A Study on Macro Measurement Methods and Volatility Characteristics of Interest Rate Risk of Commercial Banks under the New LPR Mechanism

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Abstract

The interest rate risk of commercial banks is closely related to the effectiveness of the LPR mechanism. In this paper, the interest rate market is divided into three stages according to the process of interest rate marketization, and a six-sector New Keynesian MS-DSGE model is constructed by adding monetary regulation variables. The parameters in the model that are influenced by interest rate marketization and the new LPR mechanism are transformed by Markov zone transformation. The interest rate risk of commercial banks is measured by the impulse response functions of uncertain interest rate shocks to the interest rate sensitivity gap and the duration gap, and the volatility characteristics of interest rate risk in different stages of interest rate marketization are compared and analyzed. The results show that in the third stage (2019-present), the LPR mechanism is transformed from old to new. Under the $\delta_g = 0.5$ shock, the commercial lending interest rate tends to stabilize around 0.00038, and the borrowing interest rate tends to 0 in all 3 differentiated target parameters in the 10th period. For this reason, the differentiated interest rate pricing behaviors of commercial banks should be considered comprehensively, and the LPR target should be set reasonably so as to get the optimal policy effect.

Keywords: Interest rate risk; LPR mechanism; MS-DSGE model; Markov zone system transformation; Duration gap.

AMS 2010 codes: 03D10
1 Introduction

Commercial bank interest rate risk is a kind of financial risk that refers to the risk of loss of income or capital of the bank due to the fluctuation of interest rates, resulting in unequal changes in the return and value of the bank’s assets relative to the cost and value of its liabilities [1-2]. Interest rate risk management has become a crucial part of the core competitiveness of modern commercial banks due to China’s interest rate marketization reform [3-4]. Under the conditions of marketization, interest rate fluctuations will be very frequent, and commercial banks will suffer serious economic losses if they cannot effectively control interest rate risk [5-6]. Interest rate marketization puts higher requirements on the independent pricing ability of commercial banks, especially on the pricing ability of risk premiums, including interest rate risk [7-8]. Moreover, a complete interest rate risk management system is a regulatory requirement in line with international standards and a necessary condition for commercial banks to go public [9]. In conclusion, Chinese commercial banks must improve their interest rate risk management ability in order to improve the efficiency of capital utilization and obtain a broad and lasting space for survival and development [10-11].

Market-oriented reform and financial product innovation in promoting the rapid development of commercial banks at the same time, but also to the commercial banks themselves and the entire financial system, has brought greater potential risks [12]. Literature [13] studied embedded sensor networks of interbank interest rate risk, put forward the key technology of sensor networks, sensor network MAC layer protocol, LEACH energy model, etc., and did the relevant experiments. The results show that the technology in the interbank risk metrics than the traditional model in efficiency and accuracy is higher. Literature [14] established a bank capital structure model to simulate bank risk hedging, the results show that the bank’s derivatives in whether or not to bring excessive risk is not so sure. Literature [15] creates a simulation optimization methodology that measures interest rate, credit and liquidity risk and finally seeks the optimal solution using the Pareto frontier. The study found that full cash allocation is risky in a low-interest rate environment. Literature [16] introduced a worst-case continuous portfolio model for analysis to seek a solution to the constrained optimization problem, which was shown to be useful for crash risk management in interest rate conflicts. Literature [17] constructs a new measure of a bank’s assets and liabilities, repricing and maturity conflict problem to analyze the stock reporting reaction and bank operating characteristics association. The results of the study show that a steep rise in interest rates or a steepening of the yield curve, a large fall in bank stock prices, and large term spreads reduce the unexpected response to yield and slope. Literature [18] used a combination of the dynamic-static modeling approach and valuation techniques, and the results of the study show that a low-interest rate environment reduces the bank’s earnings from performance and spreads but also has implications for financial stability due to low reserves. Literature [19] examines issues related to interest rate risk in the Dutch banking book from 2008 to 2015. The results of the study show that the return curvature flattens, then the bank’s interest rate risk is at a low level, if the bank has no derivatives, interest rate risk is negatively correlated with on-balance sheet leverage and has a U-shape relationship with the resolvable linearity, and finally during the financial crisis, banks assisted by the state have a higher risk.

In this paper, we first construct a six-sector structural New Keynesian (MS-DSGE) model that includes expected shocks. The Calvo staggered pricing model was chosen to adjust the price according to the thumb rule and encourage intermediate goods producers to adopt the C-D production function. Next, the Markov zone shift model is used to study the zone characteristics of the interest rate level and exchange rate yield, respectively, and the binary Markov zone shift vector model is applied to study the zone correlation between the interest rate level and exchange rate yield. Then, the interest rate sensitivity gap and duration gap interest rate risk measurement models are utilized to measure the interest rate risk of commercial banks on a macro level. Finally, data from the period between 2019 and December 2022 using the new LPR mechanism are analyzed.
2 New Keynesian (MS-DSGE) model setting

This paper constructs a New Keynesian (MS-DSGE) model incorporating expected shocks, which is a six-sector model including households, intermediate goods producers, final goods producers, capital goods producers, commercial banks, and the monetary regulatory authority. In addition, the model contains a series of nominal and real frictions such as habit formation, capital adjustment costs, variable capital utilization, and wage and price stickiness. The introduction of this series of frictions allows the model to better fit the real economy. In terms of shocks, the model contains eight unanticipated shocks, such as productivity shocks, investment shocks, consumption preference shocks, government spending shocks, interest rate shocks, labor supply shocks, price markup shocks, and wage markup shocks, as well as two anticipated shocks such as productivity expectation shocks and investment expectation shocks.

2.1 Family sector

The economy contains a large number of homogeneous households and its utility function is expressed as:

\[
U_t = E \sum_{s=0}^{\infty} \beta^s \left\{ \frac{c_t^{1-s^{-1}}}{1-s^{-1}} + \eta_N \ln (1-N_t) + \eta_x \ln x_t \right\}
\]

(1)

Where \( C_t \) is the consumption basket, \( N_t = \int_0^t N_j d j \) is the total labor time provided by households to firms producing intermediate goods, \( N_j \) is the labor time provided by households to \( j \) firms. \( x_t = (m_t^H) \nu d_t^{1-v} \) is a composite index of real money assets, \( \beta^s \in (0,1) \) is a discount factor, \( s > 0 \) is the intertemporal elasticity of substitution of consumption, \( \eta_N, \eta_x > 0 \). \( m_t^H \) denotes cash money held by the household, \( d_t \) denotes bank deposits held by the household, and \( \nu \in (0,1) \).

The household’s budget constraint in period \( t \) is:

\[
M_t^H + D_t + B_t^H + P_t^V V_t + P_t (C_t + I_t) = P_t \left( r_t^K K_t + \alpha_t N_t \right) + \left( 1 + \gamma_{t-1}^D \right) D_{t-1} + \left( 1 + \gamma_{t-1}^B \right) B_{t-1}^H \\
+ \left( 1 + \xi_{t-1}^V \right) P_{t-1} V_{t-1} + J_t^B + J_t^I \\
+ M_{t-1}^H - \Theta_t P_t \frac{Z_t V_{t-1}^2}{2}
\]

(2)

Where \( M_t^H \) is the nominal cash money held by households in period \( t \) and \( P_t \) is the price of final goods. \( D_t \) is the nominal deposits held by the household in period \( t \), \( K_t \) is the physical capital owned by the household in period \( t \). \( P_t^V \) is the nominal price of shares issued by the bank in period \( t \), \( V_t \) is the share of bank shares held by the household in period \( t \). \( B_t^H \) is the nominal government bonds held by the household in period \( t \).

In summary, the first-order condition for maximizing the utility of a representative household is:
\[ C_t^{x^{-1}} = \beta E_t \left[ C_{t+1}^{x^{-1}} \left( \frac{1 + t_t^B}{1 + \pi_{t+1}} \right) \right] \]  
(3)

\[ C_t^{x^{-1}} = \beta E_t \left[ C_{t+1}^{x^{-1}} \left( t_t^K + (1 - \delta) \right) \right] \]  
(4)

\[ N_t = 1 - \frac{\eta_x C_t^{x^{-1}}}{\omega_t} \]  
(5)

\[ m_t^H = \eta_x v \left( 1 + t_t^B \right) C_t^{x^{-1}} \]  
(6)

\[ d_t = \frac{\eta_x (1 - v) \left( 1 + t_t^B \right) C_t^{x^{-1}}}{i_t^B - i_t^0} \]  
(7)

\[ z_t V_t^d = \frac{1}{\Theta_v} \frac{i_t^v - i_t^B}{1 + i_t^B} \]  
(8)

\[ \pi_{t+1} = \left( P_{t+1} - P_t \right) / P_t \]  
(9)

### 2.2 Product Manufacturing Sector

In order to achieve "nominal price rigidity", the product production sector is divided into final goods producers and intermediate goods producers.

#### 2.2.1 End-product producers

The final product producer has a production function of \( Y_t \) in period \( t \):

\[ Y_t = \left[ \int_0^1 (Y_j)^{-\theta} \right]^{-\theta} \]  
(10)

Where \( Y_j \) tabulates the output of intermediate goods produced by intermediate firm \( j \), and \( \theta > 0 \), represents the elasticity of demand for each intermediate good, this type of production technology is called a "packer" with constant elasticity of substitution.

The firm producing the final product maximizes its profit, i.e.:

\[ \text{profits} = P_t Y_t - \int_0^1 (P_j Y_j) dj \]  
(11)

Where \( P_j \) denotes the price of the intermediate product produced by intermediate product producer \( j \). Since the market for the final product is a perfectly competitive market and hence the economic profit is zero, the pricing equation for the final product can be obtained as:
\[ P_t = \left[ \int_0^1 \left( P_{t-j} \right)^{1-\theta} \, dj \right]^{1-\theta} \]  

### 2.2.2 Producers of intermediate products

Since the market for intermediate goods is monopolistically competitive, there are different ways of pricing intermediate goods. In this paper, we have chosen the Calvo staggered pricing model, which is the most popular model today, where a proportion of firms are individually and randomly sampled in each period and these firms can change their prices. The rest of the intermediate goods producers can only adjust their prices according to the thumb rule, and the intermediate goods producers will accept a given level of wages and rents, The intermediate goods producer \( j \) uses the following C-D production function:

\[ Y_{ji} = A_i \left( N_{ji} \right)^{1-\alpha} \left( K_{ji} \right)^{\alpha} \]  

Where \( N_{ji} \) is the labor time demanded by the manufacturer, \( \alpha \in (0,1) \), \( A_i \) denote the production technology which obeys the following process:

\[ \ln A_i = \rho_A \ln A_{i-1} + \xi_i^A \]  

Where, \( \rho_A \in (0,1) \). At the beginning of each period, the intermediate goods producer takes a loan from the bank to pre-pay the wages of the labor force, viz:

\[ L^F_{jt} = P_{jt} \omega_t N_{jt} \]  

Firm \( j \) maximizes its profit in period \( t \), so there:

\[ P_{jt}^{1-\theta} = \tau P_{t-1}^{1-\theta} + (1 - \tau) \left( P_{jt}^{*} \right)^{1-\theta} \]  

### 2.2.3 Producers of capital goods

Suppose the production function of a representative producer of capital goods is:

\[ Y_i(i) = K_i(i)^{\alpha} N_i(i)^{1-\alpha} \]  

where \( K_i(i) \) and \( N_i(i) \) are the capital and labor employed by firm \( i \), respectively.

If wages and rents are given, cost minimization for the firm implies:

\[ \frac{K_i(i)}{N_i(i)} = \frac{\alpha}{1 - \alpha} \frac{W_i}{R_i} \]  

Real marginal cost is the same for all firms for:

\[ MC_i = \alpha^{-\alpha} (1 - \alpha)^{\alpha-1} \left( R_i^k \right)^{\alpha} \left( W_i \right)^{1-\alpha} \]
Assuming that intermediate goods manufacturers adjust their nominal prices according to the nominal GDP approach, the probability that each firm adjusts the price of its product in each period is $1 - \gamma$. Thus, in each period, a $(1 - \gamma)$ proportion of intermediate goods manufacturers adjust their prices, and a $\gamma$ proportion of them keep their price levels unchanged. The average duration of price persistence is $(1 - \gamma)^{-1}$. In this case, $\gamma$ is a natural indicator of price stickiness. And any degree of price rigidity is tolerated, with elastic prices when $\gamma = 0$ and full price rigidity when $\gamma = 1$.

A firm that adjusts its price in period $t$ will seek to maximize:

$$\max_{P_t^*} E_t \sum_{k=0}^{\infty} \gamma^k E_t \left\{ \Lambda_{t,t+k} \left[ \frac{Y_{t+k}(i) P_{t+k}^*}{P_{t+k}} - \Psi_{t+k}(Y_{t+k}(i)) \right] \right\}$$

Budget constraints for:

$$Y_{t+k}(i) = \left( \frac{P_t^*}{P_{t+k}} \right)^{-\theta} Y_{t+k}$$

Where $P_t^*$ is the price chosen by the firm that adjusted its price in period $t$, $\Lambda_{t,t+k}$ is a stochastic discount factor, and:

$$\Lambda_{t,t+k} = \beta^k \left( \frac{Z_{t+k}}{Z_t} \right)^{-\eta} \left( \frac{C_{t+k}}{C_t} \right)^{-\eta} \frac{P_t}{P_{t+k}}$$

The first-order condition for the above optimization problem is:

$$\sum_{k=0}^{\infty} \gamma^k E_t \left\{ \Lambda_{t,t+k} Y_{t+k}(i) \left[ \frac{P_{t+k}^*}{P_{t+k}} - \frac{\theta}{\theta - 1} MC_{t+k} \right] \right\} = 0$$

2.3 Commercial banks

Commercial banks obtain deposits $D_t$ from households at the beginning of period $t$ and lend these deposits to intermediate goods producers for the payment of labor wages. Thus, an expression for bank lending can be obtained:

$$L_t^F = \int_0^t L_{\mu,t}^F \, d\mu = P_t \omega_t N_t$$

The balance sheet of the bank in period $t$ is represented as follows:

$$\begin{cases} L_t^F + B_t^R + RR_t = D_t + P_t^V V_t + L_t^B \\ V_t = V_t^R + V_t^E \\ RR_t = \mu D_t \end{cases}$$
Where, $L^B_t$ is the commercial bank’s borrowing from the central bank, $V^r_t$ is the minimum amount of capital, i.e., statutory capital, set by the banking regulator, $V^E_t$ is excess capital; and $\mu \in (0,1)$, is the deposit reserve ratio.

Meanwhile, commercial banks are subject to risk-based capital requirements:

$$P^V_t V^r_t = \rho \sigma^E_t L^F_t$$  \hspace{1cm} (26)

Where, $\rho \in (0,1)$, denotes the capital adequacy ratio; and $\sigma^E_t$ denotes the risk weight of the bank’s assets, as determined by loan repayment, i.e:

$$\sigma^E_t = \left( \frac{q^F_t}{q^F} \right)^{-\delta_t}$$  \hspace{1cm} (27)

Where $q^F_t$ denotes the repayment rate of the loan, $1 - q^F_t$ is the default rate of the loan, and $\bar{q}^F$ is the steady state value of $q^F_t$.

The following equation determines the bank’s expected profit at the end of each period:

$$E_t \left[ \frac{\Lambda^B_{t+1}}{P_t} \right] = \left(1 + i^B_t\right) b^B_t + q^F_t \left(1 + i^E_t\right) \left( \frac{L^B_t}{P_t} \right) + \left(1 - q^F_t\right) \kappa K_t + \mu d_t$$

$$- \left(1 + i^B_t\right) d_t - \left(1 + i^E_t\right) \left( \frac{L^B_t}{P_t} \right) - \left(1 + i^E_t\right) z_i V_i^r + 2\gamma_z z_i \left( V_i^E \right)^{1/2}$$  \hspace{1cm} (28)

The third of these represents the compensation banks receive from collateral on loans that have defaulted, where $\kappa \in (0,1)$, a measure of market imperfections. The eighth term denotes the bank’s return from holding a capital buffer.

The first order condition for a commercial bank to maximize its expected profit is:

$$i^D_t = \left(1 + \frac{1}{\eta_D} \right)^{-1} (1 - \mu)i^B_t$$  \hspace{1cm} (29)

$$1 + i^E_t = \frac{1}{\left(1 + \eta^E_t\right)^{q^F_t}} \left[ \left(1 + i^F_t\right) (1 - \rho \sigma^E_t) + (1 + i^E_t) \rho \sigma^E_t \right]$$  \hspace{1cm} (30)

$$i^B_t - i^F_t = 0$$  \hspace{1cm} (31)

$$i^B_t - i^E_t + \frac{\gamma_V}{\sqrt{V^E_i}} = 0$$  \hspace{1cm} (32)
Where, \( \eta_D = \frac{\partial d_t}{\partial i_t} \frac{i_t^D}{d_t} \), denotes the elasticity of the supply of household savings to the savings rate. 
\[ \eta_F = \frac{\partial \Phi}{\partial L_t} \frac{i_t^L}{L_t} \]
denotes the elasticity of the change in demand for business loans to the lending rate.

### 2.4 Monetary regulatory authorities

In China, monetary policy is regulated by the central bank, which holds assets including government bonds, \( B^C_t \), funds lent to commercial banks, \( L^B_t \). At the same time, the central bank provides cash money to firms and households, \( M_t^s \), and deposit reserves paid by commercial banks, \( RR_t \). The cash money and the deposit reserves make up the base money, and thus the central bank balance sheet formula is:

\[
B^C_t + L^B_t = M_t^s + RR_t
\]

The central bank achieves its desired objectives by adopting a monetary policy rule, assuming that the refinancing rate is the central bank’s operational tool, and taking into account the characteristics of China’s staid money supply intermediation target, the monetary policy rule takes the form of a Taylor rule as:

\[
i_t^R = \chi i_t^B + (1-\chi) \left[ \bar{t}^B + \varepsilon_1 \ln \left( \frac{\pi_t}{\bar{\pi}} \right) + \varepsilon_2 \ln \left( \frac{Y_t}{\bar{Y}} \right) + \varepsilon_3 \ln \left( \frac{m_t^s}{\bar{m}^s} \right) \right] + \varepsilon_t^m
\]

Where \( \bar{t}^B \), \( \bar{\pi} \), and \( \bar{m}^s \) denote the steady state values of the government bond yield, the steady state value of inflation, the steady state value of aggregate output, and the steady state value of the money growth rate, respectively. Coefficient \( \chi \in (0,1) \) measures the degree of interest rate smoothing and represents the different weights given by the central bank to deviations of the same inflation, output, and money growth rates from their steady-state values. \( \varepsilon_t^m \) denotes monetary policy shocks that follow a standard normal distribution.

### 3 Interest rate risk management for commercial banks under the new LPR mechanism

#### 3.1 New LPR mechanism

The Lending Base Rate (LPR), which has been in formal operation since 2013, is based on the lending rate of the Bank to its best-quality customers quoted by representative banks. The weighted average interest rate is calculated by the National Interbank Offered Rate Center using the loan balances of each quoting bank as weights and then announced to the public and is supervised and managed by the Self-Regulatory Mechanism for Pricing Interest Rates in the Market under the guidance of the Central Bank. Loan pricing was changed to use LPR as the reference benchmark for loan interest rates, and the actual execution rate of loans was formed by adding or subtracting points on this basis.

Interest rate marketization in China can be divided into three stages, according to the process.
1) The first stage is January 2001-December 2012. This interval is the main part of China’s gradual interest rate marketization reform, which can be taken as a typical representative of the market cultivation stage.

2) The second stage is January 2013-December 2018, and this interval is the stage of full liberalization of interest rate control, which can represent a higher level of interest rate marketization.

3) The third stage is from January 2019 to the present. This interval is the closing stage of interest rate marketization, which can represent that the marketization of loan interest rates has been basically realized.

The formation pattern of the real interest rate on loans is shown in Figure 1, and the real interest rate on commercial bank loans is jointly determined by the bank’s cost of funds, cost of fees, and risk premium. Among them, the cost of funds is determined by a combination of the cost of deposit-type funds and the cost of market-based funds, and the risk appetite of commercial banks determines the risk premium. With the cost of fees relatively fixed, the effective interest rate on loans depends on the cost of funds and the level of risk premium.

![Figure 1. Formation model of the real interest rate of loans](image)

### 3.2 Markov Vector District System Transfer Model

The zone shift model is a nonlinear model that studies time series in finance and is commonly utilized for analyzing exchange rate volatility and forecasting. In this paper, the Markov zone shift model is used to study the zone characteristics of the interest rate level and the exchange rate return respectively, and then the binary Markov zone shift vector model is applied to study the zone correlation between the interest rate level and the exchange rate return.

Define $M$ as the number of feasible zone systems with, $S_t \in \{1, \ldots, M\}$, giving the conditional probability density of the observation vector $y_t$ as:

$$P(y_t \mid y_{t-1}, S_t) = \begin{cases} f(y_t \mid y_{t-1}, \theta_1) & \text{if } S_t = 1 \\ \vdots & \text{if } S_t = M \\ f(y_t \mid y_{t-1}, \theta_M) & \text{if } S_t = M \end{cases}$$ (35)
Where $\theta_m$ is the parametric vector of VARs in zone system $m = 1, 2, \ldots, M$ and $y_{t-1}$ is the observations $\{y_{t-j}\}_{j=1}^{\infty}$. For a given zone system $S_t$, the time series vector $y_t$ is generated by a $p$th order autoregressive process. Thus there is:

$$E(y_t | y_{t-1}, S_t) = v(S_t) + \sum_{j=1}^{p} A_j(S_t) \cdot y_{t-j}$$  \hspace{1cm} (36)

Where $u_t = y_t - E(y_t | y_{t-1}, S_t)$ is an updating process with variance matrix $\sum(S_t)$, assuming that it follows a normal distribution, has:

$$u_t \sim NID(0, \sum(S_t))$$  \hspace{1cm} (37)

If the VAR process is defined as conditionally dependent on an unobserved zone system, the mechanism of data generation is considered to be a zone system generation process.

In the zone transfer vector autoregressive model, zone $S_t$ is assumed to be generated by a discrete chi-squared Markov chain:

$$\Pr\left(S_t | \{S_{t-j}\}_{j=1}^{\infty}, \{y_{t-j}\}_{j=1}^{\infty}\right) = \Pr\left(S_t | S_{t-j}, \rho\right)$$  \hspace{1cm} (38)

Where $\rho$ is the parameter vector of the zone system generation process.

### 3.3 LPR Reform’s Macro Measure of Interest Rate Risk for Commercial Banks

The interest rate risk of commercial banks is based on two factors: firstly, the change of interest rates in the external market, and secondly, the deficiencies in the internal management mechanism of interest rate risk. Commercial banks can reduce the impact of interest rate fluctuations on net interest income through reasonable adjustments of assets and liabilities to match the repricing term or maturity of interest rate-sensitive assets and liabilities or utilize financial derivatives to prevent, transfer or hedge interest rate risks, and comprehensively apply a variety of management methods to control interest rate risks. Commercial banks’ interest rate risk management methods mainly include interest rate sensitivity gap management, duration gap management, value-at-risk (Var) model and stress test, which are four macro-measurement methods of interest rate risk in commercial banks. Below, we specifically introduce interest rate sensitivity gap management and duration gap management methods.

#### 3.3.1 Interest rate sensitivity gap interest rate risk measurement models

The interest rate sensitivity gap model is a static model applicable to the short term and serves as the most basic model commonly used by commercial banks to manage interest rate risk at present. It is able to reflect changes in interest income and expenses through changes in interest rates, sizes and matches of assets and liabilities, i.e., the response of interest rate-sensitive assets and liabilities to changes in interest rates. From there, it further analyzes what kind of impact it has on commercial banks’ spreads and earnings, whether there is a positive or negative gap, and manages for the gap in a categorical manner to minimize the loss as much as possible. The formula is:
A Study on Macro Measurement Methods and Volatility Characteristics of Interest Rate Risk of Commercial Banks under the New LPR Mechanism

\[ GAP = RSA - RSL \]

\[ IRSL = \frac{RSA}{RSL} \]

\[ \text{Deviation} = IRSL - 1 \]

Where \( GAP \) is the interest rate sensitivity gap, \( RSA \) is the interest rate sensitivity asset, \( RSL \) is the interest rate sensitivity liability, and \( IRSL \) is the interest rate sensitivity factor.

There are three types of shortfall situations, the first is a positive shortfall where interest rate sensitive assets are greater than interest rate sensitive liabilities, meaning that \( IRSL \) is greater than 1, deviation is greater than 0, and the bank’s net interest income increases. The negative gap is \( IRSL \) is less than 1, the deviation is less than 0, when the short-term increase in interest rates will lead to a higher repricing of liabilities than assets, which makes the bank’s net interest income decrease; when the gap is 0, it means that at this time there is no deviation, the bank’s operation is relatively stable. The details of the relationship between the interest rate sensitivity gap and changes in banks’ net interest income are shown in Table 1. Generally speaking, actively operating banks should maintain a certain positive gap with a deviation greater than 0 in a generally increasing trend of interest rates and a certain negative gap with a deviation less than 0 in a decreasing trend of interest rates in order to make net interest income increase.

<table>
<thead>
<tr>
<th>Interest rate sensitivity gap (GAP)</th>
<th>Interest rate sensitivity coefficient (IRSL)</th>
<th>Degree of deviation (IRSL-1)</th>
<th>Interest rate movement</th>
<th>Net interest change</th>
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Table 1. Relationship between interest rate sensitivity gap and changes in bank interest income

3.3.2 Models for measuring interest rate risk of the duration gap

The duration gap model was first used to calculate the average repayment period of bonds. In the process of commercial bank operations, the interest rate risk appeared and increased, so the duration model is used to measure interest rate risk in the study. It has become one of the important methods to predict and measure the size and direction of interest rate risk of financial institutions.

For commercial banks, when assets and liabilities are repriced for a longer period of time or a longer period of time from the interest payment date, the less interest it pays before maturity, and the greater the absolute value of the duration gap. In a volatile interest rate market, commercial banks will face more uncertain interest rate risk.

The McCauley duration calculation formula is:

\[ D = \frac{\sum_{i=1}^{n} c_i}{P} \left(1 + r\right) \times t = \sum_{i=1}^{n} W_i \times t \]  

(42)
Where $D$ is the McCauley duration, $P$ is the bond price, $\sum_{t=1}^{n} \frac{C_i}{(1+i)^t}$ is the present value of the bond’s $t$th cash flow, $t$ is the time, and $r$ is the market interest rate.

Applied to interest rate risk management, first of all, according to the McCauley duration of assets and liabilities, respectively, can be found when the price of assets, liabilities and interest rates show inverse changes, when the longer the duration, the greater the change in the price of assets or liabilities will also be greater. The difference between asset duration and liability duration is the duration gap, which is used to measure interest rate sensitivity and reflect the degree of risk exposure. The formula calculates it:

$$D_{\text{GAP}} = D_A - \frac{L}{A} \times D_L$$  \hspace{1cm} (43)

$$\Delta \alpha = -D_{\text{GAP}} \times \left( \frac{\Delta r}{1+r} \right) \times A$$  \hspace{1cm} (44)

Where, $D_{\text{GAP}}$ is the duration gap, $D_A$ is the weighted average duration of total assets, $D_L$ is the weighted average duration of total liabilities, $\frac{L}{A}$ is the gearing ratio, $\Delta \alpha$ is the magnitude of the change in the net equity gap of commercial banks, $\Delta r$ is the magnitude of the change in interest rates, and $A$ is the value of total assets of commercial banks.

The relationship between the duration gap and the change in the net equity value of banks is shown in Table 2. When the duration gap is positive, the net equity value of commercial banks is negatively related to the direction of interest rate changes. The direction of interest rate changes positively affects the net equity value of commercial banks when the duration gap is negative. If there is no duration gap, the net equity value stays the same. Therefore, the duration gap method can determine the changes in the net equity value of the bank, and by predicting the interest rate changes and thus taking active interest rate management measures, the net equity value of the bank will increase.

<table>
<thead>
<tr>
<th>Duration gap</th>
<th>$D_{\text{GAP}}$</th>
<th>Interest rate movement</th>
<th>Assets</th>
<th>Be in debt</th>
<th>Net equity value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive notch</td>
<td>↑</td>
<td>↓</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Negative notch</td>
<td>↑</td>
<td>↓</td>
<td>Decrease</td>
<td>Augment</td>
<td>Augment</td>
</tr>
<tr>
<td>Zero notch</td>
<td>↑</td>
<td>↓</td>
<td>Decrease</td>
<td>Augment</td>
<td>Augment</td>
</tr>
</tbody>
</table>

4 Empirical study of interest rate risk of commercial banks under LPR pricing mechanism

4.1 Sample Selection and Experimental Methods

4.1.1 Sample Selection and Data Sources

In order to ensure the validity and completeness of the research in this paper, among all commercial banks listed in China (the time period ends at the end of 2022), 15 commercial banks with more
missing values of financial data are excluded. Therefore, the research object of this paper has a total of 42 commercial banks, and the research time period is 2001-2022, in which the central bank has adjusted the lending base (LPR) interest rate 2 times during the 21 years. Therefore, we divide the study period into 3 stages: the first stage is 2001-2012, the second stage is 2013-2018, and the third stage is 2019-2022. Such a two-way adjustment move can reflect the fluctuating changes in the benchmark lending rate more clearly.

A total of 515 research observations are obtained in this paper, and the data on net interest margin and other indicators are obtained in the financial statements of various commercial banks and the Wind database. Among them, the values of the economic growth rate of GDP (RGDP) benchmark deposit rate and benchmark lending rate are obtained from the official website of the central bank, and the values of the one-year benchmark deposit and lending spread (BS) of the explanatory variables are obtained by calculation. For individual missing financial data, the average of the bank’s annual reports for the previous and subsequent periods or the values from the previous year were used as substitutes.

4.1.2 Experimental measurement methods

As we all know, the impact of commercial bank interest rate changes on the macroeconomy is very important, and thus the LPR mechanism, which is the “two-track and one-track” interest rate on the lending side, will profoundly affect the macroeconomic operation. Therefore, the experimental measurement method in this paper is based on the MS-DSGE model of the pressure index of differential interest rate pricing behavior of commercial banks, to analyze the macro effect of differential interest rate pricing behavior of commercial banks in the case of interest rate shocks, reflecting the effectiveness of the LPR mechanism. The MS-DSGE model conduction mechanism based on the LPR mechanism constructed in this paper is shown in Figure 2, which uses the data since the new LPR mechanism, i.e., between December 2019 and 2022, to analyze, and the index of intermediate business income share lacks quarterly statistics, and the monthly data are obtained by interpolation.

![Figure 2](image)

Figure 2. Conduction mechanism of MS-DSGE model based on LPR mechanism

4.2 Macro-cyclical trend analysis of interest rate risk in commercial banks

In this paper, we consider the six sectors of the New Keynesian (MS-DSGE) model, namely, households, intermediate goods producers, final goods producers, capital goods producers, commercial banks, and monetary regulatory authorities. The historical decomposition of the cyclical
components of output $\hat{y}_t$, $\hat{c}_t$, and $\hat{i}_t$, i.e., output, consumption, and investment, yields the real GDP, consumption, and investment macrocyclical trends shown in Figure 3. In terms of output (GDP), in the first stage (2001-2012) before the LPR reform, the persistent negative investment efficiency shock from 2001 to the end of 2012 had a serious negative impact on real GDP, leading to negative real GDP growth and declining to -0.1283 in 2012, and this persistent negative investment efficiency shock also had a persistent negative investment impact. As 2013 comes to the second stage (2013-2019), the impact of the investment efficiency shock turns positive after the implementation of the old LPR mechanism, and the impact on real GDP and investment also turns from negative to positive. The preference shock delivers a negative persistent shock to consumption until 2013 and a positive persistent shock to consumption after 2013 and reaches a maximum value of 0.0987 in 2018. Starting in 2019, the cycle comes to the third stage (2019-2022) with the shift from the old LPR mechanism to the new LPR mechanism. In the historical decomposition of the components of the consumption cycle, the largest contribution is the initial value, indicating that there is a large consumption inertia in China, and although the economy is developing rapidly, the Chinese people’s consumption attitudes are changing very slowly.

![Figure 3. Historical breakdown of the macro cycle of personal investment](image)

### 4.3 Interest rate volatility analysis with simulated interest rate impulse response shocks

Suppose that a positive $\delta_R = 0.5$ interest rate shock is added to the commercial bank lending market when the economy is in steady state. The results of the shock are shown in Fig. 4, where Fig. 4(a) is the lending rate shock, and Fig. 4(b) is the borrowing rate shock, with the differentiation target parameters set to 1, 5, and 10, respectively. It can be seen that the lending rate tends to stabilize around 0.00038 under the $\delta_R = 0.5$ shock, and the borrowing rate tends to 0 in the 10th period for the three differentiation target parameters.
The above results indicate that, under the shock of rising commercial bank interest rates, there is a process of first narrowing and then widening the deposit and loan spreads of commercial banks; the size of deposits fluctuates more drastically under the impact of the shock compared to the size of loans, and households increase and then decrease consumption to return to the steady state.

Overall, the larger the gap between the differentiated targets of the new LPR reforms for commercial banks, the smaller the affected volatility of each economic variable. However, when the differentiation target gap is larger, the steady state values of each economic variable are smaller. This indicates that it is necessary to consider the differential interest rate pricing behavior of commercial banks comprehensively and set the LPR reform target reasonably, so as to get the optimal policy effect.

5 Conclusion

Based on the analysis of interest rate marketization at home and abroad, this paper analyzes the data of 45 samples of listed small and medium-sized commercial banks during the period from 2001 to 2022 and investigates the impact of the process of interest rate marketization as well as the net interest margin on the interest rate risk of small and medium-sized commercial banks by constructing a panel data model. The process of interest rate marketization is also divided into three stages depending on the time of the LPR formation mechanism. The sample is divided into three time phases for empirical research on fixed effects, resulting in the following:

1) In the first stage (2001-2012) before the LPR reform, the negative investment efficiency shock had a serious negative impact on commercial bank interest rates, which led to the growth of the wind of commercial bank interest rates and declined to -0.1283 in 2012.

2) In the second stage (2013-2018), when the old LPR mechanism was, most of the small and medium-sized commercial banks were unable to carry out timely countermeasures, resulting in the interest rate risk under interest rate freedom not being fully controllable, and can only be explored step by step in the context of its business strategy.
At the third stage (2019-2022) of the new LPR mechanism, the interest rate risk of commercial banks still shows a downward trend, indicating that after several years of exploration and development, it can be assumed that the risk management ability of commercial banks has been improved and that they are able to establish their risk prevention mechanism. Interest rate risk can be managed by adjusting asset and liability structures, as well as off-balance sheet business.

To summarize the overall view, the larger the gap between the differentiated objectives of the new LPR reform of commercial banks, the smaller the affected volatility of each economic variable. Therefore, it is necessary to comprehensively consider the differential interest rate pricing behavior of commercial banks and reasonably set the LPR reform target, so as to get the optimal policy effect.

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