H	V	H	V	H	V	H	V	H	V
1	–	–	19.50	21.29	34.55	41.30	51.80	64.35	74.00	94.06
2	1.42	7.90	16.84	19.67	32.79	37.35	51.40	57.29	77.37	89.53
3	1.98	7.14	15.38	18.01	33.41	36.08	53.27	56.13	82.74	90.76
4	1.63	3.86	15.17	16.64	34.60	36.12	56.04	57.12	88.21	92.36
5	–	–	16.06	16.25	36.12	37.03	58.44	58.97	91.99	93.24
			MAE of excess return (annualized)							
1			217.59	241.10	103.44	129.37	50.48	69.49	–	–
2			394.00	396.31	225.74	253.99	146.26	170.03	66.60	84.66
3			549.69	560.81	360.28	385.50	250.40	269.07	140.23	165.07
4			718.58	746.90	505.16	530.36	367.22	382.07	225.18	249.46
5			944.26	957.17	663.81	683.61	492.44	500.95	318.40	334.35

This table reports MAEs (mean absolute errors, in BPs) of fitting bond yields, forecasting bond yields and annualized returns using the two interest rate models. The yields and excess returns are for zero-coupon bonds with maturities of 1 to 5 years. The 'H' means the preferred habitat model; 'V' indicates the two-factor Vasicek model. 'p-month' ($p = 1, 3, 6, 12$) means that forecasting horizon is p months. Maturity i ($i = 1, 2, 3, 4, 5$) is in unit of years, and the corresponding row reports the MAEs for bond yields with maturity of i years or returns on bonds with maturity of i years.

Table 6: Variance decomposition

k	Latent 1	Latent 2	The official rate	Demand factor
			1-year	
1	0.9	84.5	11.1	3.5
12	3.8	75.5	16.9	3.8
60	61.7	20.6	16.2	1.5
			2-year	
1	1.7	77.5	17.0	3.8
12	15.1	60.1	21.2	3.6
60	70.1	13.4	15.4	1.1
			3-year	
1	12.7	62.5	21.2	3.6
12	32.1	42.4	22.6	2.9
60	76.3	8.6	14.3	0.8
			4-year	
1	29.5	44.9	22.7	3.0
12	48.5	27.5	21.9	2.2
60	80.8	5.6	13.0	0.5
			5-year	
1	46.0	29.7	22.1	2.2
12	61.5	16.8	20.2	1.5
60	83.9	3.9	11.8	0.4

This table shows the contributions of the factors to the k-step ahead forecasts of market interest rates with maturities from 1 to 5 years using the preferred-habitat interest rate model. The k are 1-month, 12-month, and 60-month respectively. 'n-year' ($n = 1, 2, 3, 4, 5$) means n-year market yields. For example, to interpret the first row of the panel for 1-year market interest rate, of the one-month ahead forecasting variance for one-year market interest rate, 0.9% is explained by the first latent factor, 84.5% is explained by the second latent factor and so on.

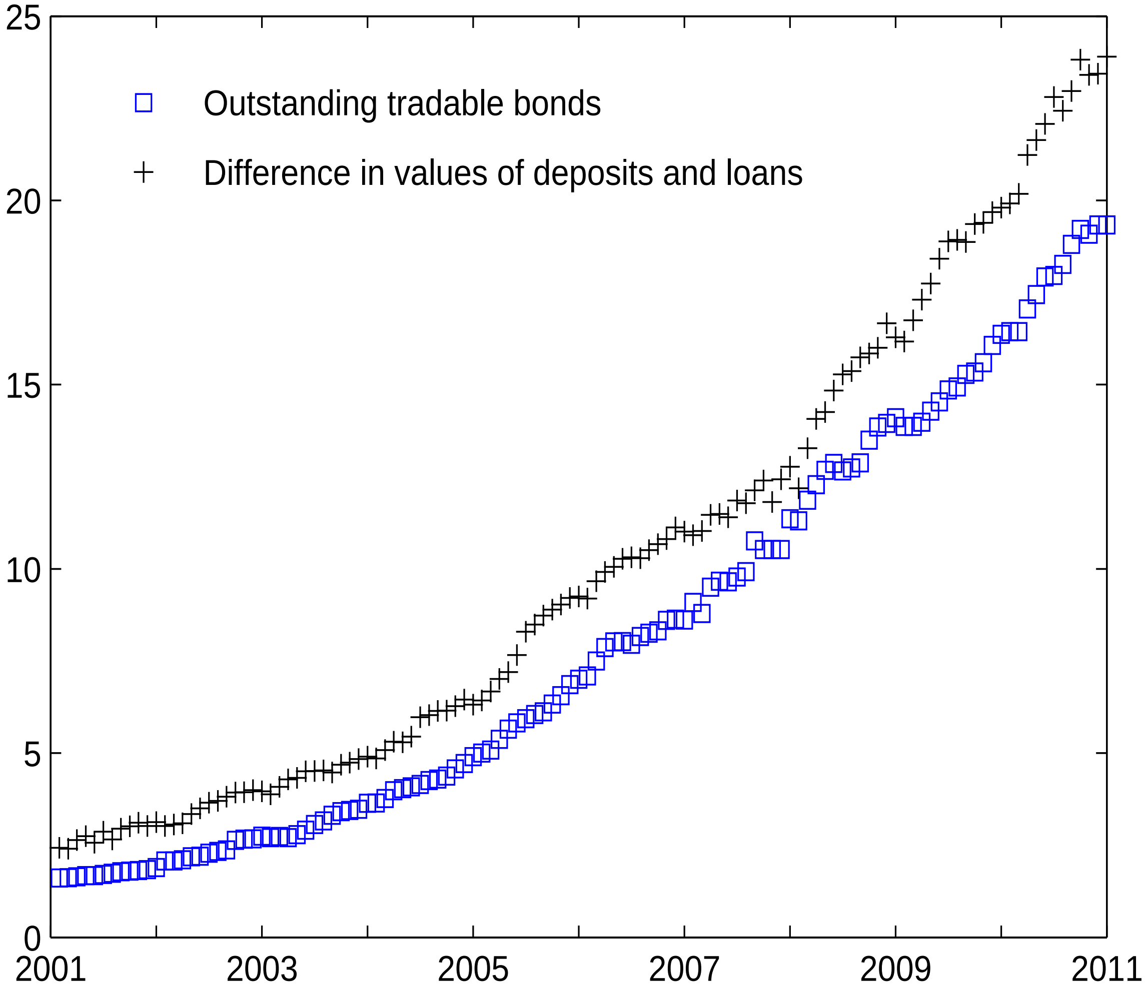

Figure 1: Value of tradable bonds outstanding and difference in values of deposits and loans of all commercial banks (in trillions RMB).

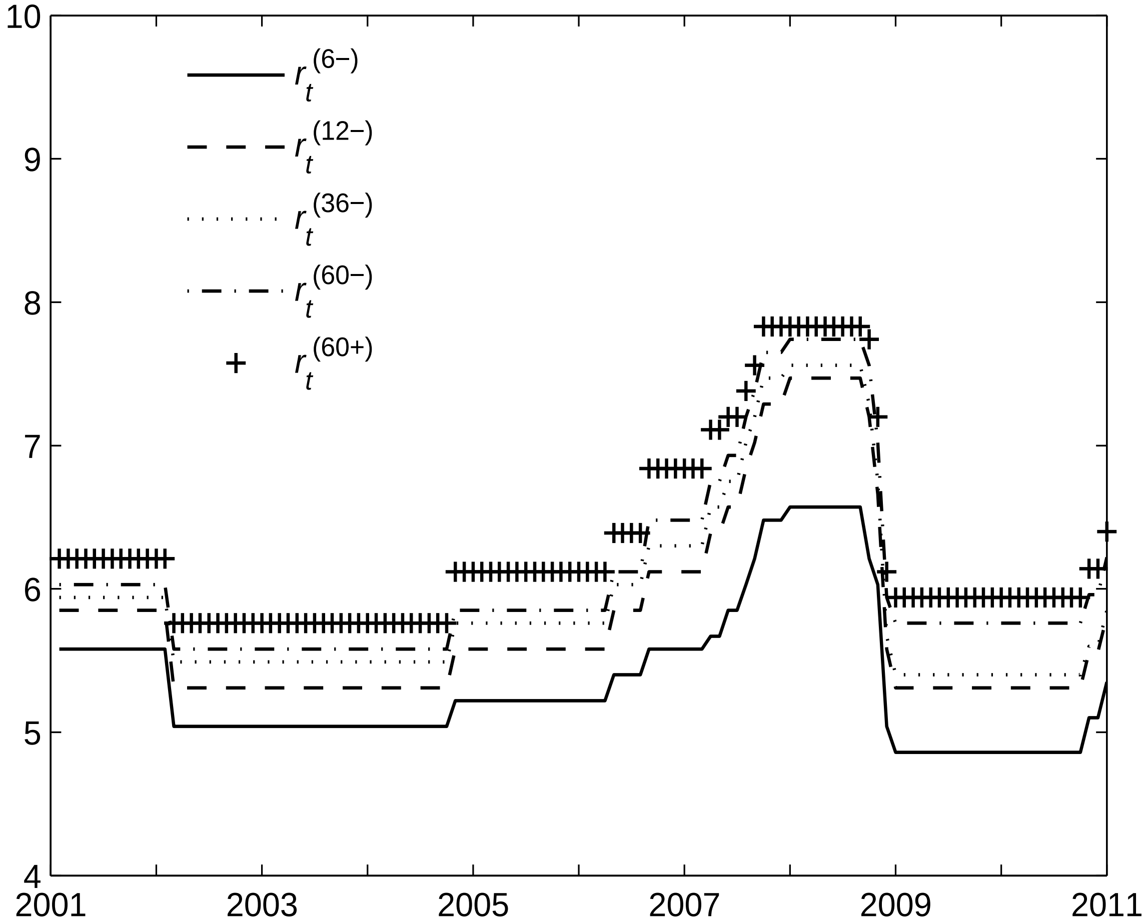

Figure 2: Official rates. $r_t^{(6-)}$ is the lending interest rate for loans with maturities less than or equal to 6 months; $r_t^{(12-)}$ is the lending interest rate for loans with maturities less than or equal to 12 months but longer than 6 months; $r_t^{(36-)}$ is the lending interest rate with maturities less than or equal to 36 months but longer than 12 months; $r_t^{(60-)}$ is the lending interest rate with maturities less than or equal to 60 months but longer than 36 months; $r_t^{(60+)}$ is the lending interest rate for loans with maturities of longer than 60 months. All figures are in percent and are annualized.

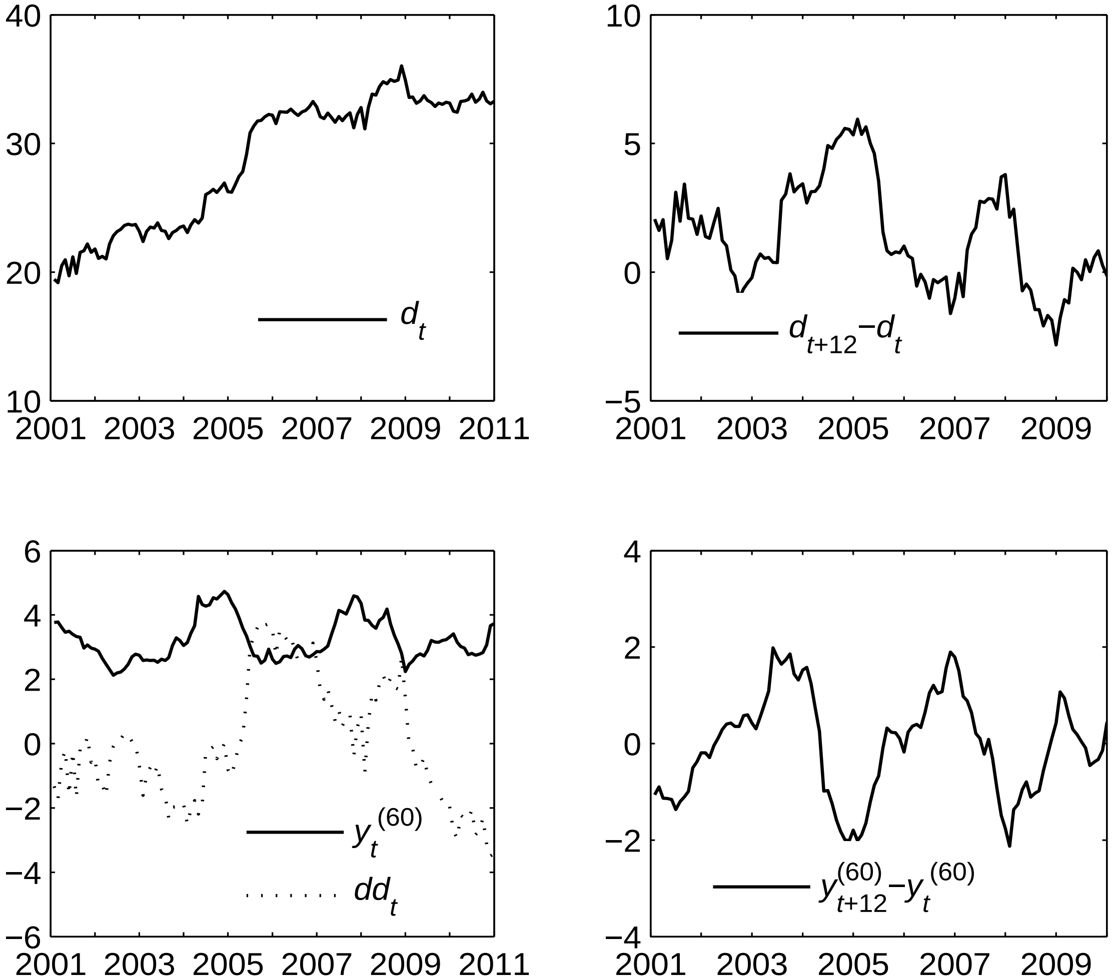

Figure 3: The demand factor. Demand factor d_t is in the upper-left panel. Its detrended value, dd_t, and 5-year interest rate, $y_t^{(60)}$, are in the lower-left panel. Annual change of demand factor, $d_{t+12} - d_t$, is shown in upper-right panel. Finally annual change of 5-year interest rate, $y_{t+12}^{(60)} - y_t^{(60)}$, is shown in lower-right panel.

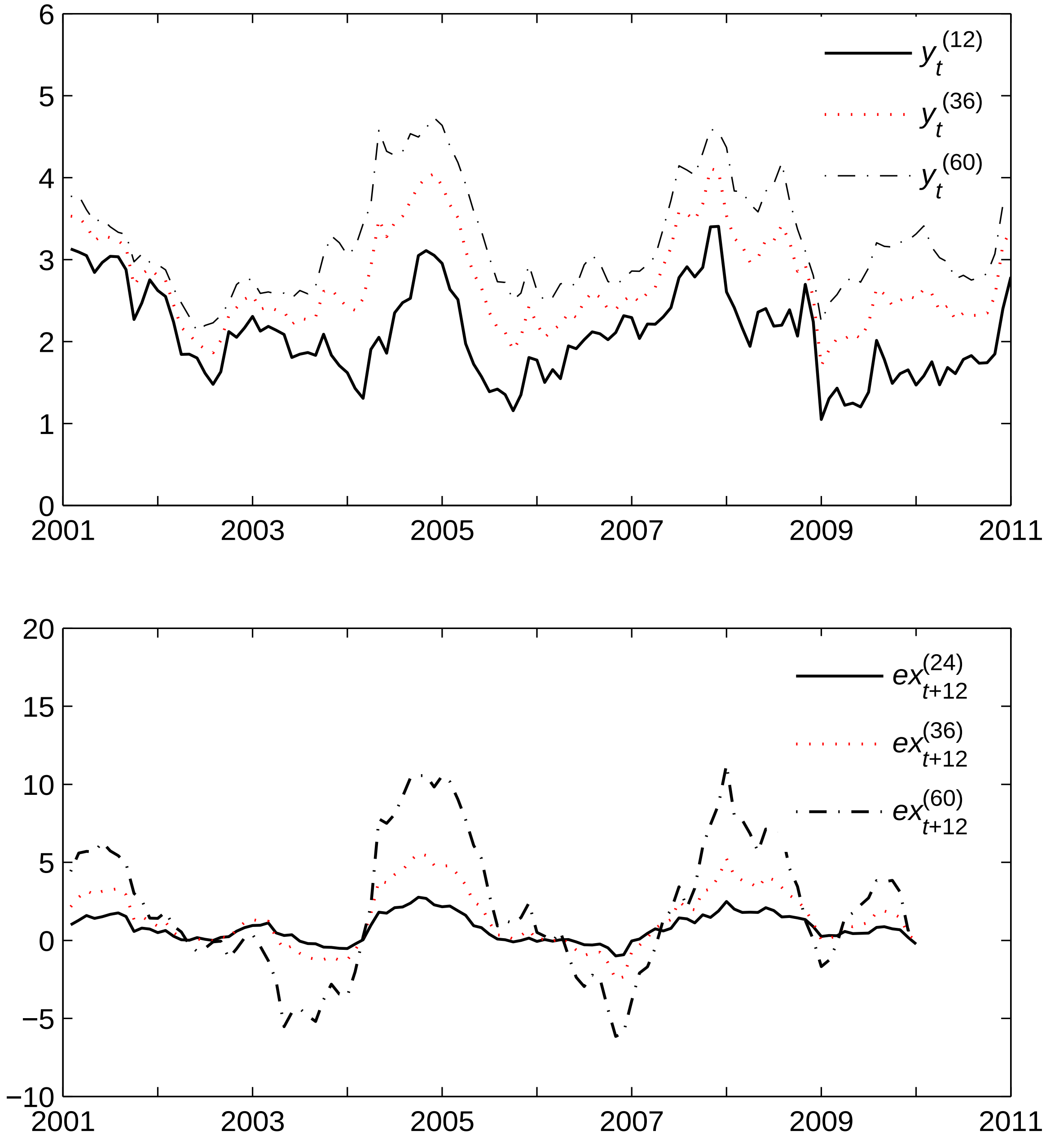

Figure 4: Market interest rate and bond excess return. One-year (12-month), three-year (36-month), five-year (60-month) market interest rates, $y_t^{(12)}, y_t^{(36)}, y_t^{(60)}$, are in the upper panel. Annual excess returns on bonds with maturities of two-year (24-month), three-year (36-month) and five-year (60-month), $ex_{t+12}^{(24)}, ex_{t+12}^{(36)}, ex_{t+12}^{(60)}$, are in the lower panel.