The People's Bank of China Working Paper Series

No.2018/2

April 3, 2018

Zero Lower Bound on Deposit Rates and Transmission Mechanism of the Negative Interest Rate Policy

Sun Guofeng[1] and He Xiaobei[2]

Abstract: There have been heated debates on the negative interest rate policy (NIRP) since it was first introduced in major economies. Critics argue that deposit interest rates cannot break through the zero lower bound (ZLB) and that banks' interest margins can be heavily squeezed under the NIRP. The underlying rationale is that deposits are the source of funding for banks. In this paper, we argue that in the modern credit money system, banks create deposits by making loans, and not the other way around. Deposit rates can be sufficiently negative without hurting banks' profitability or curbing credit supply. We use a dynamic stochastic general equilibrium (DSGE) model to demonstrate the quantitative importance of ZLB on deposit rates in the transmission mechanism of monetary policy. Simulation results show that the ZLB on deposit rates heavily impede the transmission mechanism of the NIRP, which might explain the limited effects of the NIPR in the Euro Area and Japan. If banks are willing to expose retail depositors to negative interest rates, the effectiveness of the NIRP will be greatly strengthened and central banks should adopt deeply negative interest rates during a deflationary recession.

Keywords: Negative Interest Rate Policy, Zero Lower Bound on Deposit Rates, Transmission Mechanism

JEL codes: E22, E32, E44, G21

[1]People's Bank of China, visiting professor of Economics Department of Princeton University. Email: sguofeng@pbc.gov.cn

[2]Tsinghua Center for Finance and Development. Email: xiaobei_he@sina.com

1. Introduction

After the 2008 financial crisis, the Euro Area and Japan adopted the negative interest rate policy (NIRP) to fight deflation, and Switzerland and Denmark adopted this measure to prevent currency appreciation.

Although in theory, there is nothing unorthodox about negative interest rates, the NIRP has been regarded as highly controversial ever since it was first introduced as a policy tool in major economies. Critics argue that the NIRP squeezes banks' interest margins and hence banks' profits. The NIRP undermines banks' profitability for the following two reasons: first, central banks typically implement the NIRP by charging negative rates on banks' reserve balances held in central banks. It is a cost imposed on banks. Second, interest rates on loans fall as policy rates move into negative territory. The underlying rationale behind these arguments is that interest rates on deposits (especially retail deposits) cannot fall into negative territory, and therefore, banks largely absorb losses from lower loan rates and additional costs. It is widely held that banks must hold deposits to make loans, and can no longer play the role of "financial intermediary" without deposits. If deposit interest rates turn negative, households may withdraw funds from banks and hold large amounts of paper currency instead of bank deposits. Banks are concerned about falling deposits and reluctant to expose households to negative interest rates, which leads to squeezed net interest margins and a weak credit supply.

Although the concern about deposits seems plausible, this is not how the banking system works in practice. It is a misperception that banks must hold deposits to make loans, which has prevented banks from charging negative rates on deposits. In fact, banks expand their balance sheets by making loans instead of taking deposits.

As Sun Guofeng (1996, 2001, 2015) argues, the banking system is a *credit money system*. Specifically, money is created through the expansion of balance sheets of commercial and central banks. Central banks are the ultimate sources of money supply. Central banks provide commercial banks with the monetary base, with which commercial banks expand their balance sheets. Through credit extension or asset purchases, banks simultaneously create a matching deposit in borrowers' bank accounts. For example, if Bank A initiates a loan of $1 billion to Corporation B, that amount will be put into the deposit account of Corporation B, thereby creating deposits.

From the accounting point of view, assets and liabilities adjust simultaneously; however, from the theoretical point of view, loans are created before deposits, and not the other way around. As "loans create deposits," the credit supply of a commercial bank is not constrained by the number of deposits initially held by banks. Instead, a bank's balance sheet is constrained by the monetary policy and regulatory requirements. For example, the monetary base of banks is one factor that determines the total credit supply of the banking sector. Specifically, banks must hold central bank liabilities, known as the monetary base, to extend credit. From the entire banking sector's point of view, the only way to acquire the monetary base is to borrow from the central bank. Individual banks trade the monetary base with other banks in the interbank market. Central banks control credit supply by providing bank reserves. From an individual bank's point of view, deposits can be transferred from one bank to another, which results in corresponding transfers of the monetary base. Although the distribution of the monetary base across individual banks shifts with the transfer of deposits, an individual bank can restore its desired level of monetary base through interbank market transactions, and thereby restore its credit supply capacity. Other important factors that bear on banks' credit expansion are the regulatory requirements. In fact, regulatory requirements are typically the binding constraints on banks' leverages, and at their core are the capital adequacy ratios. For example, the Basel III Accords have imposed higher regulatory costs and thereby strengthened the capital requirements on banks. Interest rates on loans are determined by broad factors that influence the demand and supply of credit.

Although it is widely believed that the ZLB has undermined the effectiveness of the monetary policy, most studies in this area suggest that negative interest rates lead to a decline in banks' profits and lending, and eventually have a negative impact on the economy. Mersch, a member of the executive board of the European Central Bank (ECB), argued in 2016 that the NIRP may bring about numerous social problems should some financial institutions go bankrupt because of the negative interest rate environment. This could cost the Euro Area another round of recession. Coeuré (2016) is also concerned about the cumulative effects on financial intermediation and financial stability. He argues that although in the short run the NIRP has a positive impact on the term premia as banks engage in maturity mismatch, its long-term effects on banks' profitability is unclear. Carlos et al. (2016) suggest that the transmission channels of the NIRP are the same as conventional monetary policies, but its effects on commercial banks and other financial institutions can be potentially detrimental. They emphasize the potential excess risk-taking behavior by banks. Brunnermeier and Koby (2016) argue that negative interest rates may have contractionary effects on lending, although these effects may be delayed.

It is worth noting that the issue of the effective zero bound will not go away easily with the recovery of the global economy. Gordon (2016), Summers (2014), among many others, suggest that the global productivity and output growth will remain low in the long term. Given the gloomy prospect of potential economic growth, the equilibrium interest rates consistent with long-term growth will be significantly lower than the historical level. According to Holston, Laubach and Williams's (2016) estimation, natural interest rates in advanced economies will remain low for an extended period. While the US is undergoing a tightening cycle, an adverse shock can easily bring its economy back to the ZLB. As the productivity continues to grow at a slow pace, interest rates may frequently hit zero and the NIRP can be as conventional as other regular policy tools.

In practice, ZLB still poses a serious constraint on retail deposit rates, and the transmission mechanism of the NIRP is not the same as conventional monetary policies. Although the NIRP has been studied extensively, the role of sticky deposit rates in the transmission of the NIRP is underexplored. Our paper explores this issue from a very different angle. Based on the theory of credit money system, we argue that commercial banks are not vulnerable to negative deposit rates. Our paper is closely related to Sun Guofeng's work on the credit money system. The underlying rationale is that banks create deposits by making loans. According to the financial frictions literature, banks typically rely on deposits to extend credit, thereby creating a link between households' deposits and banks' credit supply. An important example is Gertler and Karadi (2011). Our paper differs in this regard. We use a micro-founded DSGE model to investigate the transmission mechanism of the NIRP. In our model, the credit supply of banks is constrained jointly by the regulatory requirement and the monetary policy, which makes the model more real-world relevant. We argue that retail deposits can eventually go sufficiently negative, making the NIRP more effective in preventing deflation and recession. To the best of our knowledge, this paper is the first attempt to address the issue of negative rates in a credit money system environment. One of the policy implications is that the NIRP can be used as a conventional monetary policy, provided central banks act as lenders of last resort. Our paper also draws heavily from the New Keynesian literature. The setup of the model closely follows Bernanke, Gertler and Gilchrist (1999) and also borrows some elements from Gerali, Neri, Sessa and Signoretti (2010). The approach to implement ZLB in simulations closely follows Guerrieri and Iacoviello (2015).

This paper is structured as follows: Section 1 provides an introduction, section 2 describes the model, section 3 produces the simulation results and section 4 concludes.

2. Model

2.1 Households

There is a continuum of identical households in the economy. Within each household there are three types of agents: workers, entrepreneurs and bankers. Workers make consumption plans and supply labor. They return their wages to their respective households and deposit funds in competitive banks. The acquisition of working capital for a project is partially financed by taking loans from banks. Bankers initiate loans and collect deposits from households. Entrepreneurs and bankers exit the industry and transfer their net worth back to the respective household. A corresponding number of workers randomly become entrepreneurs and bankers, keeping the number of each occupation constant. There is perfect consumption insurance within a household. C_t denotes the consumption of a representative household and H_t a worker's labor supply. The worker is risk averse. He/she derives utility from consumption and disutility from labor supply.

$$\text{Max}\ E_t \sum_{i=0}^{\infty} \beta^i [\ln (C_{t+i}\text{-h}\ \ C_{t+i-1}) - \frac{\chi}{1+\varphi}\ H_{t+i}^{1+\varphi}]$$

with $0 < \beta < 1, 0 < h < 1, \chi > 0$ and $\varphi > 0. \beta$ is a household's discount factor. To facilitate comparison to many DSGE models, we allow for habit formation with the parameter h_t to capture consumption dynamics. Φ_t represents the inverse of the elasticity of work effort with respect to the real wage. Demand deposits D_t are the only savings vehicles, which yield a risk-free return of $R_t$in period t. W_t is the real wage and Π_t denotes the net transfers from entrepreneurs and bankers to the household. The worker's consumption decision must satisfy the household's budget constraint, and is given by

$$C_t = W_t H_t + R_{t-1} D_{t-1} - D_t + \Pi_t$$

ϱ_t denotes the marginal utility of consumption. The worker's optimal choices for consumption and labor supply are given as follows:

$$\frac{1}{C_t - hC_{t-1}} - \frac{\beta h}{C_{t+1} - hC_t} = \varrho_t$$

$$\varrho_t W_t = \chi \, H_t^{\varphi}$$

$$E_t R_t \frac{\rho_{t+1}}{\rho_t} = 1$$

2.2 Intermediate Goods Firms

2.2.1 Production Function

Intermediate goods firms are in perfect competition. Firms are risk neutral and aim to maximize their terminal wealth, which is accumulated retained earnings. The production technology is given by the conventional Cobb-Douglas production function

$$Y_t = A_t K_t^{\epsilon} \, H_t^{1-\epsilon}$$

where A_t is the total factor productivity. K_t and H_t are the factors of production, physical capital and labor, respectively. The capital share is ϵ_t, while labor is $1 - \epsilon_t$. The factor market is perfectly competitive, and the real wage is given by the marginal product of labor

$$W_t = (1 - \epsilon) \frac{Y_t}{H_t}$$

Q_t denotes the price of capital[3] and δ denotes the depreciation rate of capital. The aggregate return on capital across all firms is given by

[3]The price of capital is derived later.

$$R_{t+1}^{k} = \frac{\epsilon \frac{Y_t}{K_t} mc_t + Q_{t+1}(1-\delta)}{Q_t}$$

The realized return for an individual project in each period, however, is subject to both aggregate and idiosyncratic risks. The return of individual firm i is given by $\omega_t^i R_t^k$, with ω_t^i being the idiosyncratic productivity shock. ω_t^i is i.i.d across firms and across time, following a log-normal distribution with the probability distribution function of $f(\omega)$ and cumulative distribution function of $F(\omega)$. Idiosyncratic shocks have a mean value of $E(\omega) = 1$ and a standard deviation of σ.

Firm i has an available net worth N_t^i in the beginning of period t. To finance the difference between the investment and the net worth, the firm takes out a loan of L_t^i. The balance sheet of entrepreneur i is given by

$$Q_t K_t^i = N_t^i + L_t^i$$

If the firm does not have enough cash flows to pay off the debt (interests plus the principal), it declares default and exits the industry.

2.2.2 Financial Contract

The firm makes investment decisions, taking the price of capital goods and the expected return to capital as given. When the optimal demand for capital is determined, capital prices and returns are derived endogenously as part of a general equilibrium solution. The financial contract of this model draws extensively from Bernanke, Gertler and Gilchrist's (1999) (BGG) model, the core of which is a costly state verification (CSV) problem according to Townsend (1979). Idiosyncratic productivity shocks are privately observed by the firm. Bankers must pay a fixed "auditing cost" to verify the realized returns. The auditing cost is interpretable as the cost of bankruptcy and equal to a proportion μ of the realized gross payoff to the capital, i.e., $\mu\omega_t^i R_t^k Q_{t-1} K_{t-1}^i$
It is worth noting that, in contrast to the state contingent lending rate presented by BGG, in this paper the contractual lending rate $R_t^{L,i}$ is not state-contingent. Put differently, the contractual loan rate is fixed *ex ante* in the contract. This feature makes our model more real-world relevant since bankers also share default costs with firms. Therefore, ex post returns earned by banks, after adjusting for default costs, are generally lower than contractual loan rates.

Although auditing entails costs, monitoring does not entail costs for bankers. The banker monitors each period. A firm's solvency condition is characterized by a threshold value of the idiosyncratic shock $\bar{\omega}_{t+1}^i$: If the idiosyncratic shock is lower than $\bar{\omega}_{t+1}^i$, the entrepreneur is unable to honor the loan at the contractual lending rate $R_t^{L,i}$ and hence files for bankruptcy.

$$\bar{\omega}_{t+1}^i R_{t+1}^k Q_t K_t^i = R_t^{L,i} L_t^i = R_t^{L,i}(Q_t K_t - N_t^i)$$

When $\omega^i \geq \bar{\omega}^i$, the entrepreneur is able to pay off the loan $R_t^{L,i} L_t^i$ and keep the difference, given by $\omega^i R_{t+1}^k Q_{t+1} K_{t+1}^i - R_t^{L,i} L_t^i$. According to the solvency condition, whenever $\omega^i < \bar{\omega}^i$, the entrepreneur declares default and the financial contract terminates automatically. Upon doing so, the banker pays an auditing cost and gets to keep the remaining, i.e., $(1-\mu)\omega_{t+1}^i R_{t+1}^k Q_t K_t^i$. A defaulting firm earns zero profit and exits the industry.

The leverage ratio of individual firm i is given by

$$\phi_t^{e,i} = \frac{Q_t K_{t-1}^i}{N_t^{e,i}}$$

As in BGG, $\bar{\omega}$ determines the allocation of total capital return between borrowers and lenders, namely, firms and banks. Given that the contractual loan rate is not state-contingent, the optimal financial contract is also different from BGG in some key respects. $\Gamma(\bar{\omega})$ denotes the expected gross share of returns going to the banking sector. $\Gamma(\bar{\omega})$ is comprised of two parts: banks earn the contractual interest rates from the firms that pay off the debt; banks get to keep what remains from defaulting firms.

$$\Gamma(\bar{\omega}) = \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega + \int_0^{\bar{\omega}} \omega f(\omega) d\omega$$

Because banks must pay the auditing cost, which is denoted by $\mu G(\bar{\omega}) = \mu \int_0^{\bar{\omega}} \omega f(\omega) d\omega$, the expected net share of returns going to them is given by

$$\Gamma(\bar{\omega}) - \mu G(\bar{\omega})$$

Therefore, the share of returns going to firms is given by $1 - \Gamma(\bar{\omega})$. The value function of firms, denoted by Ω_t, is the expected discounted cash flow. Firms choose the optimal leverage ratio of ϕ_t^e and the default threshold $\bar{\omega}_{t+1}$ (alternatively, the optimal contractual loan rate R_t^L) to maximize the value function

$$\Omega_t = \text{Max}\, E_t R_{t+1}^K [1 - \Gamma(\bar{\omega}_{t+1})]$$

Assuming that banks hold a market portfolio, their participation constraint is identical. Given the probability of default, a bank's realized return on loans, denoted by R_t^B differs from the contractual loan rate. R_{t+1}^B can be interpreted as the expected return on loans (adjusted for default), which is jointly determined by credit supply and demand. The participation constraint for banks is given as follows:

$$E_t[(Q_t K_t - N_t^e) R_{t+1}^B] = E_t\{R_t^K Q_t K_t [\Gamma(\bar{\omega}_{t+1}) - \mu G(\bar{\omega}_{t+1})]\}$$

The optimization problem closely follows BGG and yields the following demand equation

$$E_t\{R_{t+1}^k\} = s\left(\frac{N_t^e}{Q_t K_t}\right) R_t^L, \quad \text{with } s' < 0$$

Function s denotes the proportionality factor, and $s' < 0$. The optimal demand for capital (credit) is given as a function of the leverage ratio and the contractual loan rate. That is, the financial contract is characterized by a firm's leverage ratio and the expectation of marginal product of capital.

According to the probability density function $F(\omega)$, $F(\bar{\omega}_t)$ is the fraction of firms that declare default and then exit the industry. In addition, a fixed fraction θ^e of entrepreneurs retire and also exit the industry, returning firms' net worth back to their respective households. Technically, this setup prevents firms from accumulating enough net worth to stay out of external financing. In the meantime, during each period, there are new firms entering the industry with starting funds of $\xi^e Q_t K_t$, suggesting that some workers become entrepreneurs and bring in their own net worth. In the steady state, the net worth brought in by new firms is equal to the net worth lost in bankruptcy, which ensures a constant level of aggregate net worth in the steady state. In the beginning of each period, the net worth in the entrepreneurial sector is comprised of the net worth of incumbent firms and the starting funds of incoming firms.

$$N_t^e = \theta^e R_t^k Q_{t-1} K_{t-1} [1 - F(\bar{\omega}_t)] + \xi^e Q_t K_t$$

2.3 The Banking Sector

The banking sector plays an essential role in the economy. Banks practice monopolistic competition and therefore enjoy some market power in intermediating funds, which allows them to adjust lending rates to changes in economic and financial conditions. N_t^b denotes banks' net worth, which is accumulated via retained earnings Π_t.

The bank capital to asset ratio ν_t^b is the inverse of its leverage ratio

$$\nu_t^b = \frac{N_t^b}{L_t} = \frac{1}{\phi_t^b}$$

Following Gerali et al. (2009), we assume that there is an "efficient" bank capital to asset ratio ν^* under which the bank makes zero profit by initiating loans. That is, when the bank's capital to asset ratio ν_t^b reaches ν^*, the lending rate and the deposit rate coincide. Around the steady state, the bank generally earns a positive interest spread between deposits and loans, and the ν_t^b is typically lower than the efficient level. We assume that any deviations from the efficient capital to asset ratio will incur an adjustment cost. The bank chooses the optimal level of loans L_t and deposits D_t to maximize its profits

$$\max E_t \sum_{i=0}^{\infty} \Lambda^i [R_t^L L_t - R_t^D D_t - \frac{\kappa^2}{2} \left(\frac{N_t^b}{L_t} - \nu^* \right)^2 N_t^b]$$

subject to its balance sheet constraint

$$L_t = N_t^b + D_t$$

First-order conditions with respect to L_t and D_t yield an optimal credit supply, which is characterized by the relationship between the interest spread and the adjustment costs

$$R_t^L = R_t^D + \eta S_t^R + \kappa\left(\bar{\nu}^b - \nu_t^b\right){\nu_t^b}^2$$

The bank's net worth is accumulated retained earnings. A fraction θ^b of the banks go bankrupt each period and their net worth is destroyed. This assumption is made to ensure a steady-state aggregate bank net worth.

$$N_t^b = R_t^L L_t - R_t^D D_t - \frac{\kappa}{2}\left(\frac{N_t^b}{L_t} - \nu^*\right)^2 N_t^b + \theta^b N_{t-1}^b$$

2.4 Retail Firms

Final output Y_t is a constant elasticity of substitution (CES) composite of a continuum of mass unity of differentiated retail firms.

$$Y_t = [\int_0^1 {Y_t^f}^{\frac{\varepsilon-1}{\varepsilon}} df]^\wedge(\frac{\varepsilon}{\varepsilon-1})$$

where ε is the elasticity of substitution, and Y_t^f is the product of the retail firm f. Cost minimization gives rise to the standard demand function

$$Y_t^f = \left(\frac{P_t^f}{P_t}\right)^{-\varepsilon} Y_t$$

where P_t^f is the price of the retail good produced by the firm f. The aggregate price level is thus given by

$$P_t[\int_0^1 {P_t^f}^{1-\varepsilon} df]^\wedge(\frac{1}{1-\varepsilon})$$

Retailers re-package the intermediate output. It takes one unit of intermediate output to make a unit of retail output. The real marginal cost is thus the relative intermediate output price mc_t[4]. Retailers set nominal prices in a staggered fashion according to la Calvo (1983). During each period, the retailer faces a probability $1-\varsigma$ to adjust his/her price freely, and the optimal price set in period t is denoted as P_t^*. The remaining ς retailers simply keep their prices constant

[4]It is derived from the cost minimization problem.

$P_t^f = P_{t-1}^f$. The retailer choose the optimal price P_t^* to maximize his/her expected profits

$$\max\ E_t \sum_{i=0}^{\infty} \varsigma^i \beta^i \frac{\rho_{t+i}}{\rho_t} \left(\frac{P_t^*}{P_{t+i}} - mc_{t+i} \right) Y_{t+i}^f$$

subject to the individual demand function.

According to the law of large numbers, the evolution of the aggregate price level is given by

$$P_t = \left[(1-\varsigma) P_t^{*\frac{1}{1-\varepsilon}} + \varsigma P_{t-1}^{\frac{1}{1-\varepsilon}} \right]^{1-\varepsilon}$$

2.5 Monetary Policy

The central bank has two monetary policy tools. The nominal policy rate R_t^N is characterized by the Taylor rule with interest-rate smoothing. Let $\bar{R}^N$ be the steady-state nominal interest rate, $\bar{Y}$ the steady-state level of output and $\bar{\pi}$ the steady-state inflation rate.

$$R_t^N = \rho_{R^N} R_{t-1}^N + (1-\rho_{R^N}) \left[\bar{R}^N + \phi_\Pi \log\left(\frac{\pi_t}{\bar{\pi}}\right) + \phi_Y \log\left(\frac{Y_t}{\bar{Y}}\right) \right] + \epsilon_t^{R^N}$$

where the smoothing parameter ρ_{R^N} lies between zero and unity, and $\epsilon_t^{R^N}$ is an exogenous shock to the monetary policy.

2.6 Capital Producing Firms

Capital goods producers are competitive and owned by households. During each period, they buy capital from entrepreneurs, refurbish depreciated capital and produce new capital. The cost of repairing worn out capital is unity. In the beginning of each period, capital producing firms package both the new and repaired capital and re-sell them to entrepreneurs at a unit price of Q_t. Following Christiano, Eichenbaum and Evans (2005), we allow for adjustment costs of investment flow $f(\cdot)$. The capital producer's objective is to maximize profits by choosing investment I_t.

$$\max_{I_t} E_t \sum_{\tau}^{\infty} \beta^\tau \frac{\rho_{t+1+\tau}}{\rho_{t+\tau}} Q_{t+\tau} I_{t+\tau} - [1 + f(\frac{I_{t+\tau}}{I_{t+\tau-1}})] I_{t+\tau}$$

The adjustment technology has the following properties: $f(1) = f'(1) = 0$ and $f'' > 0$. These properties are sufficient to justify that there is no adjustment cost in the steady state. The optimal investment decision yields the price of capital

$$Q_t = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - E_t \frac{\rho_{t+1}}{\rho_t} \left(\frac{I_{t+1}}{I_t}\right)^2 f'\left(\frac{I_{t+1}}{I_t}\right)$$

2.7 Market Clearing Conditions

Capital accumulation is given by

$$\mathrm{K_t} = (1-\delta)K_{t-1} + I_t$$

The economy-wide resource constraint is given by

$$\mathrm{Y_t} = C_t + I_t + R_t^k Q_{t-1} K_{t-1} \mu \Gamma(\overline{\omega}_t) + \left[1 + f\left(\frac{I_t}{I_{t+1}}\right)\right] I_t$$

2.8 Parameters

Some of the conventional parameters are set to values consistent with the literature, and the rest of the parameters are calibrated to match empirical evidence. Parameter values are reported in Table 1. The parameters pertaining to the entrepreneurial sector are mostly set to be in line with BGG: The steady-state quarterly default rate is 0.0075 and the bankruptcy cost μ is 0.12. The standard deviation of the idiosyncratic productivity shock σ is calibrated to achieve the targeted entrepreneurial leverage ratio of 1.8, which matches the average leverage ratio of the nonfinancial corporate business sector in the flow of funds. The steady-state real deposit rate is set to 2% (annualized) to be consistent with the empirical evidence. The default rate, the bankruptcy cost and standard deviations jointly pin down the steady state interest spread $\mathrm{R^K - R^L}$, which is equivalent to 40 basis points, and the steady state interest spread of $\mathrm{R^L - R^D}$ is set to 20 basis points based on the micro data[5]. θ^e and ξ^e are pinned down by the size of the balance sheets of entrepreneurs with ongoing projects and new projects. θ^b is calibrated to achieve a steady-state bank leverage ratio $\overline{\phi^b}$ of 12.5, which implies a capital to asset ratio $\bar{\nu}^b$ of 8%. The parameters pertaining to the retail sector and the monetary authority are fairly standard as in the New Keynesian literature. The steady-state inflation rate $\bar{\pi}$ is assumed to be 1 . The elasticity of substitution ε is set to be 7, and the probability of reoptimization of price $1-\varsigma$ is 0.25. The policy parameters $\rho_{\mathrm{R^N}}$, ϕ_π and ϕ_Y are given by $0.8, 1.5$ and 0.3, respectively.

Table 1：Model parameters

Parameter	Description	Value
β	Household discount factor	0.995
ϵ	Factor share of capital	0.33
φ	Inverse Frisch elasticity	0.27
h	External habit formation	0.7

[5]Data source: Bankscope

η^i	Investment adjustment cost	1.5
δ	Depreciation rate	0.025
μ	Bankruptcy cost	0.12
σ	Standard deviation of idiosyncratic shocks	0.3
$F(\bar{\omega})$	Steady state default rate	0.75%
θ^e	Survival probability of firms	0.968
ϕ^e	Firm leverage ratio	1.8
κ	Interest rate adjustment cost	5
θ^b	Survival probability of banker	0.975
$\bar{\phi}^b$	Steady state of bank leverage ratio	12
ε	Elasticity of substitution between varieties	7
ς	Share of nonreoptimizing prices	0.75
$R^K - R$	Spread	60 BPS
ρ_{R^N}	Interest rate smoothing	0.8
Φ_π	Taylor rule (inflation)	1.5
ϕ_Y	Taylor rule (output gap)	0.3

3. Simulation Results

Before we examine the quantitative effects of the negative interest rate policy, we show the properties of our model by plotting impulse response functions. To facilitate comparison with the existing literature, we simulate the model with a persistent negative technology shock. Figure 1 plots the impulse response of key variables. A 1% negative technology shock causes output to decline and inflation to rise. Monetary policy tightens in response to rising inflation and output gap. Banks increase lending rates accordingly. Anticipating a prolonged negative productivity shock and an interest rate hike, firms deleverage and cut back on investment. Households cut back on consumption following a decline in real wages. Declines in both consumption and investment cause the actual output to fall by 8%.

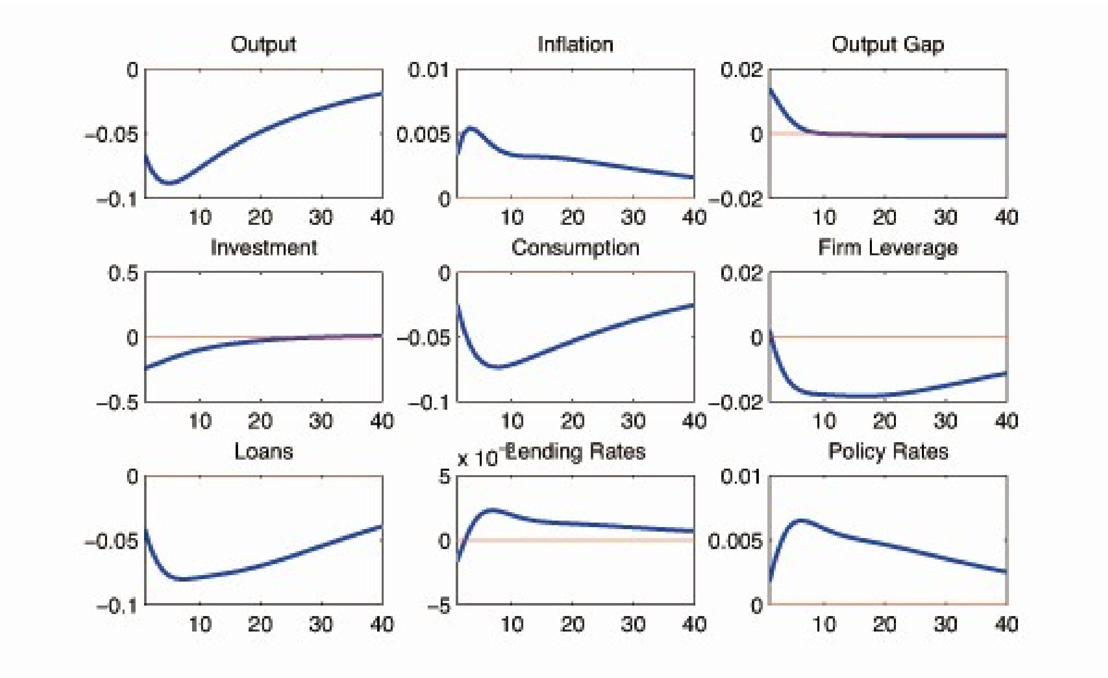

Figure 1: Impulse Response Functions to a Negative Technology Shock

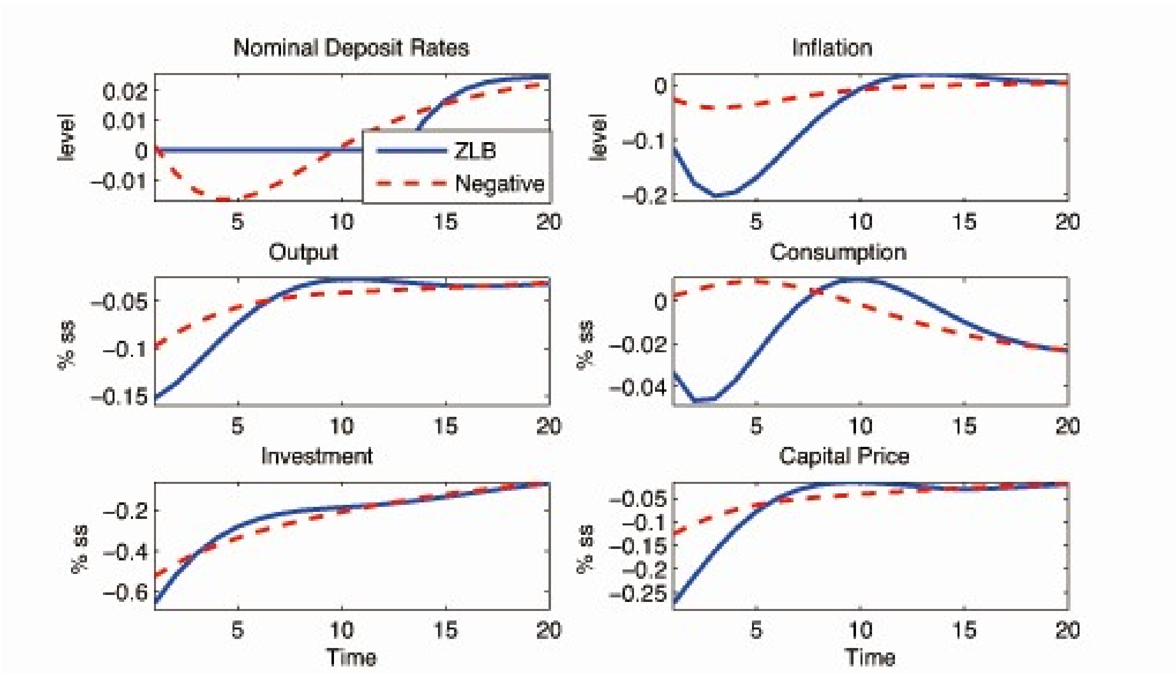

Figure 2: A Risk Shock

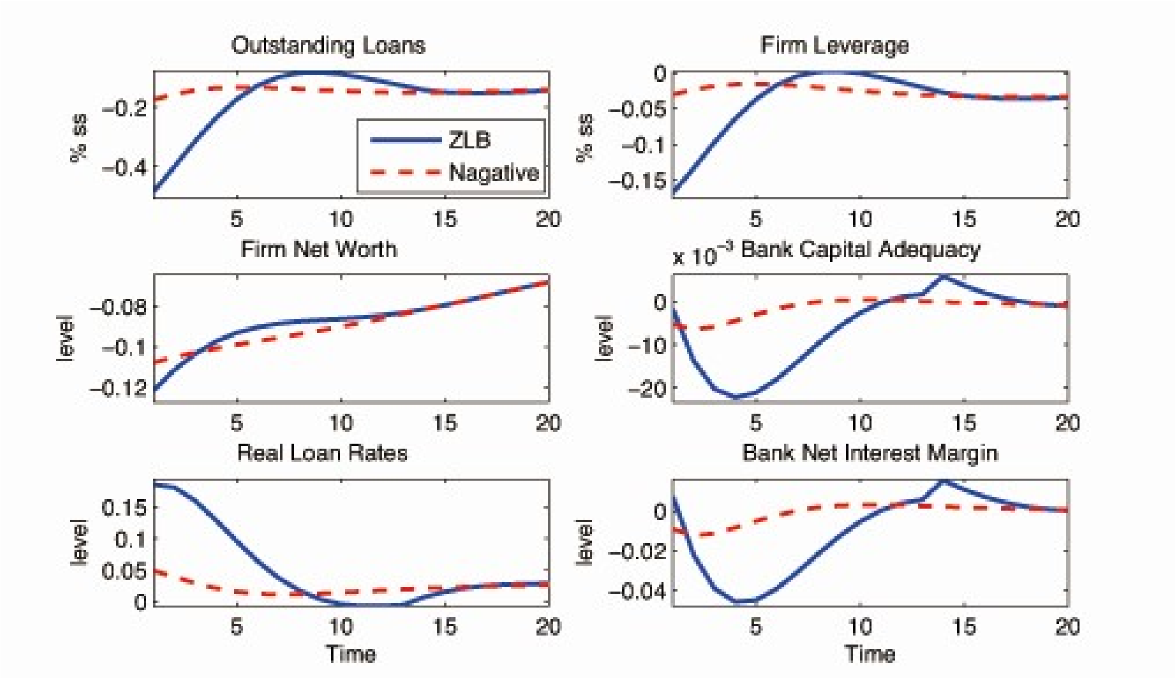

Figure 3: A Risk Shock

There have been heated debates on the implications of the NIRP on banks' profitability and credit supply. We deliberately address this issue in the following analysis. In practice, retail deposits are largely shielded from negative interest rates. However, as discussed in previous sections, under the credit money system, deposits are made from loans but not the other way around, and therefore the banking sector as a whole is not perturbed about the loss of deposits. We specifically discuss the above two different cases in which banks behave differently: where deposit rates are sticky and remain positive under all circumstances, and deposit rates can move into negative territory.

We follow Christiano, Motto and Rotagno (2014) and simulate the model to create a severe economic downturn when negative policy rates are needed. The authors find that idiosyncratic investment risks faced by firms is a determining factor in shaping business cycles. Specifically, idiosyncratic risks alter the allocation of resources across different sectors and amplify business cycle fluctuations, which also accounts for the global recession after the 2008 financial crisis. In our model, investment risks faced by firms are characterized by idiosyncratic productivity shocks, measured by the standard deviations of the shock σ. A higher σ suggests greater risks on the investment return. Figures 2 and 3 plot the impulse responses of key variables to an increasing uncertainty in idiosyncratic capital return by 60%. The blue solid line represents the case of a sticky deposit rate, labeled "ZLB," and the red dashed line represents the case in which banks charge negative interest rates on deposits.

A rise in uncertainty depresses capital investments. Households cut back on consumption due to the decline in real wages. Unexpected deflation increases the real interest rate. The central bank lowers the nominal policy rate significantly, in response to the negative output gap and deflation. The interbank rate, at which a bank borrows reserves from another bank, follows the policy rate closely.

On the real activities side, firms cut production and prices further in response to dampened consumption. The decline in capital investment implies weaker demand for credit, and results in the deleveraging of the real sector. Owing to the effects of financial accelerators, a decreasing leverage ratio in the real sector implies a decreasing spread between the return on capital and the return on loans. However, the real interest rates of loans continue to rise due to deflationary pressure. This, in turn, further depresses the credit demand, and the newly-initiated loans fall significantly.

Banks raise funds from either the interbank market or the deposit market, and the policy rates pass through to the deposit rates due to banks' portfolio rebalancing behaviors. However, the interest rate pass-through from the interbank market to the deposit market is incomplete. If deposit rates face downward rigidities at zero, banks suffer a greater loss in terms of shrinking net interest margins. This result captures what has happened in reality: The historically low policy rate has been a squeeze on the banking sector's net interest margins and profits. As shown in Figure 2, if banks behave in an optimal fashion, the nominal deposit rates should be -2%. If the nominal deposit rates are constrained by the ZLB, the real deposit rates increase sharply and become a heavy burden on banks' liabilities. Under these circumstances, banks suffer a greater loss as the interest margins decline, which eats into their capital. As banks operate under the regulatory constraint that tightens the credit supply to the bank's capital adequacy ratio, the loss of banks' capital causes the credit supply to decline. When nominal deposit rates are constrained by the ZLB, the fluctuations in interest rates are hence largely absorbed by the banks. In the case of sticky deposit rates with ZLB, the number of loans declines by 50% and the economy experiences a "credit crunch."

In a nutshell, the ZLB on deposit rates undermines the effectiveness of the NIRP. The transmission channel of the NIRP hinges on the banks' downward adjustments on the deposit rates. Removing the ZLB on the deposit rates helps smooth the fluctuations of interest rates, including the nominal and real loan rates. Stable interest rates help stabilize the real activities and output. With the deposit rates fixed at zero, banks' net interest margins are squeezed. This leads to a decline in banks' net worth and causes them to reduce credit supply, which helps explain the limited effects of the NIRP in the Euro Area and Japan. Our model suggests that the pass-through of the NIRP in the banking sector is critical in maintaining financial stability and preventing the economy from falling into a credit crunch.

4. Policy Implications

We draw the following policy implications from the simulation results. First, if the interest rate pass-through to deposit markets is complete, central banks can resort to deeply negative interest rate policies during a deflationary recession. Second, because the natural rate of interest rates in advanced economies may stay low in the long run, the NIRP can be used as a conventional policy tool. Third, central banks should promote central bank digital currency (CBDC), which will facilitate the implementation of the NIRP.

As mentioned in the previous sections, the major concern about the implementation of the NIRP is that paper currency is always an alternative to bank deposits. However, in practice, depositors are unlikely to withdraw large amounts of cash to avoid negative deposit rates. According to the estimates of Bridgewater, the cost of paper currency storage in the US and in the Euro Area is 0.4% and 1.6%, respectively. The total costs of holding paper currency would be even higher given the extra costs associated with transportation, transaction and insurance. In addition, the costs of insurance and transaction are not linear with respect to the level of cash holdings. Instead, the costs increase substantially when the amount of paper currency reaches a certain level. In practice, major economies do not issue currency in large denotations to combat money laundering and terrorism. Currently, the largest denomination of paper currency is €500, which will be phased out by the end of 2018. It is going to be increasingly costly for depositors to hold paper currency. Therefore, even with aggressive negative deposit rates (for instance, -2%), the costs of holding paper currency may still outweigh the costs of bank deposits. More importantly, digital currency developed by central banks will eventually solve this problem and break the hard zero bound on deposit rates. In fact, central banks' digital currency will strengthen the effectiveness of the NIRP.

5. Conclusions

The transmission mechanism of an NIRP has not been exactly the same as conventional interest rate cuts. Banks' profitability is still a major concern, and the central banks that implement the NIPR only take modest action. Negative interest rates have not reached retail depositors and the effects of the NIRP are limited.

We present a DSGE model to show that sticky deposit rates have impeded the transmission channel of the NIRP. This result explains the limited effects of the NIRP in Japan and the Euro Area. We challenge the prevailing view that banks cannot pass on negative policy rates to retail deposits. If the interest rate pass-through to deposit markets is complete, the NIRP is very effective in boosting credit growth and inflation. Given that natural interest rates in advanced economies have stayed low, central banks may resort to the NIPR more often in the future. When the ZLB is no longer a constraint, to raise the inflation target, as heatedly debated, is not a necessary move anymore.

References

[1] Adrian, T., P. Colla and H. S. Shin, 2012. "Which Financial Frictions? Parsing the Evidence from the Financial Crisis of 2007-9," NBER Chapters, in: *NBER Macroeconomics Annual 2012*, Volume 27

[2] National Bureau of Economic Research, Inc.

[3] Agarwal, R. and M. Kimball, 2015. "Breaking Through the Zero Lower Bound," *IMF Working Papers* 15/224, International Monetary Fund.

[4] Bech, M. L. and A. Malkhozov, 2016. "How Have Central Banks Implemented Negative Policy Rates?" *BIS Quarterly Review*, Bank for International Settlements, March.

[5] Bernanke, B. and M. Gertler, 1989. "Agency Costs, Net Worth, and Business Fluctuations," *American Economic Review*, vol. 79(1), pages 14-31, March

[6] Bernanke, B., M. Gertler and S. Gilchrist, 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework," *Handbook of Macroeconomics*, in: J. B. Taylor and M. Woodford (ed.), Handbook of Macroeconomics, edition 1, volume 1, chapter 21, pages 1341-1393.

[7] Brunnermeier, M. K., T. M. Eisenbach and Y. Sannikov, 2012. "Macroeconomics with Financial Frictions: A Survey," *NBER Working Papers 18102*, National Bureau of Economic Research, Inc.

[8] Brunnermeier, M K., and Y. Koby. "The Reversal Interest Rate: The Effective Lower Bound of Monetary Policy", Work in Progress, 2017

[9] Calomiris, C. W. and C. M. Kahn, 1991. "The Role of Demandable Debt in Structuring Optimal Banking Arrangements," *American Economic Review*, vol. 81(3), pages 497-513, June.

[10] Calvo, G. A., 1983. "Staggered prices in a Utility-maximizing Framework," *Journal of Monetary Economics*, vol. 12(3), pages 383-398, September.

[11] Carlos, A., A. Kose, M. Stocker and T. Taskin, 2016. "Negative Interest Rate Policies: Sources and Implications," Policy Research Working Paper No.7791, Volume No1

[12] Christiano, L., M. Eichenbaum and C. L. Evans, 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, vol. 113(1), pages 1-45, February.

[13] Christiano, L., M. Eichenbaum and S. Rebelo, 2011. "When Is the Government Spending Multiplier Large?" *Journal of Political Economy*, University of Chicago Press, vol. 119(1), pages 78 -121.

[14] Christiano, L., R. Motto and M. Rostagno, 2010. “Financial Factors in Economic Fluctuations,” Working Paper Series 1192, European Central Bank.

[15] Christiano, L., R. Motto and M. Rostagno, 2014. “Risk Shocks,” *American Economic Review*, American Economic Association, vol. 104(1), pages 27-65, January.

[16] Cœuré, B., 2016. “Assessing the implications of negative interest rates” Speech at the Yale Financial Crisis Forum, Yale School of Management, New Haven

[17] Disyatat, P. 2011. “The Bank Lending Channel Revisited,” *Journal of Money, Credit and Banking*, Blackwell Publishing, vol. 43(4), pages 711-734, 06.

[18] Eggertsson, G. and M. Woodford, 2003. “The Zero Bound on Interest Rates and Optimal Monetary Policy,” *Brookings Papers on Economic Activity*, Economic Studies Program, The Brookings Institution, vol. 34(1), pages 139-235.

[19] Gerali, A., S. Neri, L. Sessa and F. M. Signoretti, 2010. “Credit and Banking in a DSGE Model of the Euro Area,” *Journal of Money, Credit and Banking*. Blackwell Publishing, vol. 42(s1), pages 107-141, September

[20] Gertler, M., and P. Karadi, 2011. “A Model of Unconventional Monetary Policy,” *Journal of Monetary Economics*, Elsevier, vol. 58(1), pages 17-34, January.

[21] Goodfriend, M., 2016. “The Case for Unencumbering Interest Rate Policy at the Zero Lower Bound,” *Jackson Hole Economic Policy Symposium*, Federal Reserve Bank of Kansas City, Jackson Hole, Wyoming, 26-27 August.

[22] Gordon, R., 2016. “The Rise and Fall of American Growth,” Princeton University Press, 2016

[23] Guerrieri, L. and M. Iacoviello, 2015. “OccBin: A Toolkit for Solving Dynamic Models with Occasionally Binding Constraints Easily,” *Journal of Monetary Economics*, Elsevier, vol. 70(C), pages 22-38.

[24] Hannoun, H. 2015. “Ultra-low or Negative Interest Rates: What they Mean for Financial Stability and Growth” Speech at the Eurofi High-Level Seminar

[25] Holston, K., T. Laubach and J. Williams, 2016. “Measuring the Natural Rate of Interest: International Trends and Determinants,” *NBER Chapters*, in: NBER International Seminar on Macroeconomics 2016 National Bureau of Economic Research, Inc.

[26] Jobst, A. and H. Lin, 2016. “Negative Interest Rate Policy (NIRP); Implications for Monetary Transmission and Bank Profitability in the Euro Area,” *IMF Working Papers* 16/172.

[27] McAndrews, J. 2015. “Negative Nominal Central Bank Policy Rates: Where Is the Lower Bound?” Speech 168, Federal Reserve Bank of New York.

[28] McLeay, M., A. Radia and R. Thomas, 2014. “Money Creation in the Modern Economy,” *Quarterly Bulletin* 2014 Q1, Bank of England.

[29] Meh, C. A. and K. Moran, 2010. “The Role of Bank Capital in the Propagation of Shocks,” *Journal of Economic Dynamics and Control*, vol. 34(3), pages 555-576, March.

[30] Mersch, Y., 2016. “The Challenge of Low Interest Rates for Banks within the Banking Union,” Speech at Public Roundtable at the University of Luxembourg on “Banking Union – Quo Vadis?”, Luxembourg.

[31] Rognlie, M. 2015. “What Lower Bound? Monetary Policy with Negative Interest Rates,” Job Market Paper, MIT

[32] Rogoff, K. 2015. “Costs and Benefits to Phasing out Paper Currency,” *NBER Macroeconomics Annual*, University of Chicago Press, vol. 29(1), pages 445-456

[33] Summers, L. 2014. “U.S. Economic Prospects: Secular Stagnation, Hysteresis, and the Zero Lower Bound,” *Business Economics*, Palgrave Macmillan; National Association for Business Economics, vol. 49(2), pages 65-73, April.

[34] Sun G. 1996. ”Research on China’s Monetary Policy Transmission Mechanism”, M*aster Thesis of Graduate School of People’s Bank of China.*

[35] Sun G. 1996. ”Research on China’s Monetary Policy Transmission Mechanism”, *Studies of International Finance,* Volume 12

[36] Sun G. 2001. ”Money Creation and Banking Operations under Credit Money System”, *Economic Research Journal in China,* Volume 2

[37] Sun G. and Cai Ch. 2014. ”Money Market Interest Rates, Liquidity Supply and Demand, and Central Bank Liquidity Management: New Analytic Framework of Money Market Interest Rates Fluctuation”, *Economic Research Journal in China,* Volume 12

[38] Sun, G. 2015. “Reforms in China’s Monetary Policy-A Frontbencher’s Perspective,” Palgrave Macmillan, 2015, 8

[39] Sun, G. 2015. “Financial Reforms in Modern China-A Frontbencher’s Perspective,” Palgrave Macmillan, 2015, 8

[40] Sun G. and Jia J. 2015. ”Defining China’s Shadow Banking and Assessing Its Scale-Seen in Term of the Creation of Money”, *Social Sciences in China,* Volume 11

[41] Sun G. 2017. ”Structural Liquidity Deficit and the Monetary Policy Operating Framework”, *Comparative Studies*, Volume 91

[42] Townsend, R. M., 1979. “Optimal Contracts and Competitive Markets with Costly State Verification,” *Journal of Economic Theory*, vol. 21(2), pages 265-293, October.