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A Quantitative Evaluation of Interest Rate Liberalization Reform in China

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Based on the characteristics of monetary policy and term structure of bond yields, this paper proposes an interest rate model to evaluate the consequences of interest rate liberalization in China. Our empirical results show that benchmark interest rates and expected inflation are strongly correlated, although the relationship between expected inflation and market interest rates of all terms is relatively weak. Additionally, our model provides a superior goodness-of-fit over the predicted mean, the variance and the correlations of treasury bond yields, and the inflation estimated from the proposed model demonstrates more preferable forecasting accuracy by outperforming the results estimated from either Langrun or Baidu CPI index. Our findings suggest that adjustment of benchmark rates and reserve requirement are the most important price-based tools for the central bank to transmit the effects of monetary policy along the yield curve. The development of interest rate liberalization further requires prudential managements by the central bank to focus on short-term interest rate intervention besides policy support, in emphasizing the power of market forces to eventually link the change in market interest rates with economic fundamentals.

Key Words: Economic fundamentals; Expected inflation rate; Interest rate term structure; Interest rate liberalization reform.

JEL Classification Numbers: E52, E58, E43, E47.

1. INTRODUCTION

During the period from late 1970s to early 1980s, many countries embarked on a wave of worldwide interest rate marketization (liberalization) reforms under the influence of the neoliberalism economic ideology pro-

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posed by McKinnon (1973) and Shaw (1973), respectively[1]. Subsequently, the Chinese government commenced its interest rate reform in early 1990s as a part of steps in developing a more advancing market-based economic structure. Within the time span of almost three decades, the Chinese government and the People's Bank of China (PBC) carried out a progressive revolution in liberalizing interest rates, starting from rates in the fixed income markets, then followed by lending rates for banks and finally the deposit rates, as the central bank gradually lifted all restrictions on interest rates to improve the market transmission mechanism. For instance, the PBC began to loosen interest rate controls for the lending and repo markets, in 1996 and 1997, respectively. In 1999, the Ministry of Finance introduced the auction-based issuance of the treasury bond in the inter-bank bond market for the first time. Furthermore, the loan prime rate (LPR) was launched in July 2013, aiming to establish a market-based interest rates quotation mechanism. In May 2015, the PBC liberalized interest rates on small-value foreign currency deposits. More importantly, in October 2015, the PBC took a critical step in liberalization by removing the ceiling on deposit rates for deposit-taking financial institutions (see Table 1 for detailed descriptions), which is known as the landmark of a completed interest rate liberalization.

FIG. 1. The timeline of different stages in China's interest rate liberalization.

In Figure 1, we list the roadmap of three different stages in the procedure of interest rate liberalization in China. Before 2003, the PBC and regulated authorities were mostly devoted to promulgating the rules of interest rate liberalization under the context of the cautious financial or macro-economic transformation. Whereas after years of intervention by "mini" protocols, the PBC had intensively published reform policies by profoundly deregulating the major controls on interest rates since 2012. For example, the PBC issued the loan-base interest rate in 2013 and implemented the LPR reform in 2019, while both were committed to improving the efficiency of monetary policy. Therefore, China has gradually completed interest rate

[1]For details, the reader is referred to the books by McKinnon (1973) and Shaw (1973).

TABLE 1.

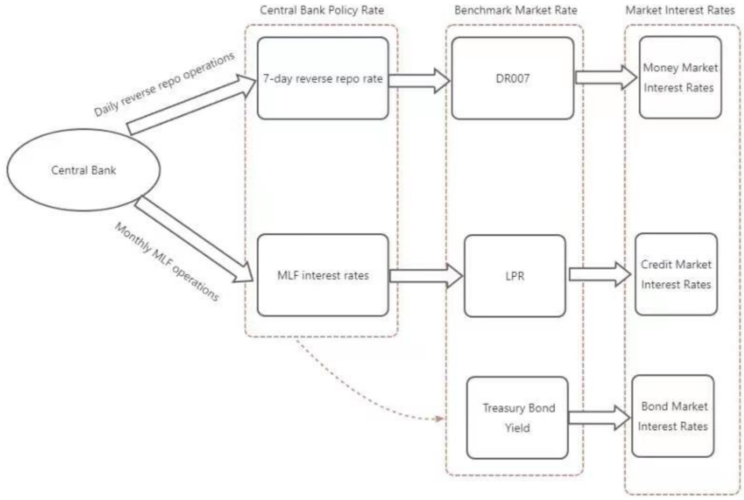
A chronicle of deregulation in the dominant interest rates of Chinese market.

Take the lead in opening up the interbank markets	1996	The PBC removed the ceiling on borrowing market interest rates.
	1997	The inter-bank market offered debt repurchase business.
Gradually relax the limitation on deposits and loans	1999	The PBC promoted liberalization of long-term deposit rates and liberalize interest rates in treasury bonds and money markets.
	2000	The PBC liberalized interest rates on foreign currency loans and foreign currency deposit rates above $3 million dollars.
	2004	The PBC removed the ceiling on lending rates by allowing interest rates to float.
Orderly nurturing of benchmark interest rates	2007	Shanghai Interbank Offered Rate (SHIBOR) was formally launched as the benchmark rate.
	2020	DR007 was gradually established as a new benchmark rate for money market instruments.
Deregulate controls on deposit and loan interest rates	2012	The PBC raised the ceiling of deposit rates to 1.1 times of the benchmark rate.
	2013	The PBC abolished the floor of loan interest rates for financial institutions, and established an optimal quotation mechanism of lending rates.
	2015	The PBC removed the ceiling on deposit rates for financial institutions
Optimize the pricing of deposit and loan interest rates	2019	The PBC carried out the loan market quotation rate (LPR) reform, which can optimize the loan rate quotation method.
	2021	The PBC promoted deposit rate ceiling pricing reform.

liberalization, by switching its interest rate policy from the predetermined Soviet model to market force related mechanism as shown in Figure 2.

In the recent years, the market volume of Chinese treasury bond issuance grows rapidly, and market instruments with integral maturities are presented to various market participants. Specifically, the amount of outstanding government bonds that are issued is over 21.94 trillion Yuan at

FIG. 2. Establishment of a relatively completed interest rate system in China.



the end of fiscal year in 2021, which is 3.2 times larger than the amount traded in 2010, suggesting an enormous expansion in both breadth and depth of the treasury bond market. In the meanwhile, the PBC began to conduct balance management for government bonds in 2006, and gradually increased international practices which are more in line with the short-end treasury bonds issuance. In 2021, the Department of Treasury published 2-year yield to maturity for the first time. Thus, the structure of yield curve contains more reliable information of market volatility as different maturities of reference rates are contributed to the construction of index.

Despite of the fact that China has already made a substantial progress in liberalizing interest rates, it is still an on-going debate whether the interest rate transmission mechanism could play a role in supporting financial stability since prices of financial assets are sensitive to interest rate volatility, raising the concern to evaluate policy effects after liberalization by diverse market participants (including commercial banks, enterprises and residents, etc.). Pertaining to the issue of interest rate liberalization in emerging economies, the prior literatures evaluated the consequences of reform from the perspectives of economic growth as in Lee and Shin (2008), profitability as in Abiad et al. (2010) and Aydemir and Ovenc (2016), and effects of monetary policy tools as in Chenbet al. (2012). These studies agree basically that the interest rate reform elevates the economic freedom and improves the regulating efficiency of monetary policy in intervening certain economic targets. On the other hand, some scholars investigated the interest rate pass-through (IRPT) mechanism in China after the liberalization; see, for example, He and Wang (2012), Jin et al. (2014), Porter and Xu (2009), Chen et al. (2013), and the references therein. In particular, both Liu (2017) and Liu et al. (2018) used quarterly panel data of some selected commercial banks to investigate the interest rate transmission in China and their empirical findings conclude that the benchmark pass-through lending and deposit rates have declined relative to bank retail rates after liberalization. More recently, Li et al. (2021) also examined the IRPT mechanism in China after liberalization by using the nonlinear autoregressive distributed lag model and their findings suggest that the interest rate transmission after liberalization is far from being as effective as expected, and policy rate cuts might not have desirable effects on the real economy under the circumstance of the recession.

In sum, by allowing for better pricing of credit demand and supply, along with risks embedded with lending business, liberalization accelerates financial allocation and efficiency of fund flow. Therefore, the central bank is also more proactive in applying monetary policy tools to transmit economic signal and monitor the variation of benchmark rates through policy rate, which further facilitates liquidity management in the credit market. As a result, the evaluation of the liberalization requires a comprehensive analysis by considering a series of crucial elements involved in interest rate price discovery process, including the volatility of reference rates in the credit market, the market participants, the effect of the monetary policy and the term structure of the bond yields, respectively. Thus, we present a theoretical model by jointly combining benchmark rate, household consumption, inflation and term structure of bond interest rate to fill the aforementioned gap.

In this study, we first develop a model by considering an endowment economy with a representative investor, in condition that the endowment is calibrated to aggregate consumption and inflation are given exogenously. Then, we describe preferences using the recursive utility model proposed by Epstein and Zin (1991) and Weil (1989), define the log-transformed real pricing kernel, and derive yields from Euler equations. At last, we derive investor beliefs from a state space system for consumption growth and inflation, with the same conditional probabilities which are used to evaluate the agent's Euler equation. With the model of combining all aforementioned factors, one can measure the sensitivity of the household consumption relative to the policy rate, and evaluate the interest rate conduction effect by examining the closeness between the yields volatility and the bond market. In addition, a by-product of our analysis is that we propose a model to precisely forecast expected inflation and examine the coincidence of bond yields and different macroeconomic variables.

To empirically test the validity of our model, we create a sample consisting of daily information on consumption, yields of treasury bonds among different maturities (ranging from 3-month to 30-year treasury bond) and all reference rates (including SHIBOR, loan interest rates and repo rates) during the period of January 2010 to May 2022. Our empirical results show that the yield curve of Chinese treasury bond market exhibits an upward sloping pattern where average short-term rates are lower than average long-term rates, yet there is no significant difference between average 1-year rates and average 10-year rates. Standard deviations of market rates among all maturities also display very little differences except that short-term rates have slightly larger volatilities. Furthermore, we find that only adjustment of benchmark rates and the reserve requirement have a jointly significant impact on change in treasury bond yields. Nevertheless, we do not observe that other monetary policy operations have such influence on the change in the yields. Finally, the model presents a superior goodness-of-fit over the predicted mean, the variance and the correlations of yields, and the estimated inflation calculated from our proposed model offers better predictability than the results estimated by Langrun Forecast or Baidu consumer price index (CPI)[2].

Our study at least contributes to the existing literatures in the following strands. First of all, this paper enriches the research in the light of investigating relationship between market interest rates and economic fundamentals. There has been a growing body of academic studies in discussing interest rate term structure from different aspects, for example, macroeconomic fundamental as in Ang and Piazzesi (2003), Diebold et al. (2005) and Bikbov and Chernov (2010)), expected inflation as in Kozicki and Tinsley (2001), Bekaert et al. (2008), Ang et al. (2008) and Chernov and Mueller (2012), bond premium as in Cochrane and Piazzesi (2005) and Ng and Ludvigson (2009), and macro-finance structure as in Wu and Rudebusch (2008), Dewachter and Leonardo (2011), Joslin et al. (2013) and Dewachter et al. (2014). In particular, a recent study by Cieslak and Povala (2015) showed that expected inflation rate is the most important factor in determining the change in U.S. treasury bond rates, and this indicator can explain up to 88% of the change in U.S. 10-year bond rate. Similarly, we also analyze the relation between market interest rates and economic fundamentals in China, however, our results show that expected inflation is only highly correlated with 1-year benchmark deposit rate, which could explain 45% of the change in the benchmark rate, suggesting that the central bank indeed adjusted the reference rates according to the level of expected inflation. On the other hand, we find a very weak relationship between expected inflation rate and market interest rates of all maturities. The explanatory power of expected inflation dramatically weakens, which accounts for only

[2]Please see Section 3.3 for details on the definition of Langrun Forecast and Baidu CPI index.

about 20% of variations in market rates, even after the periods of liberalization. In other words, as a result of this weak relationship, and volatility of market rates is overwhelmingly determined through intervention of central bank to the benchmark rates, revealing that liquidity premium in the bond market does not correctly incorporate the change in expected inflation. Our results recommend that as a part of market-oriented reform, interest rate liberalization in China might be a continuous revolution, which requires consecutive policy support in prompting fundamental role of market forces.

Secondly, the model proposed in this study is built on the characteristics of macroeconomic fundamentals and bond market in China. It not only incorporates the factors that measure the effectiveness of monetary policy transmission mechanism, but also evaluates the outcomes of interest rate liberalization. To the best of our knowledge, our research is among one of pioneering studies to consider this point of view for existing literatures regarding China's interest rate liberalization. This study provides a sharp incentive to effectively evaluate the transmission effects of monetary policy in China along the treasury bond yield curve.

The remainder of this paper is organized as follows. Section 2 presents the structure of econometric modeling, with a scope of derivation in consumer preference, pricing kernel, yield curves and investor beliefs. Section 3 reports empirical analysis in two parts. The first part is to investigate the extent of monetary policy transmission effects and evaluate the consequences of interest rate liberalization in China and the second two is to report the results for robustness tests. Finally, Section 4 concludes the paper.

2. ECONOMETRIC MODELING

Our model is built on the foundation of consumption capital asset pricing model and non-arbitrage interest rate term structure model, so as to jointly combining factors of consumption, inflation, short term interest rate and bond yield. By assuming that consumption growth and inflation are exogenous in this model, then yields are derived from Euler equations. In addition, an endowment economy is considered with one representative investor. Finally, the total consumption is denoted by C_t and the inflation is represented by π_t.

2.1. Consumer Preference

Consumer's utility functions consist of classical power utility function (CRRA) and generalized expected utility function (Epstein-Zin-Weil utility function). With a constant coefficient risk-averse utility function, the

CRRA is expressed as

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

where γ is the consumer's constant risk-aversion coefficient and $U(\cdot)$ is a utility function. If $\gamma = 1$, the model reduces to the standard logarithmic utility.

An implicit assumption for the CRRA utility function is that the relative risk aversion coefficient and the inter-temporal substitution elasticity of consumption are negatively correlated, however, this assumption barely hold economically. Relative risk aversion coefficient stands for consumption substitution inclination for an agent in different economic status, while the latter represents the consumption substitution inclination at different time horizons. It is common to believe that these two parameters are not mutually reciprocal. To mitigate the defects associated with the CRRA utility function, Epstein and Zin (1989) and Weil (1989) developed the generalized expected utility function, which relaxes the relation between inter-temporal substitution elasticity and relative risk-aversion coefficient. Their utility function is also named as the Epstein-Zin-Weil utility function.

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

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

where the certainty equivalent CE_t imposes constant relative risk aversion with coefficient γ as

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

and the sequence of weights α_t is given by:

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

For $\beta > 1$, the weights on expected future consumption growth are decreasing. For large T, they remain equal to one for many periods.

2.2. Pricing Kernel

We divide (1) by current consumption on both sides to get:

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

By taking logarithms and replacing all alphabets with lower case letters, we obtain the following recursive equation:

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

We assume that the variables are conditionally normal, leading to:

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

Again, by assuming that the agents' beliefs are homoskedastic and solving the recursive function above, we can express the log-transformed ratio of continuation utility to consumption, as an infinite sum of expected discounted future consumption growth:

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

For finite T, the weights $\alpha_{t,i}$ are given by $\alpha_{t,i} = \alpha_t$. Payoffs denominated in units of consumption are valued by the real pricing kernel:

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

Now, by assuming normality again, we obtain the log-transformed real pricing kernel:

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

Finally, we define the log-transformed nominal pricing kernel to be used for evaluating payoffs in the following empirical studies, given by $m_{t+1}^{nominal} = m_{t+1} - \pi_{t+1}$.

2.3. Nominal and Real Yield Curves

The Euler equation of a real bond for an agent 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:

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

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

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

and the n-period real yield is defined by the following relation:

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

At time t, the real yield curve maps the maturity n of a bond to its real yield y_t so that equations (2) and (2) show that log-transformed prices and yields of real bonds in this economy are determined by expected future marginal utility. The log-transformed prices and yields of nominal bonds also depend on expected inflation.

Next, we can obtain the deviations of real yields from their mean 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 of consumption growth rate. This equation 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. Nominal growth rate is given as:

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

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

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

Clearly, the first three terms represent the mean real short-run rate in the log-transformed utility case.

When high 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 $rx_{t+1}^{(n)} = p_{t+1}^{(n-1)} - p_t^{(n)} - y_t^{(1)}$, and expected excess return is expressed as:

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

where the covariance term on the right-hand size is the risk premium, while the variance term is presented due to Jensens 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-term bonds are less attractive than short-term bonds, because payoffs tend to be low in bad times (when marginal utility is high). Over a relative long period of samples, the average excess return on an n-period bond is approximately equal to the average spread between the n-period yield and the short-run rate.

2.4. State Space Model and Estimation Method

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. We use maximum likelihood approach to estimate this system with data of consumption growth and inflation. Given the normality assumption on the disturbance vector e_{t+1}, the logarithmic likelihood function of the vector z_{t+1} is easily derived as the sum of logarithmic Gaussian conditional densities.

2.5. Calibrating Parameters

For the consumer risk aversion coefficient γ and discount factor β, we use the real data to estimate. In this paper, we adopt Epstein-Zin-Weil utility function, and obtain the maximization utility function:

$$U_t = \left[(1-\beta)C_t^{(1-\gamma)/\theta} + \beta\left(E_t U_{t+1}^{1-\gamma}\right)^{1/\theta}\right]^{\theta/(1-\gamma)},$$

where β is discount factor, C is total consumption, γ is the consumer risk aversion coefficient, and $\theta = (1-\gamma)/(1-/\psi)$ with ψ being inter-temporal substitution elasticity of consumption. Then, the Euler equation is given by

$$1 = E_t \left\{ \left[\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\psi}} \right]^{\theta} \left[\frac{1}{(1+R_{p,t+1})} \right]^{1-\theta} (1+R_{i,t+1}) \right\},$$

where R_p is return on portfolio and $1+R_{i,t+1}$ is the total return on any available assets, including risk-free asset and the risky portfolio itself. By assuming that $(1+R_{i,t+1}) = (1+R_{p,t+1})$ with a combined log-normal distribution of portfolio income and consumption, one can derive the expected consumption growth rate as:

$$E_t(\Delta c_{t+1}) = \psi \lg \beta + \psi E_t(r_{p,t+1}) + \frac{\beta}{2\psi} \mathrm{Var}(\Delta c_{t+1} - \psi r_{p,t+1}). \quad (6)$$

Due to limitation on investment varieties of our residents, which mainly include only fixed deposits, we denote the 1-year fixed bank deposit rate as $r_{p,t+1}$ and express the fluctuation deviation between the consumption growth rate per capita and the deposit interest rate as $\mathrm{Var}(\Delta c_{t+1} - \psi r_{p,t+1})$. By using the data from 1993 to 2020 and (6), we calibrate the consumer risk aversion coefficient γ and discount factor β, which are 3.0985 and 1.005, respectively, used in the subsequent sections.

3. EMPIRICAL ANALYSIS

3.1. Descriptions of Data

According to the categories compiled by the PBC at the end of 2018, the current policy operational tools conducted by central bank 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), standing lending facility (SLF), medium-term lending facility (MLF), pledged supplementary lending (PSL) and targeted MLF (TMLF). Table 2 reports the statistics of different monetary policy operations implemented by the PBC from January 2010 to October 2021, except for cash bond transaction, central bank refinancing, TMLF and PSL. Here, deposit and loan rates and reserve requirement respectively refer to the adjustment of benchmark deposit and loan rates and the reserve requirement 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 changes in the winning rate for issuance of central note. In addition, operation of MLF means medium-term lending facility operation, interest rate means change in medium-term loan facility winning bid interest rate, and SLF means change in standing lending facility interest rate. Since the central bank usually announced benchmark deposit and lending rates, and reserve requirement adjustments after the bond market closed, the standard deviation of the yield changes under these two circumstances is calculated one day after the announcement. The source of data is from the website of the PBC and the Wind database.

TABLE 2.

The daily standard deviation of monetary policy operations (bps).

Time	Interest rates on deposits and loans	Reserve requirement	Open market operation				MLF		SLF
			Repo	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

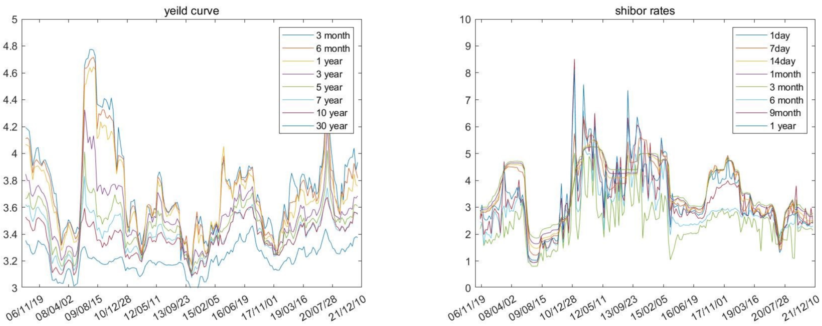
The Federal Reserve pegs London Interbank Offered Rate (LIBOR) as benchmark for short-term interest rates in the U.S. However, the scandal of LIBOR manipulation in 2012 exposed the structural inferiority in the design of LIBOR, and severely deteriorated the public confidence in the banking sector and the financial market. Therefore, the global regulators are seeking a way to ameliorate the foundation of benchmark rates as to prevent crisis of trust and confidence. The benchmark rates for short-term interest rates was used to be SHIBOR in China before 2012, however, the newly-launched LPR in recent years replaced SHIBOR as the benchmark. In our analysis, we select SHIBOR as benchmark for 1-year loan and 7-day pledged repo rates, even though it is still a controversial issue on whether banks should replace SHIBOR with deposit and loan rates as benchmark. We obtain data of bond yields with various maturities (ranging from 3-month to 30-year) from Wind Database and the PBC website. In Table 3, we present descriptive statistics (mean, min, max and standard deviation, denoted by SD) of the daily bond yields among different representative maturities under each category of monetary policy operations, such as 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} denoting 3-month, 6-month, 1-year, 3-year, 5-year, 7-year, 10-year and 30-year bond yields, respectively. Finally, we display yield curves and SHIBOR of all terms in Figure 3 with the left panel for treasury bond yields with different maturities and the right panel for yields of SHIBOR, respectively.

TABLE 3.

Descriptive statistics of treasury bond yields.

Variables	Mean	SD	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

FIG. 3. Left panel: treasury bond yields with different maturities. Right panel: yields of SHIBOR.



In Figure 3, one can observe that, similar to that of in developed economies, the term structure of treasury bond rates in China also displays a relative upward sloping pattern, where on average short-term rates are lower than long-term rates, with only exception that 1-year rates and 10-year term do not differ significantly. Standard deviations of market rates of all terms exhibit small disparity, while short-term rates have slightly larger volatilities. Secondly, when benchmark rates are at their troughs, the market interest rates, especially for short-term rates, are usually at relatively low level as well, for example in periods of 2002-2003, or in periods of 2005-2006. However, one can also observe some exceptions in the second half of 2004, when policy rates are low yet the market rates, especially for long-term rates, arrive at the peak over our sample period. In 2017, the benchmark rates remained stable at the historical low level. Nevertheless, as a result of deleveraging policy imposed by the central bank, the entire financial system underwent a tightening of credit supply, and such decisions exacerbated the exhaustion of liquidity in bond market in which we could observe a spike of bond yields during the same period. Finally, we do not observe significant influence of monetary policy tools to the change in the bond yields, except for adjustment of benchmark rates and reserve requirement. In fact, most of monetary policy tools, such as open market operations or MLF, unveils the characteristics of endogeneity which aims to preserve market liquidity balance, and those operations include very limited information to signal specific economic target. It is also noteworthy that, even though the PBC never admitted any types of short-term rates as the benchmark, they did explicitly declare that the adjustment of deposit and loan rates is the foundation of interest rate intervention. In addition, the interest rate corridor mechanism was still at the start-up stage, therefore the markets were likely to hold the belief to choose market rates occasionally in positioning interest rates ceiling instead of SLF, which eventually eroded the policy efficiency of SLF.

3.2. Empirical Results

3.2.1. Impulse Response Function

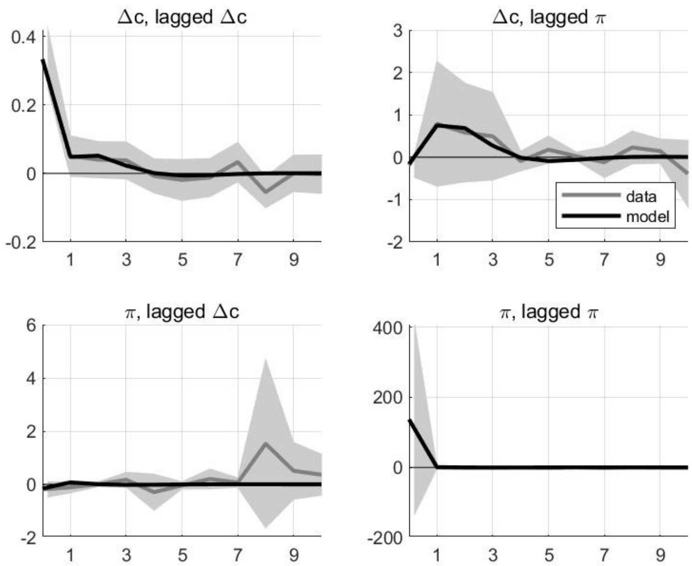
In this section, we conduct empirical analysis and report all results by using 7-day SHIBOR as the short-term reference rate[3]. The state space system given in (5) nests a first-order vector autoregression (VAR). Starting with the VAR $z_{t+1} = \mu_z + \phi z_t + e_{t+1}$ and set $x_t = \phi(z_t - \mu_z)$, this results 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 we can verify by 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, we report covariance functions which completely characterize the linear Gaussian system given in (5). Figure 4 plots covariance functions computed from both the model and the raw data. At 0 months, these lines represent variances and contemporaneous covariances. The black solid lines estimated from the model mostly match with the gray lines computed from data. The shaded areas in Figure 4 represent boundaries for twice the standard error around the covariance functions estimated with raw data. The boundaries

[3]Due to the limited length of the paper, all analysis results with figures using other short-term rates as reference rates are available upon request

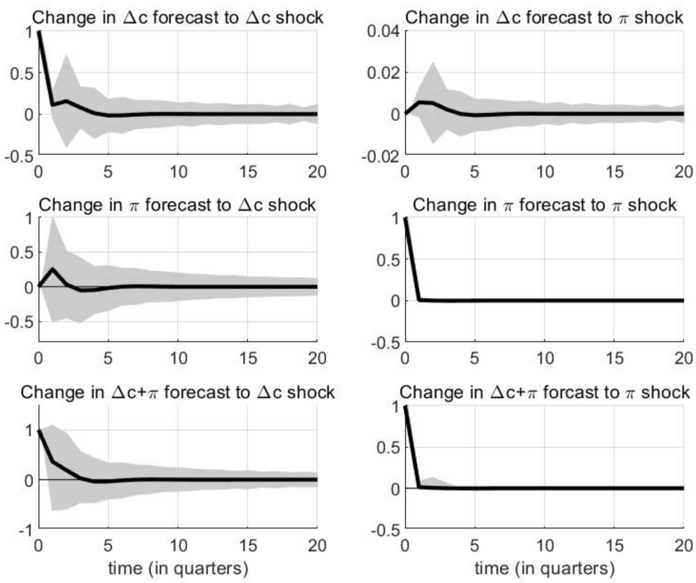
of standard error are estimated by GMM. An important feature of the data is that consumption growth and inflation are not only negatively and contemporaneously correlated, but also able to forecast each other with a negative sign. For example, the upper right panel in Figure 4 shows that high inflation is a leading indicator of recession. 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 are important for determining yields of longer maturities.

FIG. 4. Covariance functions computed from the estimated model and the raw data. Shaded areas indicate twice the standard error bounds around the covariance function from the data computed with GMM. For example, the graph titled as consumption, lagged consumption shows the covariance of current consumption growth with consumption growth lagged months, where measured on the horizontal axis



From (4), the dynamics of equilibrium interest rates are driven by forecasts of growth and inflation. Real yield movements are generated by changes in growth forecasts over the lifetime of the bond, while nominal yield movements are generated by varying nominal growth forecasts. Furthermore, to better understand the conditional dynamics of these forecasts, as opposed to the unconditional covariances and univariate regression forecasts plotted in Figure 4, impulse responses are plotted in Figure 5. The signs of the self-shock responses are not surprisingly consistent with the unconditional covariances; they are positive and decaying over time. The speed of decaying for consumption growth is slower for that of inflation, where a 1-percent increase in shock raises inflation forecasts by 50 basis points. However, the cross-shock responses demonstrate interesting patterns. The graph in middle left shows that a 1-percent increase in growth shock leads to approximately 20 bps increase in inflation over the next 1-2 years. The top right graph shows that a 1-percent increase in inflation shock reduces growth forecasts by almost 5bps over the next year. Additionally, both inflation and growth shocks lead to higher nominal growth forecasts for longer time horizons. These findings imply that both growth and inflation shocks lead real rates with shorter maturities in opposite directions, yet both shocks would not significantly affect real rates with longer maturities. In contrast, both growth and inflation shocks indeed affect nominal rates in longer maturities due to their long-lasting effects on inflation forecasts. In general, both shocks lead the nominal rates in the same direction.

FIG. 5. Impulse responses to 1-percentage point shocks e_{t+1} in consumption growth and inflation. The responses are measured in percentage term. Shaded areas are boundaries for twice the standard error estimated by maximum likelihood approach.



In the next step, we include other interest rates into the model. Results of the analysis show that expected inflation rate tends to exhibit highest correlation with the 1-year deposit benchmark rate, with a fact that expected inflation explains up to 45% of the volatility in the benchmark rates. These findings suggest that the central bank should adjust the benchmark rates based on level of expected inflation. Especially, change in expected inflation rate explains about 87% of the change in benchmark rates since 2012. These results suggest that the central bank should increasingly facilitate intervention with price-based tools. Surprisingly, the relationship between expected inflation and market rates of all terms is very weak. Less than 20% of variation in market rates could be explained by the change in expected inflation, with no prominent improvement until now. The explanatory power is much lower than that of in the U.S. market as in Cieslak and Povala (2015). In other words, expected inflation is only weakly tied with market rates, and the adjustment of benchmark rates is only channel in which the central bank could influence market rates, indicating a mismatch between expected inflation and funding liquidity in the bond market.

3.2.2. Average Nominal Yields

In Table 4, we compare the properties of average nominal yields estimated by the model with the data of three reference rates, such as SHIBOR in the top of Table 4(I), interest rates on loans in the middle of Table 4(II), and repo rate in the bottom of Table 4(III), respectively. It is clear from Table 4 that the results for interest rates on loans and repo rate are similar to those for SHIBOR so that our following interpretations are only on SHIBOR. In Panel A of Table 4(I) for SHIBOR, interestingly, the estimation also generates an upward sloping nominal yield curve. The average difference between the 30-year yield and the 3-month yield is approximately 2 percent, or 200 bps, and difference is statistically significant with a measured standard error of 26 bps. In contrast, the estimated level of the nominal yields are lower than actual yields for bonds with all terms, except for 3-month rate. The difference in standard errors is approximately 32 bps for the yields between shortest and longest end along the curve. The economic intuition behind this observation is apparent: during the periods of high inflation, nominal bonds have low payoffs. Since inflation deteriorates payoffs of bonds with longer maturities in a larger magnitude than those of bonds with shorter maturities, in this case an agent requires a higher premium, or higher yields, to hold long-term bonds.

TABLE 4.

Comparison of raw data and estimation results by using nominal yields.

I. Estimation results with SHIBOR

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

II. Estimation results with interest rates on loans

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	2.22	2.45	2.87	3.01	3.31	3.47	4.11

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	0.72	0.73	0.71	0.61	0.61	0.55	0.52	0.49

Panel C: Autocorrelation of Nominal Yields

	3 month	6 month	1year	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	0.9105	0.919	0.926	0.933	0.9281	0.93	0.945	0.946

In Panel A of Table 4(I), we also find that the curvatures of average nominal yields are larger than that of estimated by the model. The disparity mostly comes from the abrupt acceleration in inclination between 6-month yield and the 1-year yield. However, the model shows improving calibration to replicate curvature if we drop out the yields in the short end of the curve.

Panel B of Table 4(I) reports the volatility of nominal yields across different maturity spectrum. Consistent with the pattern of volatility calculated by real data, estimated volatilities are also higher for the nominal rates in the short run. According to the estimated state space model (5), changes

TABLE 4—*Continued*

III. Estimation results with repo rate

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	2.20	2.29	2.66	2.68	3.29	3.3	3.98

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	0.69	0.65	0.61	0.52	0.51	0.42	0.41	0.33

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	0.906	0.918	0.927	0.928	0.93	0.943	0.945

in expected fundamentals (consumption growth and inflation) contribute to 68 percent of volatility in the short-term rates, which is 8 percent lower than volatility calculated by real data. Compared with that of estimated by real rates, the shape of estimated volatility curve is much steeper due to the low persistency in consumption growth. In general, the estimated volatility is lower than actual volatility for yields with longer maturities, for example, the estimated volatility for 30-year yield is 29 percent, while actual volatility for 30-year yield is 55 percent. The slope of estimated volatility curve is also downward sloping with a flatter shape.

The benchmark model also demonstrate superior capacity to synthetically replicate autocorrelation of yields with different maturities, as shown in Panel C of Table 4(I). The actual autocorrelation for the nominal 3-month rate is 91.75 percent, in comparison with an estimated value of 91 percent generated by model. We obtain similar conclusion if 30-year rate is replaced with 3-month rate. These discrepancies between actual and estimated value of autocorrelation fall within corridor boundaries of twice the standard error. Among all three reference rates, the predicted values estimated by loan rates demonstrate the best goodness-of-fit.

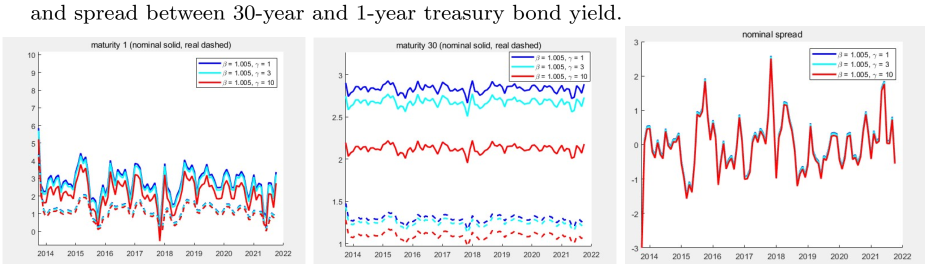
Theoretically speaking, expected inflation is the most important indicator in determining market rates of all terms, which is also evidenced by prior literatures studying term structure of interest rate in developed economies. Instead, we identify a very weak explanatory power of expected inflation to market rates. We conclude that liberalization does not significantly strengthen market mechanism transmission by closely tying expected rate with market rates. In fact, the connection between monetary supply and real economy is relatively weaker even as direct financing becomes popular. It is recommended that the central bank should make more efforts in ameliorating regulation tools to enhance the connection between price-based tools and real economy, as well as the relationship between market rates of all terms and expected inflation.

3.3. Robustness Checks

3.3.1. Robustness Checks for Parameters

Relative risk-averse coefficient γ determines the proportion of wealth that an investor is willing to pay to avoid a risk relative to a given wealth size. The bigger the γ, the more risk-averse investors are, and the less risk-taking they become, and vice versa. In Section 2.5, we obtain the relative risk aversion coefficient $\gamma = 3$ by estimating the data from 1993 to 2020. We re-estimate it by using the data from 1978 to 1993, and obtain an alternative γ value of 8. A large value of γ indicates that the residents associated with relative low level of wealth have a higher degree of risk-averse during early era of economic transformation. With the development of economy, the degree of risk-averse decreases, and the risk-bearing capacity of investors strengthens. We test the sensitivity of the model by estimating fitted values of 1-year treasury bond yield, 30-year treasury bond yield and the spread between these two yields, respectively. In Figure 6, we do not observe a large deviation in change of the estimated values, indicating that the model is not subject to parameter calibration.

FIG. 6. Fitted values of 1-year Treasury bond yield, 30-year treasury bond yield and spread between 30-year and 1-year treasury bond yield.



3.3.2. Robustness Checks for Estimating Inflation

In this section, to further verify the validity of our model, we compare the estimated inflation rate with alternative foretasted inflation index, namely Langrun Forecast and Baidu index, respectively. We obtain Langrun quarterly CPI forecast index from National School of Development at Peking

University, which is the mean value of the economists' forecasted CPI of each quarter published by 15 institutions and it was kept updating till the fourth quarter of 2015.

Additionally, Baidu is one of the most important searching engines and data sharing platforms based on behaviors of the enormous internet users. Baidu index is able to provide multiple mega-data analysis such as identifying the scale of the search for a key word, the trend of the search for news and public opinions, type of users, location of users, and etc. This index is widely used for corporate decision making and help users to optimize their digital marketing plans. Up to 2014, functional modules of Baidu index include, but not limited to, for example, trend study, spectrum of demand, public opinion house keeper, portrait of the crowd, geographic location, crowd property, and characteristics of search time. We search the key word "CPI" in data search engine, and compute CPI index by the data parsing from web crawler[4]. We find that the root mean squared error (RMSE) is 0.087 between the our estimated inflation and the real value, which is much smaller than the RMSE values calculated by Langrun CPI index (RMSE=0.178) and Baidu Index (RMSE=0.13), respectively. The results estimated by our model outperform those estimated by either Langrun or Baidu index. Therefore, one can conclude that our model can provide a better predictabitive power.

4. CONCLUSIONS

In conclusion, this paper evaluates the interest rate liberalization in China. Building on a sample consisting of daily treasury bond yields and benchmark rates with different maturities during the period from 2010 to 2021, we empirically examine the term structure of bond yields by proposing a model incorporating macroeconomic fundamentals and measurement of monetary policy efficiency. Our results show that on average short-term interest rates are lower than long-term interest rates, while standard deviations of market rates in all terms display no significant disparity, with exception that short-term rates have slightly larger volatilities. In addition, most of monetary policy operations are weakly related to change in bond yields, except for adjustment of benchmark rates and reserve requirement. Expected inflation rate is strongly correlated with the 1-year benchmark deposit rate, however, the relationship between expected inflation and market

[4]Because of the limited length of the paper, readers may ask for Python codes of the Web Crawler and computational results.

rates is relatively weak. Our model shows a superior goodness-of-fit over the predicted mean, the variance and the correlations of treasury bond yields, and our estimated inflation rate outperforms CPI index estimated by either Langrun or Baidu index, among which presents a lower root mean squared error.

Furthermore, our results find that adjustment of benchmark rates and reserve requirement are the most important price-based tools for the central bank to transmit the effects of monetary policy along the yield curve. In 2019, the central bank replaced benchmark rates with LPR to link the price quote of commercial bank's LPR to MLF, which assures the benchmark position of LPR. The LPR reform, as a continuous process in liberalization, implies that the central bank would successively intervene the interest rate market from direct transmission into indirect transmission. The development of interest rate liberalization requires prudential management by central bank to focus on short-term interest rate intervention besides policy support, in emphasizing the power of market forces to eventually link the change in market interest rates with economic fundamentals.

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