A Quantitative Evaluation to Interest Rate Marketization Reform in China*

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Abstract: The structure of market yield curve and the relationship between term structure of market interest rates and economic fundamentals are of great concerns to the Chinese economy. Based on the characteristics of monetary policy and bond interest rate term structure, this paper proposes an interest rate model to evaluate quantitatively interest rate liberalization in China. The empirical findings suggest that treasury bond yield react prominently to both benchmark deposit/lending rates and the deposit reserve rate adjustment, while other monetary policy operations have little influence on the change in the yield. Benchmark rates and inflation rate have a high correlation, but the relation between expected inflation rate and market interest rates among all maturities is weak. The proposed model fits well the mean, the variance and the correlations of yields in Chinese bond market, and the fitted value estimated by inflation rate provides better calibration than the results estimated by Langrun Forecast or Baidu consumer price index.

Keywords: Economic fundamentals; Expected inflation rate, Interest rate term structure, Interest rate marketization reform.

JEL classification: G1, E4, C5.

1 Introduction

In China, marketized funding price and marketized interest rates play a much more important role in financial market and real economy, as the connection between money supply and real economy has become weaker and weaker due to the rapid development of financial market and financial innovation. Under the circumstance where factors of production become mostly marketized, Chinese government has been gradually promoting the marketized interest rates, along with the liberalization (marketization) of financial market in the recent

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years. More importantly, in October, 2015, the People's Bank of China (PBOC) deregulated the intervention of interest rates for financial institutions such as commercial banks. Despite the fact that the central bank will continue to publish benchmark deposit and lending rates, theoretically, the commercial banks are able to determine upper bound of interest rates for deposits and loans according to their own interest. Among all other financial products traded in interbank lending market, repurchase market, bond market, swap market or network finance such as peer-to-peer lending (P2P), the prices of those products are jointly determined by the independent buying and selling trading activities, thereby offering marketized interests rates for potential market participants in those markets. Interest rates of different maturities form a complete interest rate term structure, which are important to the pricing of financial capital and the allocation of funds. However, the structure of yield curve and the relationship between monetary policy and term structure of those marketized interest rate are not adequately addressed in the extant literatures. This paper tries to fill the gap by developing a theoretical model to evaluate the consequences of interest rate liberalization in China, and investigate whether marketized interest rates can accurately forecast future economic fundamentals.

The answers to the aforementioned questions are built on the characteristics of monetary policy and structure of financial market. In China, market interest rates are largely influenced by monetary policy, nevertheless the monetary policy is significantly different from those in developed economies such as United States or countries resided in European Union. Originally, the intermediate target of monetary policy primarily relies on the money supply and the PBOC will adjust the target growth rate of money supply (M_1, M_2) every year accordingly. In the meanwhile, the central bank assigns benchmark deposit and lending rates for commercial banks. As China made substantial progress in liberalizing its financial market, the central bank gradually paid more attention in conducting public market operations such as reverse repurchase aiming to stabilize short-term money market interest rates, in addition to the regulation of the money supply. In contrast to their peers from developed economies, the PBOC implemented the monetary policy in a way which could simultaneously intervene both price and quantity of the funds, resulting in apparent distinction of channels to influence the market interest rates. On the other hand, the structure of Chinese financial market, which gives the leading position to commercial banks in the financial system, is also prominently different from those of developed economies. Taking bond market as an example, commercial banks as a whole are not only the largest investors, but also the primary traders. However, bond price and market interest rates are mainly determined by benchmark deposit and lending rates, rather than funding cost and the alternative investment income of the bonds held by commercial banks. Specifically, lending rates imposed by commercial bank have been highly correlated with benchmark lending rates imposed by the central bank.

Due to the *dual-duties* features of monetary policy implemented by the PBOC, interest rate controls might perpetuate distortion in the macro-economy. Most of developed economies primarily rely on short-term interest rates to monitor the intermediate target. For example, the intermediate target of monetary policy in the United States is the federal funds over night lending rate. The Federal Reserve publishes the short end of market interest rate term structure through monetary policy, whereas medium and long-term market interest rates depend on the market equilibrium. According to interest rate expectation theory, the investors' forecast of the future trend of short-term interest rates combined with preference of the bond market risk is attributable to the expectations of the medium and long-term rates in the market. On one hand, one observes that the reference rates still play a critical role, and on the other hand, one also perceives the difference between marketized short-term rates and benchmark interest rates. When there is plenty of liquid fundings in the bond market, short-term rates such as the 3-month treasury bond rate or the repo rate are very low. However, when the liquid fundings are tight, short-term market interest rates may exhibit a spike, an apparent example being the cash crunch in the second half of the year 2013, implying that funding liquidity is another important factor that might affect market interest rates. Even though it is tough to measure liquidity premium of funding, the most commonly practice is to judge market tightness using the level of short-term market interest rates.

As such, this paper aims to ask what affect the interest rate liberalization and evaluate how the liberalization has an influence on structures of yield curve in China. Building on a sample combining data of consumption, yields of treasury bonds among different maturities and all reference rates in daily frequency during the period of January, 2010 to October, 2021, our empirical results show that yield curve of Chinese treasury bond market exhibits a upward sloping pattern where average short-term rates are low and average long-term rates are high, yet average one-year interest rates and average ten-year interest rates do not differ much. Standard deviations of market interest rates among all maturities display very little differences, while short-term rates have slightly larger volatilities. In addition, the benchmark deposit and lending rates and the deposit reserve rate adjustment jointly have a significant impact on change in yields of treasury bond, while other monetary policy operations have little influence on the change in the yield. The final model fits well the mean, the variance and the correlations of yields in Chinese bond market, and the fitted value estimated by inflation rate provides better calibration than the results estimated by Langrun Forecast or Baidu consumer price index (CPI); see Section 4.3 for details on the definition of Langrun Forecast and Baidu CPI.

Moreover, this paper enriches the literatures in the light of the relation between market interest rates and economic fundamentals. There has been a growing body of academic studies in discussing interest rate term structure under different circumstances (for example, Ang and Piazzesi (2003), Wu and Rudebusch (2008), Ng and Ludvigson (2009), Bikbov and Chernov (2010), and Chernov and Mueller (2012)). A recent study by Cieslak and Povala (2015) reveals that expected inflation rate is the most important factor that determines the change in U.S. treasury bond market rates, and that the explanatory power of expected inflation rate increases with the term of the bond. Indeed, this factor can explain up to 88% of the change in U.S. ten-year interest rate. Based on the interest rate model, we analyze the relation between market interest rates and economic fundamentals in China and our results show that expected inflation rate is highly correlated with one-year benchmark deposit rate, and explains 45% of the change in the benchmark interest rate, suggesting that the Central Bank indeed intervene the benchmark rates in line with expected inflation rate. Most importantly, the benchmark interest rate and expected inflation rate have been highly correlated since 2011. During this period, expected inflation rate explains 87% of the change in the benchmark interest rate. When expected inflation rate increases by one percent, the benchmark interest rate also increases by almost one percent. This means that the Central Bank has been paying more attention to the regulation with price-based tools. Surprisingly, we find that the relation between expected inflation rate and market interest rates of all maturities are very weak. The explanatory power of expected inflation rate to the change in market interest rates is less than 20%, even after the periods of interest rate liberalization. In other word, expected inflation rate is very weakly related to market rates, and decides on the market interest rates only through its influence to benchmark deposit interest rates, while funding liquidity premium in the bond market does not correctly incorporate the change in expected inflation rate.

Another main contribution of research in this paper is as follows. First of all, this paper proposes an interest rate model building on the characteristics of macroeconomic fundamentals and bond market in China. This model not only incorporates the effectiveness of monetary policy transmission through the channel for interest rates, but also evaluates interest rate liberalization reform in China. To the best of our knowledge, existing literatures on interest rate marketization reform for Chinese market has not yet considered this point of view. Secondly, this paper provides a new method and way of thinking for effectively evaluating the transmission of China's monetary policy along the treasury bond yield curve.

The remainder of this paper is organized as follows. Section 2 is a review of relevant literature. Section 3 proposes the models, including interest rate term structure model, and specifically, the model by combining short-term interest rates and inflation through the pricing kernel under the context of consumption capital asset pricing model (CCAPM). Section 4 presents the empirical analysis from two aspects. Part one illustrates the power of monetary policy transmission through the modeling of characteristics of inflation and interest rate term structure, and consequently evaluates interest rate marketization reform, and part two provides robustness test of the proposed model through a comparison among the forecasted inflation rate in this paper, Langrun CPI forecast index, Baidu Index forecasted CPI, and real data. Finally, Section 5 concludes the paper.

2 Literature Review

The literature related to this paper includes interest rate term structure theory and applications, and theory and empirical analysis on the relation between interest rate term structure and effects of monetary policy.

2.1 Review on Interest Rate Term Structure Models

As the development of the finance theory, interest rate term structure theory is originated from classical qualitative methods and well developed with quantitative analysis of stochastic processes and construction of dynamic models at the modern stage.

Classical interest rate term structure theory includes the expectation theory, the liquidity preference theory, the market segmentation theory and the term preference theory. This line of study mainly concentrates on the discussions about the shape of yield curve existing in the market, the reason behind some specific morphology of yield curve, and the implicit economic meaning that they represent. For the classical interest rate term structure theory, it can be traced back to the early work such as the expectation theory proposed by Fisher (1896), the liquidity preference theory considered by Hicks (1939), the market segmentation theory initiated by Gulbertson (1957), and the term preference theory documented by Modigliani and Sutsh (1966). Although some assumptions and conclusions of the classical interest rate term structure theory are not in line with reality, the economic ideology included in the theory still have guiding significance, and many scholars rediscovered its theoretical value. For example, Amihud and Mendelson (1991) discovered that treasury bond yield contains a compensation for liquidity risk. More recently, Vayanos and Vila (2021) proposed a new interest rate term structure model under the assumption that introduced investors with term preferences into non-arbitrage financial markets. Based on this model, Hamilton and Jing (2012) discussed the influence of the quantitative easing policy to the U.S. interest rate term structure. Finally, Fan et al. (2013) used this model to study the influence of supply and demand on the term structure of treasury bond.

Compared to the qualitative analysis in classical interest rate term structure theory, modern interest rate term structure models study the interest rate term structure from a quantitative perspective. The seminal work by Merton (1973) takes the stochastic process expression of stock returns as a reference, and builds a foundation for studying modern interest rate term structure models by assuming a specific stochastic process for the interest rate.

To distinguish whether an interest rate term structure model has a non-arbitrage constraint, modern interest rate term structure theory consists two different types of assumptions as follows. The first type of models contains the non-arbitrage assumption, meaning that no arbitrage profit can be realized by constructing portfolios of bonds with different term structures and this type of models is termed as "non-arbitrage models", which are divided into relative pricing models and absolute pricing models according to their ways of derivation. Relative pricing models derive mutual prices of assets according to non-arbitrage conditions (one of the conditions for equilibrium models) that must be satisfied by relative bonds. These models were originated by Vasicek (1977). For absolute pricing models, there are no direct assumptions on the interest rate. Instead, they are derived using the stochastic process for the interest rate according to market clearance, and further the expression can be computed for interest rate term structure. The earliest absolute pricing theory is the model proposed by Cox et al. (1985), as the CIR model. Subsequently, Scott (2003) and Longstaff and Schwartz (1992) extended the CIR model from one factor to multi-factors. On the other hand, the second type of models do not contain the non-arbitrage assumption and this type of models is called as "reduced-form models". The modeling of reduced-form models is based on statistic properties of the yield curve, and does not consider whether the yield curve satisfies the non-arbitrage assumption. A representative of reduce-form models is the dynamic models after the dynamic expansion of the static Nelson-Siegel-type interest rate term structure models, termed as "the reduced-form NS-type models" in this paper.

The reduced-form NS-type models reduce the dimensionality of the entire yield curve by fixing factor loadings at different terms, and extract a few factors from the entire yield curve. These extracted factors fit very well the entire curve. Through further dynamic modeling of the factors, the models have the ability to do a good forecast. A representative of the reduced-form NS-type models is the dynamic Nelson-Siegel model proposed by Diebold and Li (2006).

Different from Vasicek (1977) and Cox et al. (1985), Ho and Lee (1986) initiated a new way of thinking towards the modeling of interest rate term structure and their model calibrated the time-variant parameters in the model given the currently observed yield curve, so that the short-term interest rates determined by the time-variant parameters satisfy the non-arbitrage assumption. Following the spirits of the Ho and Lee model, Heath et al. (1992) developed a more general framework for interest rate term structure models, called "the HJM model", which assumes a stochastic process for the forward instantaneous interest rate. Under the non-arbitrage assumption, the drift in the stochastic process may be determined by the volatility and the corresponding market price risk. The HJM model is the basic model among all non-arbitrage models. Models with context of the non-arbitrage assumption can be derived in accordance with conditions formulated in the HJM model. However, because the range of the conditions for the HJM model is very wide, under the most of the settings, the interest rates become non-Markovian. Therefore, many scholars have studied the conditions under which the HJM model may be represented as a Markov process with finitely many states (for example, Carverhill (1994), Ritchken and Sankarasubramanian (1995), Chiarella and Kwon (2001), Björk and Svensson (2001), Björk and Landén (2002), and Chiarella and Kwon (2003)).

In particular, Duffie and Kan (1996) initiated the affine term structure model in the framework of risk neutral pricing and they proved that if the drift and the square of the volatility in the stochastic process expression are followed by the risk factors, and the short-term interest rates are linear combinations of those risk factors, then the yield curve is also a linear combination of the risk factors, vice versa. In fact, plenty of earlier research discussed interest rate term structure models that exist in the affine form, while their study provides a more generalized summary of models in this type. Later, Dai and Singleton (2000) categorized affine interest rate term structure models under the "completely affine" price of risk assumption, and at the same time discussed characteristics of affine interest rate term structure models in different categories. Additionally, Duffee (2002) expanded the setting of price risk in affine models, and proposed the "essentially affine" risk premium setting.

The constant term added to the price risk overcomes the disadvantage of invariant signs of factor risk premium, and increases the applicability of affine interest rate term structure models. Finally, Chiarella and Kwon (2003) further proposed the setting of "expanded linearity". Therefore, affine interest rate term structure models are well established as a mature modeling tool with many applications with affluent literatures.

2.2 Review on the Relation Between Interest Rate Term Structure and Monetary Policy

On the basis of non-arbitrage interest rate term structure theory, the dynamics of short-term interest rates determines the shape (by dynamics under the risk-neutral measure) and the dynamics (by dynamics under the physical measure) of the yield curve. According to the Taylor rule in the macroeconomic theory, the central bank adjusts short-term interest rates with respect to the change of inflation and production, thus achieving the policy target in stabilizing the economy. Taking the relation between monetary policy and short-term interest rates as a bridge, scholars have incorporated the macroeconomic department into the modeling of yield curve, and built an analytical framework of macro-finance. The work by Ang and Piazzesi (2003) was the pioneer in this area. In the discrete time setting, they built a macro-finance model according to the Taylor rule, with production and inflation as two risk factors that measure the condition of real economy and interfering factor of yield curve, respectively. They discovered that non-arbitrage assumption and the addition of macroeconomic variables increase the respective forecasting power of the vector autoregression (VAR) model and the interest rate term structure model without macro variables. Their empirical results verify the validity of the macro-finance model. Since then, the model in Ang and Piazzesi (2003) has been generalized to many applications in macro-finance. For example, Wu (2005) extended the model in Ang and Piazzesi (2003) under a relatively simple Keynesian model and compared a two-variable affine interest rate term structure model with a macro-finance model containing the new Keynesian model. As a result, they found that the level factor and the slope factor in the affine interest rate term structure model are closely related to the inflation target and the rule of discretion in monetary policy, respectively. Furthermore, Moreno et al. (2010) considered a macro-finance model under the new Keynesian model including the yield curve, and obtained similar conclusions to those found in Wu (2005). Additionally, Andreasen (2008) and E-Hordahl et al. (2007) modeled the macro department along with the same route in a more complex DSGE model. In the aforementioned papers, the macro department and the yield curve are modeled separately. In the macro department, treasury bonds with different terms are not part of the model setting, and the modeling of the yield curve is a byproduct after the derivation of the short-term interest rate formula and the stochastic discount factor. In contrast, the model built in Wu (2005) completely incorporates the macro department and the treasury bond yield curve into one single modeling procedure. In this model, treasury bonds with different terms are part of the consumers' portfolio, so that the yield curve and the dynamics of macroeconomic variables are simultaneously determined in one unified general equilibrium model.

Theoretically, whether or not to build a structured model for the dynamics of macro variables, the dynamics of macro variables eventually appear as a VAR process. Therefore, Ang et al. (2008) pursued a general exploration and discussion on the settings of monetary policy in macro-finance models by incorporating the non-arbitrage assumption solely. In fact, the emphasis on the economic base in the macro department strengthens economic implications embedded with the models, even if this approach increases the complexity of the models, and weakens the models' ability to investigate certain issues. Therefore, when addressing certain economic issues, scholars tend to build macro-finance models in a simplified macro setting. By assuming a time-variant coefficient of monetary policy's reaction towards inflation and production, Ang et al. (2011) discussed the policy attitude (sensitivity to inflation and production) of the Federal Reserve in a quadratic interest rate term structure model and they found that the reaction coefficient to production from Federal Reserve is relatively stable, but the reaction coefficient to inflation has experienced relatively large fluctuations. At the same time, the increasing reaction coefficient to inflation prompts the short-term rates, and widens the term spreads. Moreover, Ang et al. (2008) decomposed a U.S. yield curve in a discrete-time regime switching model, and extracted the expected inflation and the real interest rates. In a continuous-time regime switching model, Christensen (2015) considered the problem of yield curve modeling when the monetary policy faces a zero lower bound constraint.

Modern finance literature focuses on examining the relationship between the entire yield curve and macroeconomic variables, instead of extracting information from part of the yield curve. The three latent factors obtained by the Gauss affine term structure model or the Nelson-Siegel model extract almost all the information in the yield curve. The connection of these latent factors to macroeconomic variables such as economic growth and inflation is further discussed. Despite of the non-arbitrage latent factor contained in the yield curve, Ang and Piazzesi (2003) employed a VAR model to explore the relation between macro variables and the yield curve and they concluded that most of the change in the yield curve can be explained by production and inflation. However, their model setting implies that the yield curve is able to predict the change in the policy rate, but not future inflation or real economy activities. Put it in another way, the model assumes a unidirectional relation between macro variables and the yield curve. More importantly, Diebold and Li (2006) considered the mutual relation between macroeconomy and the yield curve and proposed a VAR model with all three latent factors (level factor, slope factor and curvature factor) from the Nelson-Siegel model, macroeconomic variables, capacity utilization, inflation rate and Federal Reserve Funds rate. Their conclusion implies that macroeconomic variables can explain most of the changes in the yield curve, but the explanation of macroeconomic variables by the yield curve is not as good as the latter. In addition, the slope factor is related to economic activities, the level factor is related to inflation, but the curvature factor is not related to any major macroeconomic variables.

In these macro-finance VAR models, a common practice is to examine the impulse response to shocks and the analysis of variance decomposition. However, Bikbov and Chernov (2010) argued that in a more stable and robust environment, the yield curve factors and macro variables are equally important in explaining each other. There is yet another method that adds directly the yield curve factors to the structural economic model to investigate their internal relation. Additionally, by combining non-arbitrage term structure model and new Keynesian rational expectation model,Wu and Rudebusch (2008) considered that the yield curve latent factors are explainable by macroeconomic variables. Among these factors, the level factor may be explained as implicit inflation target, the slope factor may be explained as periodic monetary policy reaction, and their model does not include curvature factor. Furthermore, Krippner (2006) used continuous-time general equilibrium model and their results show that the level factor is related to long-term inflation expectation and increases of production, and the slope factor and curvature factor are related to both inflation cyclicality and increase of production. Based on the empirical analysis in Krippner (2006) with U.S. data, the findings conclude that the relation between yield curve and macroeconomic variables is influenced by latent economic growth, as well as the change in the yield curve term premium. Furthermore, Joslin et al. (2010) conducted an empirical analysis and obtained similar conclusions as those in Krippner (2006), but they found that the term premium had a regime shift in 1985. Finally Aruoba (2020) proposed a reduced-form Nelson-Siegel model with survey data of U.S. inflation expectation (SFP, Blue Chip Forecasts, University of Michigan Inflation Expectation), and constructed a term structure for expected inflation in monthly frequency.

2.3 Review on China's Interest Rate Liberalization Reform

Currently, a monetary policy conducted by the PBOC is in the process of switching from quantity-based to price-based. Under a quantity-based monetary policy framework, money base and supply are the operational indicator and the intermediate indicator of monetary policy, respectively.Correspondingly, under a price-based monetary policy framework, short-term interest rates and medium to long-term interest rates are the operational indicator and the intermediate indicator of monetary policy, respectively. As the pricing benchmark in the financial market, treasury bond yield curve at the same time determines cost of capital for the real economy. To achieve of the goal of regulation and control of real economy, central bank commonly publish the short end of the treasury bond yield curve, through channel of transmission to affect the long end yield curve. Therefore, in a special era of policy switching, the policy role of the treasury bond yield curve is getting more and more prominent, and the study of the transmission of monetary policy along the treasury bond yield curve has significant economic meaning and policy implication.

In the process of monetary policy switching, the composition of monetary policy tools is one of the standpoints. According to the category from the PBOC, China's current monetary policy operational tools mainly include open market operations (forward and reverse repurchase, Central Bank ticket distribution, cash bond buy out and short-term liquidity adjustment tool), deposit reserve adjustment, deposit and loan interest rate policy (deposit and loan interest rates and deposit and loan reserve rates) and the new monetary policy tools launched since the year 2013 (standing lending facility, medium-term lending facility and pledged supplementary lending). Currently, China has a diversity of monetary policy operational tools, including quantity-based tools and price-based-tools alike. The Central Bank may choose different monetary policy tools in different situations to achieve their target of regulation. For example, the adjustment of deposit and loan interest rates affects the funding cost of real economy, and simultaneous adjustment of deposit and loan reserve rates will keep the consistency between money supply and interest rate level. In the process of switching from quantity-based monetary policy to price-based monetary policy, China's Central Bank has to face the choice and renewal of monetary policy tools. In fact, the Central Bank has canceled restrictions on deposit and loan interest rates, improved open market operational tools (building short-term liquidity adjustment tools with shorter repurchase term) and constructed monetary policy reform like the interest rate corridor. These practices reflect the Central Bank's choice of monetary policy tools in the process of monetary policy reform.

Under a price-based monetary policy framework, a mature treasury bond market and a reasonable treasury bond yield curve are an important prerequisite for the successful transformation of China's monetary policy. However, the imperfection of China's bond market and treasury bond market makes monetary policy operations hard to transmit through the treasury bond yield curve. Firstly, the treasury bonds' structure of issuance is not reasonable. Short-term and super-long-term treasury bonds are not stably enlisted in the issuance plan of key terms. Currently, China's treasury bond issuance mainly implements the key term treasury bond issuance system. In this system, the Ministry of Finance publishes at the end of every year the issuance plan for next year's key term treasury bonds. At the current stage, key terms of the Chinese treasury bonds mainly include one, three, five, seven and ten-year terms. As time goes by, short-term treasury bonds may be automatically supplemented by medium to long-term treasury bonds, but super-long-term treasury bonds with terms longer than ten years face the situation of low issuance frequency, low quantity of issuance and scarcity of transactions. The liquidity premium resulted from a relatively low liquidity further leads to the inconsistency of internal information on the cross-section of the yield curve, which affects the transmission of monetary policy along super-long-term treasury bonds. Secondly, commercial banks are completely unable to enter the exchange bond market, which results in the liquidity spread between the exchanges and the inter bank bond market. Before 1997, exchange treasury bond market had been the only tier two treasury bond market in China. On June 6, 1997, to prevent funds in commercial banks from entering the stock market through the treasury bond market, the PBOC published "Notice on the Commercial Banks' Cessation of Security Repurchase and Bond Transaction in Exchanges". Up till then, commercial banks had quitted from exchange treasury bond market, and switched to treasury bond transactions in the newly founded inter bank treasury bond market. As the major liquidity supplier in the Chinese financial market, and at the same time the top investor in the treasury bond market, commercial banks' inability to transact in exchanges lowers the liquidity supply in exchanges. This also leads to the phenomenon that once for a while exchange treasury bond yield curve was higher than inter bank treasury bond yield curve. In China, funding supply from commercial banks is an important channel through which monetary policy acts on the financial market. At the same time, treasury bond yield curve as an expression of financial market funding cost determines a firm's financing cost. The fact that exchange and inter bank treasury bond market form their respective yield curves to some extend distorts the transmission of monetary policy to the real economy. On October 28, 2010, Shanghai Stock Exchange and Shenzhen Stock

Exchange launched a pilot project for commercial banks to trade bonds in the exchanges' call auction trading system. However, commercial banks are still unable to enter the exchange bond repurchase market, which is a major financing platform for investors in the exchange. Commercial banks' contribution to the liquidity supply in exchange bond market is still limited. The liquidity spread between exchange bond market and inter bank bond market has not been completely eliminated. Therefore, even with the background where treasury bond markets keep merging and treasury bond yield curves converge, the overall segmentation of the bond market is still an important factor that affects the transmission of monetary policy towards the bond market.

In the recent years, there has been some literature on discussing the transmission mechanism of the monetary policy along the yield curve; see, for example, Guo and Song (2008), Sun and Shi (2011), Yuan and Xue (2012), and Hong and Niu (2020). Among these papers, Guo and Song (2008) estimated the yield curve with the Nelson-Siegel model, analyzed the influence of monetary policy on interest rate term structure, and discussed the relation between yield curve and inflation, while Sun and Shi (2011) combined the new Keynesian model and affine interest rate term structure models in the framework of macro-finance models, and explored the influence of monetary policy to the three factors of the yield curve. The interesting findings in Sun and Shi (2011) are that monetary policy shocks increase the level and curvature of yield curve, while decreasing the slope of the yield curve. Furthermore, Yuan and Xue (2012) used a macro-finance model along the same way of thinking and their empirical results show that monetary policy shocks have relatively large influence on the slope of the yield curve. Based on mixed-frequency non-arbitrage Nelson-Siegel interest rate term structure generalized model, and under the constraint of consistency pricing theory for bonds with different terms, Hong and Niu (2020) extracted the term structure of China's inflation expectation and analyzed its influential factors. Although existing literature provides abundant models and empirical tools and reaches a series of conclusions, the literature does not comment on the effectiveness of China's monetary policy from the perspective of various monetary policy tools and interest rate marketization reform.

3 Econometric Modeling

In the following modeling, the CCAPM model is combined with non-arbitrage interest rate term structure model, so as to jointly model consumption, inflation and bond yield. The representative agent asset pricing approach considered in this paper takes the distribution of consumption growth and inflation as exogenous and then derives yields from Euler equations.

To this end, an endowment economy is considered with a representative investor. The total consumption is denoted as C_t and the inflation is represented by π_t.

3.1 Consumer Preference

Consumer's utility functions include some classical power utility functions such as constant relative risk aversion (CRRA) and generalized expected utility function (Epstein-Zin-Weil utility function). With a constant coefficient risk-averse utility function, a consumer's relative risk-averse coefficient is a constant, and CRRA is expressed as

$$U(C_t) = \left[C_t^{1-\gamma} - 1\right] / (1-\gamma),$$

where γ is the consumer's risk-aversion coefficient, and U is the utility function. An implicit assumption in the CRRA utility function is that the relative risk aversion coefficient and the consumption inter-temporal substitution elasticity are negatively correlated, but it is problematic that this implicit assumption can barely hold economically. Relative risk aversion coefficient stands for an agent's consumption substitution inclination in different economic status, while inter-temporal substitution elasticity stands for the agent's consumption substitution inclination at different times. There is no reason to believe that the two are mutually reciprocal. To overcome the disadvantage of CRRA utility function, Epstein and Zin (1989) and Weil (1990) developed the generalized expected utility function, which relaxes the relation between inter-temporal substitution elasticity and relative risk-aversion coefficient, termed as the Epstein-Zin-Weil utility function.

For a finite horizon T and a discount factor $\beta > 0$, utility function of C_t at time t

$$U_t = C_t^{1-\alpha_t} CE_t(U_{t+1})^{\alpha_t}, \tag{1}$$

where $U_{t+1} = 0$, the certainty equivalent CE_t imposes constant relative risk aversion with coefficient γ,

$$CE_t(U_{t+1}) = E_t\left(U_{t+1}^{1-\gamma}\right)^{\frac{1}{1-\gamma}}.$$

The sequence of weights α_t is given by:

$$\alpha_t = \sum_{j=1}^{T-t} \beta^j \left[\sum_{j=0}^{T-t} \beta^j\right]^{-1}.$$

If $\gamma = 1$, the model reduces to the standard logarithmic utility.

3.2 Pricing Kernel

The equation in (1) is divided by current consumption to get

$$\frac{U_t}{C_t} = CE_t\left(\frac{V_{t+1}}{C_{t+1}}\frac{C_{t+1}}{C_t}\right)^{\alpha_t}$$

Taking logarithms, denoted throughout by small letters, leads to the following recursion,

$$u_t - c_t = \alpha_t \ln\left\{CE_t[\exp(u_{t+1} - c_{t+1} + \Delta c_{t+1})]\right\}.$$

By assuming that the variables are conditionally normal, then, one has

$$u_t - c_t = \alpha_t E_t(u_{t+1} - c_{t+1} + \Delta c_{t+1}) + \frac{1}{2}(1-\gamma)\mathrm{Var}_t(u_{t+1}).$$

Assuming that the agent's beliefs are homoskedastic and solving the recursion forward, the log ratio of continuation utility to consumption can be expressed as an infinite sum of expected discounted future consumption growth:

$$u_t - c_t = \sum_{i=0}^{T-t} \alpha_{t,1+i} E_t(\Delta c_{t+1+i}) + constant,$$

where, for finite T, the weights $\alpha_{t,i}$ are given by

$$\alpha_{t,i} = \sum_{j=1}^{T-t} \beta^j \left[\sum_{j=0}^{T-t} \beta^j\right]^{-1},$$

where $\alpha_{t,i} = \alpha_t$ and β is discount factor. For $\beta > 1$, the weights on expected future consumption growth are decreasing and concave in the forecast horizon i For large T, they remain equal to one for many periods. Payoffs denominated in units of consumption are valued by the real pricing kernel

$$M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(\frac{U_{t+1}}{CE_t(U_{t+1})}\right)^{1-\gamma}.$$

Again using normality, the log real pricing kernel is obtained, given by

$$\begin{aligned} m_{t+1} &= \ln(\beta) - \Delta c_{t+1} - (1-\gamma)(u_{t+1} - E_t(u_{t+1})) - \frac{1}{2}(1-\gamma)^2\mathrm{Var}_t(u_{t+1}) \\ &= \ln(\beta) - \Delta c_{t+1} - (1-\gamma)\sum_{i=0}^{T-t-1} \alpha_{t+1,i}(E_{t+1} - E_t)\Delta c_{t+1+i} \\ &\quad - \frac{1}{2}(1-\gamma)^2\mathrm{Var}_t\left(\sum_{i=0}^{T-t-1} \alpha_{t+1,i}(E_{t+1} - E_t)\Delta c_{t+1+i}\right) \end{aligned}$$

Finally, define the log nominal pricing kernel as $m_{t+1}^{nominal} = m_{t+1} - \pi_{t+1}$, so that that one can use the below to value payoffs.

3.3 Nominal and Real Yield Curves

The agent's Euler equation for a real bond that pays 1 unit of consumption n periods later determines its price $P_t^{(n)}$ at time t as the expected value of its payoff tomorrow weighted by the real pricing kernel:

$$P_t^{(n)} = E_t(P_{t+1}^{(n-1)} M_{t+1}) = E_t\left(\prod_{i=1}^{n} M_{t+1}\right). \tag{2}$$

Here, the one-period bond $P_t^{(1)} = E_t(M_{t+1})$. Under the normality assumption, one can get in logs

$$p_t^{(n)} = E_t\left(p_{t+1}^{(n-1)} + m_{t+1}\right) + \frac{1}{2}\mathrm{Var}_t\left(p_{t+1}^{(n-1)} + m_{t+1}\right) = E_t\left(\sum_{i=1}^{n} m_{t+i}\right) + \frac{1}{2}\mathrm{Var}_t\left(\sum_{i=1}^{n} m_{t+i}\right). \tag{3}$$

The n-period real yield is defined from the relation:

$$y_t^{(n)} = -\frac{1}{n}p_t^{(n)} = -\frac{1}{n}E_t\left(\sum_{i=1}^{n} m_{t+i}\right) - \frac{1}{n}\frac{1}{2}\mathrm{Var}_t\left(\sum_{i=1}^{n} m_{t+i}\right).$$

For a fixed date t, the real yield curve maps the maturity n of a bond to its real yield y_t. Equations (2) and (3) show that log prices and yields of real bonds in this economy are determined by expected future marginal utility and the log prices and yields of nominal bonds also depend on expected inflation. Now, the deviations of real yields from their mean is written as

$$y_t^{(n)} - \mu^{(n)} = \frac{1}{n}E_t\left[\sum_{i=1}^{n}(\Delta c_{t+1} - \mu_c)\right], \tag{4}$$

where μ_c denotes the mean consumption growth rate, which shows that the dynamics of real yields are driven by changes in expected future consumption growth. Importantly, these dynamics do not depend on any preference parameters. Therefore, nominal growth rates are given by

$$y_t^{(n)norminal} - \mu^{(n)norminal} = \frac{1}{n}E_t\left[\sum_{i=1}^{n}(\Delta c_{t+1} - \mu_c + \pi_{t+1} - \mu_\pi)\right],$$

and the unconditional mean of the one-period real rate is

$$\mu^{(1)} = -\ln(\beta) + \mu_c - \frac{1}{2}\mathrm{Var}_t(\Delta c_{t+1}) - (\gamma - 1)\mathrm{Cov}_t\left(\Delta c_{t+1}, \sum_{i=0}^{T-t-1} \alpha_{t+1,i}(E_{t+1} - E_t)\Delta c_{t+i+i}\right),$$

in which, the first three terms represent the mean real short rate in the log utility case. When inflation occurs, the real yield on nominal bonds is very low. Nominal bonds are not an attractive investment option if the covariance between inflation and consumption is negative. If we buy n-period bond for $p_t^{(n)}$ at time t, and sell it for $p_{t+1}^{(n-1)}$ at time $t+1$, then the return is $r_{t+1}^{(n)} = p_{t+1}^{(n-1)} - p_t^{(n)} - y_t^{(1)}$, and expected excess return is:

$$E_t\left(r_{t+1}^{(n)}\right) = -\text{Cov}_t\left(m_{t+1}, E_{t+1}\sum_{i=1}^{n-1} m_{m_{t+1+i}}\right) - \frac{1}{2}\text{Var}_t\left(p_{t+1}^{(n-1)}\right),$$

from which, one can see clearly that the covariance term on the right-hand size is the risk premium, while the variance term is due to Jensen's inequality The risk premium on real bonds is positive when the pricing kernel and long bond prices are negatively correlated. This correlation is determined by the autocorrelation of marginal utility. The risk premium is positive if marginal utility is negatively correlated with expected changes in future marginal utility. In this case, long bonds are less attractive than short bonds, because the payoffs tend to be low in bad times (when marginal utility is high). For a large sample, the average excess return on an n-period bond is approximately equal to the average spread between the n-period yield and the short rate.

3.4 State Space Model and Estimation Procedure

The vector of consumption growth and inflation $z_{t+1} = (\Delta c_{t+1}, \pi_{t+1})$ has the state-space representation

$$z_{t+1} = \mu_z + x_t + e_{t+1}, \quad \text{and} \quad x_{t+1} = \phi_x x_t + \phi_x K e_{t+1}, \tag{5}$$

where $e_{t+1} \sim N(0, \Omega)$, the state vector x_{t+1} is 2-dimensional and contains expected consumption and inflation, ϕ_x is the 2×2 autoregressive matrix, and K is the 2×2 gain matrix. Then, this system is estimated with data on consumption growth and inflation using maximum likelihood. Given the normality assumption on the disturbance vector e_{t+1}, the log likelihood function of the vector z_{t+1} is easily derived as the sum of log Gaussian conditional densities. Based on the existing literature on the Chinese economy, $\gamma = 3.0$ and $\beta = 1.005$ are taken for monthly data and this system is estimated with data on consumption growth and inflation using maximum likelihood.

4 Empirical Analysis

4.1 Data

At the end of the year 2018, according to the category by the PBOC, China's current policy operational tools include open market operations (forward and reverse repurchase, Central Bank ticket distribution, cash bond transaction and short-term liquidity adjustment tool), deposit and loan reserve rates, Central Bank refinancing, interest rate policy (benchmark deposit and loan interest rates), SLF, MLF, PSL and targeted MLF (TMLF for short). To sort the monetary policy operations of the PBOC during the period of our study and the corresponding changes in the yield curve, Table 1 lists statistics of the monetary policy operations of the PBOC from January, 2010 to October, 2021, except cash bond transaction, Central Bank refinancing, TMLF and PSL, together with the standard deviations of daily change of key-term treasury bond yield curve under corresponding monetary policy operations.

Table 1: Descriptive statistics of treasury bond yield.

Variables	Mean	S.D	Min	Max
y_t^3	2.16	0.76	0.78	2.43
y_t^6	2.22	0.75	1.03	2.89
y_t^{12}	2.55	0.74	0.97	4.22
y_t^{36}	2.92	0.66	1.33	4.47
y_t^{60}	3.19	0.6	1.83	4.51
y_t^{84}	3.43	0.59	2.22	4.85
y_t^{120}	3.65	0.58	2.4	5.57
y_t^{360}	4.17	0.55	3.11	6.78

Note: y_t^3, y_t^6, y_t^{12}, y_t^{36}, y_t^{60}, y_t^{84}, y_t^{120}, and y_t^{360} denote three-month, six-month, one-year, three-year, five-year, seven-year, 10-year and 30-year bond yields, respectively.

The benchmark for short-term interest rates in the U.S. is the London Interbank Offered Rate (LIBOR). However, the 2012 LIBOR manipulation case exposed the structural defection of the design of LIBOR, and seriously hurt the public's confidence in the banking industry and the financial market. Therefore, the world is carrying out a reform in benchmark interest rates. The benchmark for short-term interest rates in China is the Shanghai Interbank Offered Rate (SHIBOR). The LPR[1] computation in recent years takes SHIBOR as its benchmark. It has been controversial in the academia and in the industry as for whether to take SHIBOR or to take benchmark deposit and loan interest rates as the benchmark for short term interest rates. This paper chooses China's one-day, seven-day, fourteen-day, one-month, three-month, nine-month and one-year SHIBOR. In this paper the choice for treasury

[1]The LPR, originally introduced by the People's Bank of China in October, 2013, is an interest rate that commercial banks charge their best clients and was intended to better reflect market demand for funds than the benchmark the PBOC sets.

bond yields is the spot yield established by China Government Securities Depository Trust & Clearing Co. Ltd. (CDC). We choose three-month, six-month, one-year, three-year, five-year, seven-year, ten-year and thirty-year treasury bond yields. The data are downloaded from China Wind Database and the PBOC website. The descriptive statistics of the treasury bond yield data are listed in Table 1, and the standard deviations of daily changes corresponding to China's monetary policy operations are presented in Table 2, respectively. Also, yield curves are plotted in Figure 1 and SHIBOR of all terms in Figure 2, respectively.

Table 2: The daily standard deviation of monetary policy operation (bps).

Time	Interest rates on deposits and loans	Reserve Requirement	Open market operation				MLF		SLF
				Repo rate	bill	bill rate	operation	Interest rate	
3M	8.61	10.48	3.62	4.13	7.98	5.09	3.44	3.87	4.73
1Y	9.77	10.04	3.2	3.93	3.73	4.63	2.84	1.49	3.19
3Y	10.43	8.16	2.98	4.1	3.71	4.99	2.50	1.93	1.97
5Y	11.15	8.62	3.21	4.16	3.92	4.98	2.61	1.75	2.56
7Y	11.31	7.83	3.04	4.05	3.59	4.57	2.4	2.37	2.34
10Y	9.8	7.00	2.89	3.53	3.16	3.76	2.44	2.84	4.5

Note: Deposit and loan and reserve requirement, respectively, refer to the benchmark interest rate of deposit and loan and the reserve requirement adjustment. In open market operations, repurchase includes both forward and reverse repurchase and operation of short-term liquidity instruments; repo rate refers to the positive and negative repo and short-term liquidity instruments; central note refers to the issuance of central note and central note interest rate means the issuance of central note changes in the winning rate; operation of MLF means medium-term loan facility operation. Interest rate means medium-term loan facility winning bid interest rate change and SLF interest rate means standing loan facility interest rate change. Since the Central Bank usually announces benchmark deposit and lending rates and reserve requirement adjustments after the bond market closes, the deposit and lending and deposit reserve measure the standard deviation of the yield changes the day after the announcement. The source of data is the website of the People's Bank of China and the Wind Database.

One can observe from Table 1 that, firstly, similar to characteristics of average market interest rate term structure in developed economies, China's treasury bond market interest rate term structure also has relatively low average short-term interest rates and relatively high long-term interest rates, but average one-year term interest rate and average ten-year term do not differ much. Standard deviations of market interest rates of all terms differ very little, with short-term rates having slightly larger volatilities. Secondly, when deposit and loan benchmark rates are at their troughs, market interest rates, especially short-term

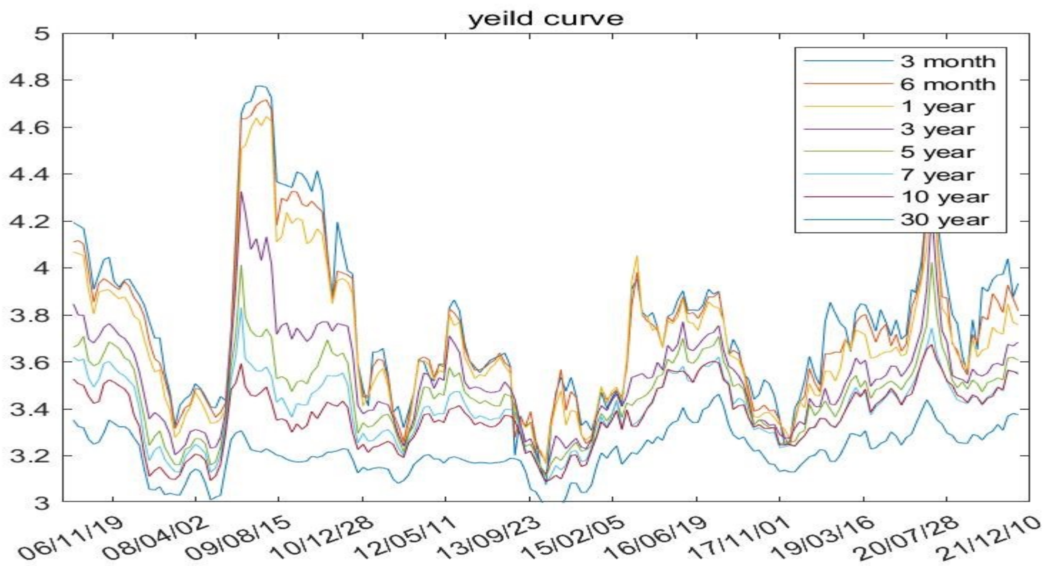

Figure 1: China's treasury yield curve.

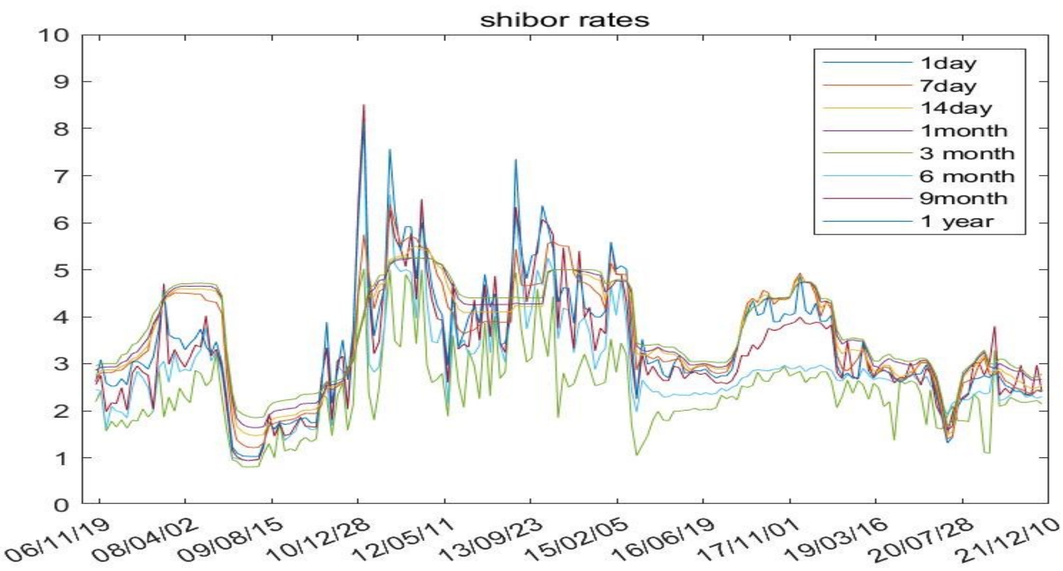

Figure 2: SHIBOR curve of China.

market interest rates, are also at relatively low levels, for example in the years 2002-2003, years 2005-2006, years 2009-2010 and year 2016. However, there are exceptions. In the second half of the year 2004, policy benchmark interest rates are low, but market interest rates, especially long-term market interest rates, arrive at the peak over the sampling period. In the year 2017, the benchmark rates do not change from the previous year and remain at the lowest level over the sampling period, but due the the Central Bank's focus on reducing the risks in the financial system and on de-leveraging, the entire financial system stays at a status of tight equilibrium, and bond market interest rates reach another spike. Finally, the reactions of treasury bond yield to benchmark deposit and loan interest rates and to deposit and loan reserve rate adjustment are significant, but the influence of other monetary policy operations to the change in the yield is very little. In fact, the everyday frequent fine-tuning that smoothes other exogenous shocks reflects the Central Bank's maintenance of the overall monetary policy target by means of open market operations and MLF. Therefore, these operations have the characteristic of endogeneity, and reflect very limited information about the monetary policy. It is necessary to mention that, although the Central Bank may guide market short-term interest rates by everyday operations, the Central Bank does not announce short-term interest rates of any type as the benchmark rates. In the sampling period of our study (before the adjustment of the LPR formation mechanism), the Central Bank explicitly points out that the adjustment of deposit and loan benchmark interest rates is the basis of Central Bank's interest rate adjustment. Open market operations and the change in the bid-winning interest rate in MLF are to some extent the result of balancing supply and demand in market liquidity. In addition, the interest rate corridor mechanism at the stage of exploration is not yet mature, and SLF as the interest rate upper bound has been overwhelmed several times by market interest rates. Seeing from the reaction of the yield, the influence of SLF is not significant.

4.2 Analyzing China's Monetary Policy Influence and Evaluating Reform

Because the literature studying China's interest rate term structure and monetary policy uses SHIBOR as short-term interest rates, this section displays all the analysis results taking SHIBOR seven-day interest rate as the short-term rate.[2]

4.2.1 Impulse Response Function

The state space system (5) nests a first-order Vector-Autoregression. To see this, start from the VAR $z_{t+1} = \mu_z + \phi z_t + e_{t+1}$ and set $x_t = \phi(z_t - \mu_z)$, this will result in a system like (5) but with $K = I(\phi_x = \phi)$. Since K is a 2×2 matrix, setting $K = I$ imposes four parameter restrictions, which one can test with a likelihood ratio test. The restrictions are strongly rejected based on the usual likelihood ratio statistic.

To better understand the properties of the estimated dynamics, covariance functions which completely characterize the linear Gaussian system are reported in (5). Figure 3 displays covariance functions computed from both the model and the raw data, respectively.

[2]Because of the limited length of the paper, all the analysis results, including tables and figures, with other interest rates as short-term interest rates in the model are omitted but available upon request.

At 0 months, these lines represent variances and contemporaneous covariances. The black

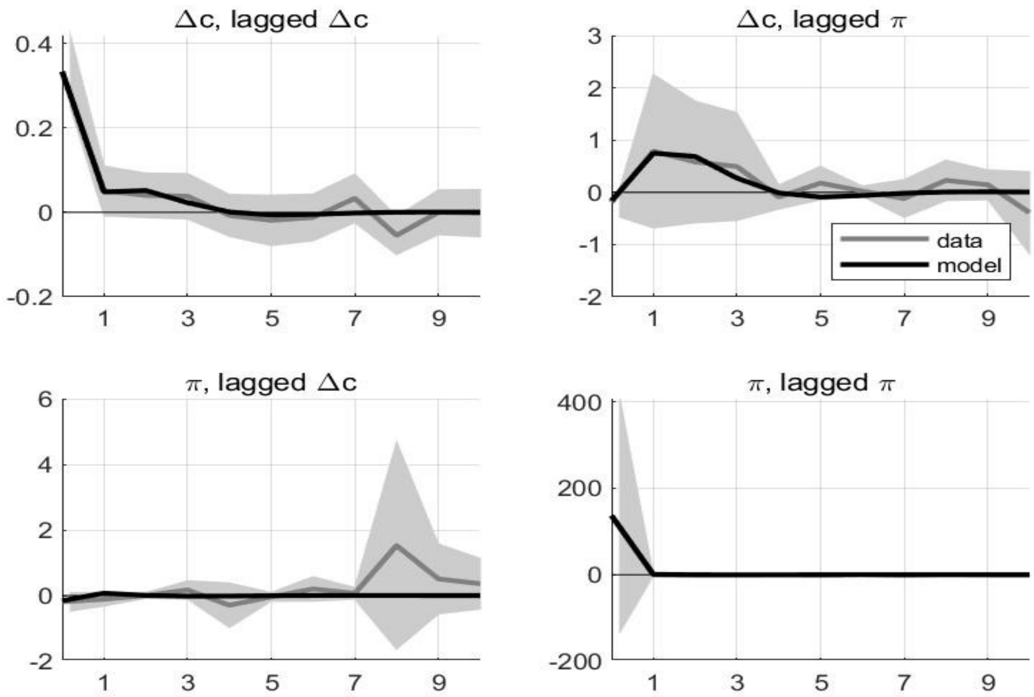

Figure 3: Covariance functions computed from both the estimated model and raw data, respectively.

Note: Shaded areas indicate 2× standard errors bounds around the covariance function from the data computed with GMM. For example, the graph titled consumption, lagged consumption shows the covariance of current consumption growth with consumption growth lagged months, where measured on the horizontal axis.

lines from the model match the gray lines in the data quite well. The shaded areas in Figure 1 represent 2× standard error bounds around the covariance functions estimated with raw data. These standard error bounds are computed with generalized method of moment (GMM). An important feature of the data is that consumption growth and inflation are negatively correlated contemporaneously and forecast each other with a negative sign. For example, the upper right panel in Figure 1 shows that high inflation is a leading recession indicator. Higher inflation in month t predicts lower consumption growth in month $t + n$ even $n = 12$ months ahead of time. The lower left panel shows that high consumption also forecasts low inflation, but with a shorter lead time. These cross-predictability patterns will be important for determining longer yields.

It is well known from the equation in (4) that the dynamics of equilibrium interest rates are driven by forecasts of growth and inflation. Therefor, real yield movements are generated by changes in growth forecasts over the lifetime of the bond, while nominal yield movements are generated by changing nominal growth forecasts. To understand the conditional dynamics of these forecasts better, as opposed to the unconditional covariances and thus univariate regression forecasts from Figure 3, impulse responses are plotted in Figure 4. The signs of

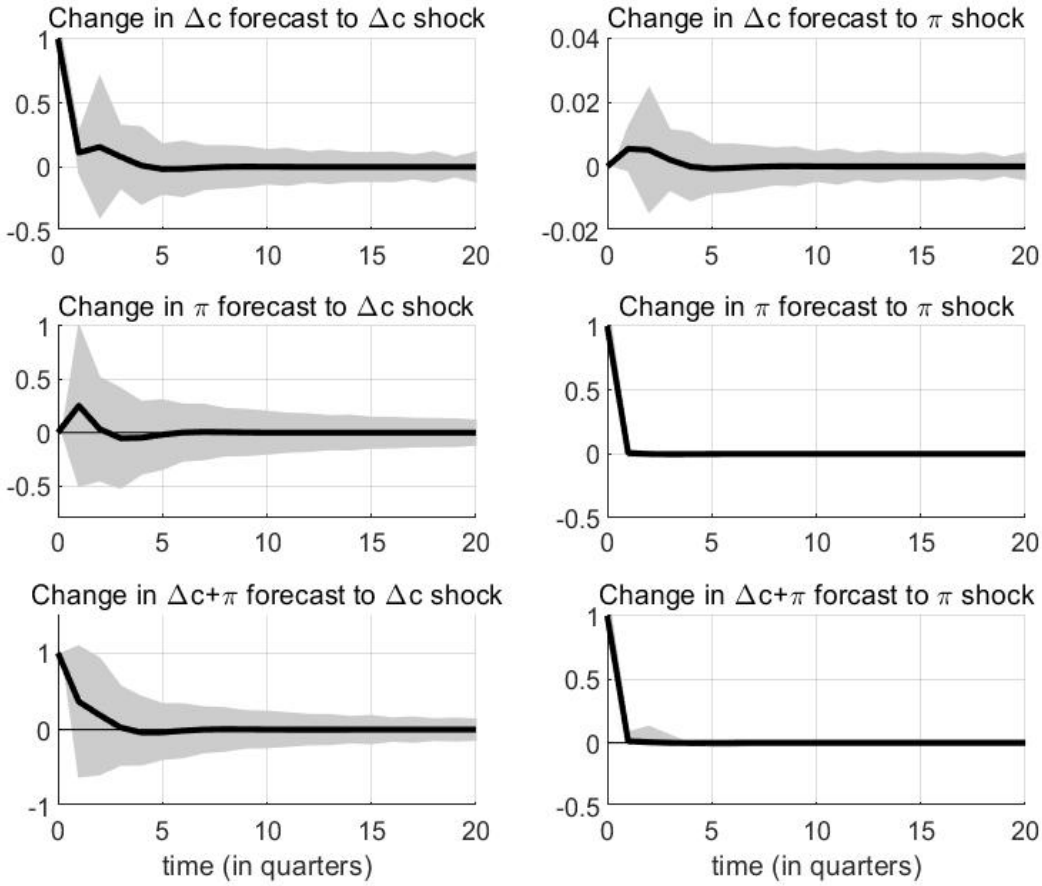

Figure 4: Impulse responses to 1-percentage point shocks e_{t+1} in consumption growth and inflation.

Note: The responses are measured in percent. Shaded areas are 2× standard error bounds based on maximum likelihood.

the own-shock responses are not surprising in light of the unconditional covariances; they are positive and decay over time. This decay is slower for inflation, where a 1-percent shock increases inflation forecasts by 50 basis points. However, the cross-shock responses reveal some interesting patterns. The middle left plot shows that a 1-percent growth shock predicts inflation to be higher by roughly 20 basis points over the next 1-2 years. The top right plot shows that a 1-percent inflation shock lowers growth forecasts over the next year by roughly 5 bp. And as seen here, inflation and growth shocks both lead to higher nominal growth forecasts even over longer horizons. From the previous discussion, this effect is entirely due to the long-lasting effect of both types of shocks on inflation. These findings imply that growth shocks and inflation shocks move short-maturity real rates in opposite directions, but will not affect long-maturity real rates much. In contrast, growth and inflation shocks affect even longer-maturity nominal rates, because they have long-lasting effects on inflation forecasts. In particular, these shocks move nominal rates in the same direction.

With other interest rates added into the model, our results of the analysis show that expected inflation rate is most strongly correlated to the one-year deposit benchmark rate, with inflation rate explaining 45% of the change in the interest rate. This means that the Central Bank indeed draws up the benchmark interest rates based on expected inflation rate. Especially since 2011, the benchmark rates and expected inflation rate have been highly correlated, with expected inflation rate explaining 87% in the change of benchmark interest rates. When expected inflation rate increases by one percent, the benchmark interest rate also increases by almost one percent. This means that the Central Bank has been paying more and more attention to the regulation with price-based tools. Surprisingly, the relation between expected inflation rate and market interest rates of all terms are very weak. The explanatory power of expected inflation rate to the change in market interest rates is less than 20%, not any improvement even in recent years. In other word, expected inflation rate is very weakly related to market interest rates, and decides on the market interest rates only through its influence to benchmark deposit interest rate, while funding liquidity in the bond market does not correctly reflect the change in expected inflation rate.

4.2.2 Average Nominal Yields

To see the properties of the average nominal yields from the model, Table 3 summarize the results based on the model and the raw data. As a result, Panel A in Table 3 compares the properties of average nominal yields produced by the model with the raw data. Interestingly, the model produces an upward sloping nominal yield curve. The average difference between the 30-year yield and the 3-month yield in the data is roughly 2 percentage point, or 200 basis points (bp). This difference is statistically significant; it is measured with a 26 bp standard error. By contrast, the average level of the nominal yield curve is not measured precisely. The standard errors around the 2.16 percent average short end and the 4.17 percent average long end of the curve are roughly 32 bp. The intuitive explanation behind the positive slope is that high inflation means bad news about future consumption. During times of high inflation, nominal bonds have low payoffs. Since inflation affects the payoffs

Table 3: Nominal yields estimation results and the raw data.

Panel A: Average nominal yield curve

	3 month	6 month	1 year	3 year	5 year	7 year	10 year	30 year
Data	2.16	2.22	2.55	2.92	3.19	3.43	3.65	4.17
Model	2.16	2.19	2.23	2.46	2.49	3.11	3.17	3.95

Panel B: Volatility of nominal yields (in % per year)

	3 month	6 month	1 year	3 year	5 year	7 year	10 year	30 year
Data	0.76	0.75	0.74	0.66	0.6	0.59	0.58	0.55
Model	0.68	0.61	0.57	0.48	0.41	0.36	0.31	0.29

Panel C: Autocorrelation of nominal yields

	3 month	6 month	1 year	3 year	5 year	7 year	10 year	30 year
Data	0.9175	0.9291	0.933	0.9379	0.9294	0.93	0.9464	0.9476
Model	0.91	0.902	0.916	0.921	0.927	0.93	0.941	0.945

of long bonds more than those of short bonds, agents requires a premium, or high yields, to hold them. Panel A in Table 3 also shows that the average nominal yield curve in the data has more curvature than the curve predicted by the model. A closer look reveals that the curvature in the data comes mostly from the steep incline from the 6-month maturity to the 1-year maturity. If the extreme short end of the curve is left out, the model is better able to replicate its average shape.

Furthermore, Panel B in Table 3 depicts the volatility of nominal yields across the maturity spectrum and it shows that the benchmark model produces a substantial amount of volatility for the nominal short rate. According to the estimated state space model (5), changes in expected fundamentals (consumption growth and inflation) are able to account for 0.68 percent volatility in the short rate. This number is lower than the 0.76 percent volatility in the data, but the model is two-thirds there. In contrast, the model predicts a smooth real short rate. This effect is due to the low persistence of consumption growth. Panel B also reveals that the model predicts much less volatility for long yields relative to short yields. For example, the model-implied 30-year yield has a volatility of 0.29 percent, while the 30-year yield in the data has a volatility of 0.55 percent. While the volatility curve in the data is also downward sloping, the slope of this curve is less pronounced than in the model.

Another feature of the benchmark model is that it does a good job to match the high autocorrelation of short and long yields, as shown in Panel C in Table 3. The autocorrelation in the nominal short rate is 91.75 percent, while the model produces 91 percent. For the 30-year nominal yield, the autocorrelation in the model is 94.76 percent and only slightly under predicts the autocorrelation in the data, which is 94.5 percent. These discrepancies are well within standard error bounds.

Theoretically speaking, expected inflation rate is the most important variable in determining market interest rates of all terms, which is also validated by interest rate term structures in developed economies. However in China, we discover that the explanatory power of expected inflation rate to market interest rates of all terms is relatively weak. On average, when expected inflation rate increases by one percent, market interest rates increase by about 0.2 percent. As the pushing forward of interest rate marketization, the relation between market interest rates of all terms and expected inflation rate is not getting stronger. As the increase in direct financing, the connection between monetary supply and real economy is getting looser. The Central Bank pays more attention to the relation between price-based tools and real economy, and the relation between short-term interest rates of all terms (including benchmark deposit and loan interest rates) and expected inflation rate is getting stronger.

4.3 Robustness Check

This section constructs models using the data of consumption, short-term interest rates and bond yield, and derives a fitted value for the inflation rate and compares the fitted inflation rate to the forecasted CPI values with both Langrun Forecast and Baidu Index. Langrun quarterly CPI forecast index is computed by National School of Development at Peking University. It is the average of the economists' forecasted CPI values of each quarter published by 15 institutions at the beginning of each quarter. This is the average of the economists' expectation of the CPI's quarterly growth rate. The relevant data was updated only till the fourth quarter of the year 2015. Baidu Index is a data sharing platform based on behaviors of the enormous amount of internet users. It is one of the most important statistical analysis platforms in the current era of internet and data. This index has been an important basis for many firms' marketing decision since its first day of publication. Baidu Index is able to tell its users: how large the scale of the search is for a key word; the up and down trend of the search and news and public opinions related to this key word; what the internet users paying attention to this key word are like; where they are located; what other words they search at the same time. This index help users optimize their digital marketing activity plans. As of the year 2014, major functional modules of Baidu Index are: trend study based single word (including overall trend, PC trend and mobile trend), spectrum of demand, public opinion house keeper, portrait of the crowd; profession-based overall trend, geographic location, crowd property, and characteristics of search time. Many contemporary literature conducts forecast analysis using Baidu Index. One can type the key word "CPI" on the page of Baidu Index, and then obtain data by Web Crawler, and finally, compute Baidu Index CPI.[3]

The mean square root error (MSRE) is 0.087 between the fitted value in this paper and the real value, 0.178 between Langrun forecasted value and the real value, and 0.13 between Baidu Index CPI and the real value. The fitted inflation rate in this paper is the best in terms of the MSRE. Although China's interest rate marketization reform is still on-going and has various problems, the forecasted inflation rate from the joint modeling based on macroeconomic fundamentals, policy interest rates and bond yield curve is better than the Langrun forecasted value and Baidu Index. This means that China's interest rate marketization reform has achieved a certain level of success.

5 Conclusions

This paper evaluates China's interest rate marketization reform in recent years. The data for the evaluation are the consumption, the three-month, six-month, one-year, three-year, five-year, seven-year, ten-year and thirty-year treasury bond market interest rates from January, 2010 to October, 2021 and all the benchmark interest rates in China. Results of the analysis show that China's treasury bond market interest rate term structure has low average short-term interest rates and high average long-term interest rates, but average one-year interest rate and average ten-year interest rate do not differ much. Standard deviations of market interest rates of all terms differ very little, with short-term interest rates having slightly larger volatilities. Secondly, when deposit and loan benchmark rates are at their troughs, market interest rates, especially short-term market interest rates are also at relatively low levels. Finally, the reactions of treasury bond yield to benchmark deposit and loan interest rates and to deposit and loan reserve rate adjustment are significant, but the influence of other monetary policy operations to the change in the yield is very little. Expected inflation rate is most strongly correlated with the one-year deposit benchmark rate, with inflation rate explaining 45% of the change in the interest rate. This means that the

[3]Because of the limited length of the paper, interested readers may ask the authors for Python codes of the Web Crawler and computation results.

Central Bank indeed draws up the benchmark interest rates based on expected inflation rate. The relation between expected inflation rate and market interest rates of all terms is weak. Expected inflation rate explains less than 20% of the change in market interest rates, with no improvement in recent years. That is to say, expected inflation rate influences market interest rates through benchmark deposit and loan interest rates, while the tightness of the funding liquidity in the bond market does not correctly reflect the change in expected inflation rate. The final model fits well the mean, the variance and the correlations of China's bond market yield, and its fitted value of the inflation rate is better than Langrun Forecast and Baidu CPI.

In terms of policy implications, results of this paper show that, benchmark deposit and loan interest rate as the Central Bank's most typical price-based tool, transmits the monetary policy along the yield curve together with deposit and loan reserve rates. In the year 2019, the Central Bank linked the price quote (computed based on SHIBOR) of commercial bank's LPR to MLF interest rate, and replaced benchmark deposit and loan interest rates by LPR, thus establishing the benchmark position of LPR. Reform of the LPR formation mechanism, on one hand pushed forward interest rate marketization, and on the other hand implies that the Central Bank's monetary policy tool at the price level had switched from direct transmission through benchmark deposit and loan interest rates to indirect transmission through MLF or other tools. At the same time, interest rate marketization can not solo rely on relaxation of the interest rate regulations. The key is whether bond market funding liquidity reflects economic fundamentals. If, at the same time of drawing up benchmark interest rates, the Central Bank pays attention to the change of the short-term interest rates in the bond market, and properly regulates the bond market funding liquidity, the relation between bond market interest rates and economic fundamentals will become tighter.

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