The Time-varying Zone-like and Asymmetric Preference of Central Banks: Evidence from China *

Chuanglian Chen † Xiaobin Liu ‡ Jun Yu § Tao Zeng ¶

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Abstract

This paper investigates the time-varying asymmetric and zone-like preferences of the People's Bank of China (PBoC) and its corresponding monetary policy reaction function. We assume that the priority given to different policy objectives in the loss function of the PBoC can evolve over time. Based on this assumption and the economic system, the central bank minimizes losses and derives an optimal forward-looking monetary policy rule with time-varying parameters. The paper explores four distinct types of loss related to inflation, output, and leverage, resulting in a total of 64 distinct models. Leveraging a modified maximum likelihood estimation approach, we estimate these models and utilize the Akaike information criterion (AIC) to identify the most suitable model. Based on the data from 1996 to 2022, we find that: (1) the PBoC's reaction to inflation differentials exhibits slight asymmetry, featuring a no-intervention zone between -1% and 1%. The monetary authority intervenes when inflation diverges by more than 1% from the target, otherwise relying on market self-regulation; (2) regarding output gaps, the PBoC asymmetrically intervenes, displaying a stronger inclination towards averting overheating compared to downturns; (3) in response to credit leverage differentials, policy reactions follow a linear pattern. The empirical results underscore the central bank's adaptability and responsiveness to economic fluctuations and strongly demonstrate the flexibility and advantages of our framework.

Keywords: Time-varying parameter model, forward-looking monetary policy rule, leverage, asymmetric and zone-like preference

JEL codes: E5, C32, C51, C52, E52, E58.

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†College of Econimics, Jinan University, Guangzhou, China. E-mail address: chenchuanglian@aliyun.com.

‡Lingnan College, Sun Yat-sen University. E-mail address: liuxb53@mail.sysu.edu.cn.

§Faculty of Business Administration, University of Macau. E-mail address: junyu@um.edu.mo.

¶School of Economics, Academy of Financial Research, Beijing Research Center, Zhejiang University. E-mail address: ztzt6512@vip.sina.com.

1 Introduction

In the field of monetary economics, understanding the policy targets and corresponding reactions within the monetary policy rules of central banks is essential. This paper proposes a framework to investigates the People's Bank of China's (PBoC) time-varying preferences, specifically focusing on the associated monetary policy rule. We emphasize the asymmetric and "zone-like" characteristics of these preferences and response, as well as the role of leverage in the presence of multiple policy objectives.

Central banks adjust policy targets as the economic environment changes. Post-subprime crisis, they have focused on financial risks alongside growth and inflation. During the COVID-19 pandemic, China used fiscal and monetary policies to boost recovery, raising its leverage ratio by 12.5% by December 2022 compared to the end of 2019. While credit expansion can aid growth, excessive expansion increases financial system vulnerability and crisis risk. Thus, the PBoC aims to balance financial stability with moderate growth.

Optimal monetary policy rules often respond linearly to deviations, corresponding to the quadratic loss in central banks's preference. However, central banks may show asymmetrical preferences when managing multiple objectives. For instance, they might prioritize avoiding deflation over inflation or vice versa. Additionally, central banks may exhibit a "no-intervention zone," allowing market self-regulation for minor deviations and intervening only during significant disruptions, which is depicted in Figure 1. This balance between regulation and market adjustment is vital for sustainable growth. Understanding these dynamics informs future policy for stability and growth. Finally, aside from asymmetry and "zone-like" preferences, the central bank's preferences and corresponding monetary policy stance adapt to changing economic conditions.

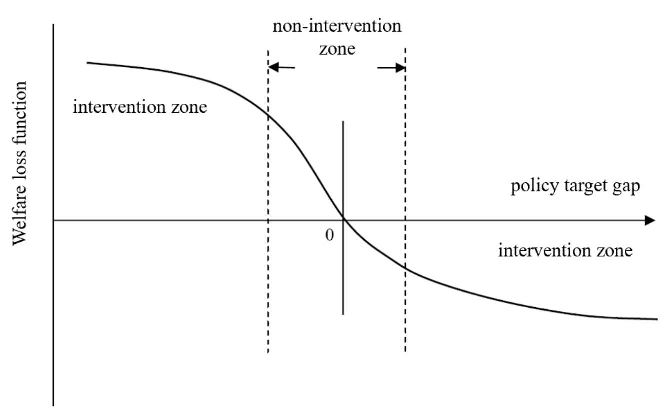

Figure 1: **The loss function with asymmetrical and zone-like properties**

This paper analyzes the behavior of the People's Bank of China (PBoC), focusing on the evolution of its asymmetric and zone-like preferences in addressing multiple policy targets. We extend the central bank's loss function by allowing the weights assigned to different policy targets to vary over time. The central bank minimizes its losses to derive an optimal forward-looking monetary policy rule characterized by time-varying parameters (TVP). [1].

Specifically, we focus on the PBoC and presume that its policy objectives include inflation control, output stabilization, and macro-leverage management. We explore four types of loss functions by assigning certain parameters for each policy objective. These functions cover diverse scenarios, such as quadratic, asymmetric, symmetrically inert, and asymmetrically inert. As a result, we estimate 64 distinct models to characterize the PBoC's preferences and associated monetary policy rules. The most complex response function can exhibit time-varying behavior with both inertia and asymmetry, forming a comprehensive model that incorporates all previously mentioned characteristics. Subsequently, following Riboni and Ruge-Murcia (2023) we utilize the Akaike information criterion (AIC) to select the best model representing PBoC's behavior.

The proposed framework enhances our understanding of the PBoC time-varying zone-like and asymmetric preferences. Empirical analysis indicates that the PBoC demonstrates notable inertia, with a slightly asymmetrical pattern in its loss function and response concerning the inflation gap. Additionally, there is an asymmetric characteristic in both the loss function and response to the output gap. The loss function exhibits a quadratic form, while the response to the leverage gap is linear. The time-varying adjustments in interest rates to these different deviations offer compelling evidence of the central bank's evolving strategies in navigating various economic transformations.

We can deduce three crucial insights upon further examining the time-varying policy reactions. First, the analysis of the loss associated with inflation gap shows that the PBoC has an inertial approach to inflation gaps, intervening only when inflation deviates more than 1% from the target. Within the "inert zone" (-1%, 1%), the central bank will not intervene. The PBoC is slightly more concerned about high inflation than low. A 1% increase in inflation above the target prompts an interest rate hike of 0.05% to 0.3%, while a 1% decrease leads to a reduction of 0.04% to 0.3%. Since late 2020, due to COVID-19, the PBoC's counter-cyclical measures have become more moderate. This suggests a relatively cautious monetary policy with clear boundaries for regulating inflation.

Second, the PBoC's approach to the output gap shows a stronger aversion to economic overheating than to recession. Since early 2020, due to COVID-19, the PBoC's losses have fluctuated and even turned into gains. Before 2020, monetary policy was counter-cyclical, but it shifted to a pro-cyclical stance afterward. Unlike inflation control, there is no "inertia zone" for output gaps. The PBoC applies more regulatory force to curb positive output gaps than negative ones of the same size, highlighting its asymmetric loss function. This suggests China prioritizes stable economic growth over strict cycle regulation.

[1] The TVP model effectively detects broad, potentially enduring changes in individual parameters, providing a smooth estimate of discrete changes and facilitating the assessment of policy dynamics. It offers a parsimonious approximation for multiple policy shifts without requiring numerous parameter and break date estimations, making it a flexible and tractable method for uncovering temporal variations in policy reaction functions (Boinet and Martin, 2008).

Third, the PBoC uses a balanced regulatory approach for leverage gaps, intervening equally whether leverage rises or falls. Before 2005, monetary policies didn't clearly target leverage, with minimal and sometimes reversed responses. Since 2005, there's been a noticeable shift towards controlling credit growth, shown by increased policy focus and intervention intensity. This change is reflected in rising time-varying losses and more active policy measures.

Related literature

This paper is related to three strands of literature. First, this paper contributes to the ongoing discussion around the modeling of responses of the monetary policy rule. Taylor (1993)'s seminal model advocates linear interest rate adjustments driven by inflation and output gaps. However, some researcher, such as Castro (2011), argues that this perspective may not fully encapsulate the complexities of real-world monetary policies. Studies by Nakajima and West (2013) and Baele, Bekaert, Cho, Inghelbrecht, and Moreno (2015) emphasize significant shifts in monetary policy response functions when the interest rate level approaches the zero lower bound. Additionally, Benigno and Rossi (2021), Surico (2007), Ruge-Murcia (2003) and Robert Nobay and Peel (2003) investigate the asymmetric responses in the monetary policy reaction function. Further, central banks' risk aversion varies under different economic conditions, and hence monetary policy rules with time-varying parameters have been used widely (Filardo, Hubert, and Rungcharoenkitkul, 2022, Boivin, 2006; Kim and Nelson, 2006; Cogley and Sargent, 2005). The evolution of these rules underscores the dynamic nature of monetary policy and the need for continual refinement to align with evolving economic conditions and policy objectives. Our paper distinguishes itself by considering monetary policy rules with time-varying, zone-like, and asymmetric properties—an area yet to be thoroughly explored in existing literature.

Second, our study contributes to the literature on the loss functions and preferences of central banks. Understanding these preferences is crucial for comprehending monetary policy decisions. Shapiro and Wilson (2022) introduces a novel estimation approach for preference using sentiment data. Riboni and Ruge-Murcia (2023) models the decision process of central banks. Some studies directly model the central bank's loss function, often suggesting asymmetric functions to better capture these preferences (Ruge-Murcia, 2003, Surico, 2007, Robert Nobay and Peel, 2003), which lead to nonlinear response functions due to the asymmetrical nature of central bank preferences. Orphanides and Wieland (2000) propose to use the"region loss function" to capture the zone-like behavior of central banks. Boinet and Martin (2008) showed the existence of an "zone" property in inflation targeting. These works underscore the limitations of the traditional quadratic loss function in capturing the nuanced preferences of central banks, highlighting the importance of nonlinear Taylor rules and asymmetries in monetary policy. In this paper, we extend the central bank's loss function, considering that weights for policy targets can change over time. This allows us to formulate an optimal time-varying parameter forward-looking monetary policy rule by minimizing losses. Our new approach also nests to the second-order approximation of the utility-based welfare function in a New-Keynesian model, which is closely related to the work by Benigno and Rossi (2021), Gross and Hansen (2021) and Giannoni and Woodford (2017).

Third, our research contributes to the body of literature that investigates the optimal monetary policy responses to the People's Bank of China's (PBoC) multiple policy objectives. Recent studies has expanded monetary policy rules to include additional objectives, such as financial imbalances Filardo et al., 2022, asset prices Gambacorta and Signoretti, 2014, and exchange rates Bruno and Shin, 2015. The leverage target have become increasingly significant in monetary policy, especially after the financial and European debt crises, as high global debt levels contribute to both a low-interest-rate environment (Adrian, Boyarchenko, and Giannone, 2019, Gourinchas and Rey, 2019, Blanchard, 2019) and exacerbated economic inequality (Auclert, 2019, Bartscher, Kuhn, Schularick, and Steins, 2020). Considering the importance of leverage in monetary policy, it is crucial to explore their role as a policy objective Chen and Dai; Dong, Xu, and Tan, 2018; 2021. Silvo (2019) demonstrated that an extended DSGE model , which accounts for inflation and total banking sector leverage, can effectively regulate cyclical fluctuations. Building on these insights, our study proposes incorporating the credit leverage gap into the loss function, thereby enhancing the applicability and realism of the expanded monetary policy rule. This approach is particularly relevant in the context of China's high leverage and the need for monetary authorities to coordinate multiple policy objectives.

This paper is organized as follows: Section 2 outlines the derivation of a novel monetary policy rule, incorporating a loss function with time-varying weights and the resulting policy implications. Section 3 discusses the estimation strategy employed for the model and the criteria used for model selection. Section 4 describes the dataset utilized in the analysis. Section 5 presents the empirical results and their interpretation. Section 6 compares the proposed model to other alternative model specifications. Finally, Section 7 provides concluding remarks.

2 The model

2.1 Preference of the central bank

We extend the loss function proposed by Boinet and Martin (2008), Ruge-Murcia (2003), Robert Nobay and Peel (2003), and Surico (2007) to incorporate time-varying weights that reflect the monetary authority's evolving preferences. Additionally, we consider the inertial or zone-like behavior and asymmetry in policy responses. The resulting loss function at time t is presented below

$$L_t = \left\{ \begin{array}{c} \frac{1}{\gamma_\pi^2 \kappa_\pi} \left[e^{\gamma_\pi (\pi_t - \pi_t^*)^{\kappa_\pi}} - \gamma_\pi (\pi_t - \pi_t^*)^{\kappa_\pi} - 1 \right] + \frac{\tilde{w}_{y,t}}{\gamma_y^2 \kappa_y} \left[e^{\gamma_y y_t^{\kappa_y}} - \gamma_y y_t^{\kappa_y} - 1 \right] \\ + \frac{\tilde{w}_{l,t}}{\gamma_l^2 \kappa_l} \left[e^{\gamma_l l_t^{\kappa_l}} - \gamma_l l_t^{\kappa_l} - 1 \right] + \frac{1}{2} \tilde{w}_{i,t} \left(i_t - i_t^* \right)^2 \end{array} \right\}. \tag{1}$$

where π_t^* represents the inflation target, and $\pi_t - \pi_t^*$ denotes the inflation gap. Additionally, y_t stands for the output gap, and l_t represents the leverage gap. The nominal interest rate is denoted by i_t, and the equilibrium interest rate is represented by i^*.

The weights $\tilde{w}_{y,t}$, $\tilde{w}_{l,t}$, and $\tilde{w}_{i,t}$ are relative, time-varying, and independent of the variables $(\pi_t - \pi_t^*)$, y_t, and l_t. The parameters γ_π, γ_y, γ_l, κ_π, κ_y, and κ_l characterize the preferences. Specifically, the asymmetry and zone-like properties of the loss function are captured by κ_π, κ_y, and κ_l, whereas the slope of the loss function and the direction of asymmetry are determined by γ_π, γ_y, and γ_l.

The loss function presented in Equation (1) is general and the specification depends on the parameter values. When $\tilde{w}_{y,t}$, $\tilde{w}_{l,t}$, and $\tilde{w}_{i,t}$ are constant and $\gamma_\pi \to 0$, $\gamma_y \to 0$, $\gamma_l \to 0$, $\kappa_\pi = \kappa_y = \kappa_l = 1$, the function degenerates to the quadratic loss function, where the response to any deviation is linear. Furthermore, if the relative weights are not time-varying, the simplified loss function becomes $\frac{1}{2}\left[(\pi_t - \pi_t^*)^2 + \tilde{w}_y y_t^2 + \tilde{w}_l l_t^2 + \tilde{w}_i (i_t - i_t^*)^2\right]$, which can be derived as a second-order approximation of the utility-based welfare function within the framework of a New-Keynesian business cycle model, as shown in Woodford and Walsh (2005) and Giannoni and Woodford (2017). Therefore, any observed asymmetry in the central bank's objectives may be interpreted as evidence of asymmetry in the utility function of the representative agent. This suggests that our framework can capture the impact of business cycle fluctuations on welfare beyond second-order approximations.

The generalized loss function accommodates asymmetry and the degree of asymmetry is captured by the γ parameters. For instance, if γ_π is greater than zero, it indicates that policymakers experience a greater loss when inflation surpasses the target compared to when it falls below the target by an same amount. This concept has been examined in several studies, including Ruge-Murcia (2003), Robert Nobay and Peel (2003), and Surico (2007).

The loss function can exhibit zone-like behavior for a policy target when its associated parameter, κ, exceeds one. This type of preference is particularly pertinent in the context of inflation target zones and was initially introduced by Orphanides and Wieland (2000). In scenarios characterized by zone-like preferences, policymakers remain indifferent to inflation rates within a specified range, where the marginal loss is zero. The width of this zone expands as κ_π increases. Furthermore, the slope of the loss function, which determines the magnitude of the marginal loss both within and outside the zone, is influenced by the parameters γ_π.

If κ_π is an even number, the zone is symmetric, and the loss from inflation outside the zone is also symmetric. However, if κ_π is odd, both the zone and the loss from inflation outside the zone become asymmetric. Specifically, when $\gamma_\pi > 0$, greater loss is incurred for positive inflation gaps. Table 2 and Table 3 in the appendix provide an overview of different specification of the loss function.

If κ_π is even, the indifference zone is symmetric, and the loss from inflation deviations outside this zone is also symmetric. Conversely, if κ_π is odd, both the zone and the associated loss from inflation deviations become asymmetric. Specifically, when $\gamma_\pi > 0$, the loss is greater for positive inflation gaps. Tables 2 and 3 in the appendix provide an overview of various specifications of the loss function.

2.2 The monetary policy rule

To analyze the behavior of the central bank and its response to different economic variables under various loss functions, we adopt the monetary policy framework from Bianchi, Lettau, and Ludvigson (2022). The IS curve describes the relationship between output gaps and nominal interest rates, while the Phillips curve relates inflation gaps to output gaps and expected inflation.

$$y_t = \theta_0 - \theta_1 \left(i_t - \mathbb{E}_t \left[\pi_{t+1}\right]\right) + \mathbb{E}_t \left[y_{t+1}\right] + \varepsilon_t, \tag{2}$$

where $\theta_1 \in (0, 1)$ is the adjustment coefficient of the output gap to the interest rate, ε_t is the i.i.d. demand shock with mean 0 and variance σ_ε^2.

The New Keynesian Phillips curve is

$$\pi_t - \pi_t^* = \eta_0 + \eta_1 \mathbb{E}_t \left[\pi_{t+1} - \pi_{t+1}^*\right] + \lambda y_t + v_t, \tag{3}$$

where $\eta_1 \in (0, 1)$ is the inflation smoothing coefficient, λ_t is the adjustment coefficient of the inflation to the output gap, v_t is the i.i.d supply shock with mean 0 and variance σ_v^2.

The credit leverage gap, often proxied by the Credit-to-GDP gap, is also known as the Cyclically Adjusted Credit-to-GDP Ratio (CAC). It measures the difference between the credit-to-GDP ratio and its long-term trend, which is estimated using the Hodrick-Prescott (HP) filter. The Bank for International Settlements has shown that setting an early warning threshold at 10% can predict approximately 66.67% of global banking crises since the 1970s (Drehmann and Tsatsaronis, 2014). Following Bruno and Shin (2015), Chen and Dai (2018), and Dong et al. (2021), since the leverage gap is positively correlated with the real interest rate and the output gap, we assume the evolution of the credit leverage gap as follows:

$$l_t = k_0 - k_1 \left(i_t - \mathbb{E}_t \left[\pi_{t+1}\right]\right) + k_2 y_t + \zeta_t, \tag{4}$$

where the credit leverage gap l_t, first introduced by Borio and Lowe (2002), is defined as the difference between the Credit-to-GDP Ratio and its long-term trend, , which is estimated using the HP filter. The coefficient $k_1 \in (0, 1)$ represents the adjustment of the credit leverage to the interest rate, meaning that a larger coefficient will result in a greater counter-cyclical effect of the interest rate on the credit leverage gap. The coefficient $k_2 > 0$ captures the dynamic relationship between the business cycle and the credit leverage gap, indicating that the scale of credit will increase as the economy expands, resulting in an increase in the credit leverage gap. The i.i.d. leverage risk shock ζ_t has a mean of 0 and variance σ_ζ^2.

The central bank aims to minimize the loss by adjusting a basket of monetary policy tools, while considering the constraints imposed by the IS curve and the Phillips curve. Since the central bank must make policy decisions before the realization of economic shocks and the determination of variables within the system, it sets a nominal interest rate that takes into account the dynamics of the economic system as below.

$$\min_{\{i_t\}} \mathbb{E}_{t-1}\left[\sum_{\tau=0}^{\infty} \delta^\tau L_{t+\tau}\right], \tag{5}$$

where δ is the discount factor and L_t is defined in Eq. (1). The central bank solves the minimization problem by assuming the first partial derivative of (5) with respect to i_t equaling to 0, which yields an optimal interest rate that satisfies:

$$\mathbb{E}_{t-1}\left[\frac{\partial L_t}{\partial i_t} + \sum_{\tau=1} \delta^\tau \frac{\partial L_{t+\tau}}{\partial i_t}\right] = 0.$$

The first-order condition above allows us to obtain the optimal interest rate for the central bank, which is

$$\begin{aligned}\hat{i}_t =& \omega_{0,t} + \omega_{y,t}\mathbb{E}_t\left[\mathcal{G}\left(y_{t+1}; \kappa_y, \gamma_y\right) y_{t+1}\right] + \omega_{l,t}\mathbb{E}_t\left[\mathcal{G}\left(l_{t+1}; \kappa_l, \gamma_l\right) l_{t+1}\right] \\ &+ \omega_{\pi,t}\mathbb{E}_t\left[\mathcal{G}\left(\pi_{t+1} - \pi^*_{t+1}; \kappa_\pi, \gamma_\pi\right)\left(\pi_{t+1} - \pi^*_{t+1}\right)\right],\end{aligned} \tag{6}$$

where $\mathcal{G}(x; \kappa, \gamma) = \frac{x^{\kappa-2}\left(e^{\gamma x^\kappa}-1\right)}{\gamma}$, $\omega_{0,t} = \mathbb{E}_t\left[i^*_{t+1}\right]$, $\omega_{y,t} = \mathbb{E}_t\left[\frac{\tilde{w}_{y,t+1}\theta_1}{\tilde{w}_{i,t+1}}\right]$, $\omega_{l,t} = \mathbb{E}_t\left[\frac{\tilde{w}_{l,t+1}(k_1+\theta_1 k_2)}{\tilde{w}_{i,t+1}}\right]$, $\omega_{\pi,t} = \mathbb{E}_t\left[\frac{\lambda\theta_1}{\tilde{w}_{i,t+1}}\right]$, and $\hat{i}_t = \mathbb{E}_t\left[i_{t+1}\right]$. The derivation is given in the Appendix A. Further, according to the Taylor expansion around $\gamma_\pi = \gamma_y = \gamma_l = 0$, we can approximate Eq. (6) as

$$\begin{aligned}\hat{i}_t \approx& \omega_{0,t} + \omega_{y,t}\mathbb{E}_t\left[y_{t+1}^{2\kappa_y-1}\left(1 + \frac{\gamma_y}{2} y_{t+1}^{\kappa_y}\right)\right] + \omega_{l,t}\mathbb{E}_t\left[l_{t+1}^{2\kappa_l-1}\left(1 + \frac{\gamma_l}{2} l_{t+1}^{\kappa_l}\right)\right] \\ &+ \omega_{\pi,t}\mathbb{E}_t\left[\left(\left(\pi_{t+1} - \pi^*_{t+1}\right)^{2\kappa_\pi-1}\left(1 + \frac{\gamma_\pi}{2}\left(\pi_{t+1} - \pi^*_{t+1}\right)^{\kappa_\pi}\right)\right)\right].\end{aligned} \tag{7}$$

Following the literature, to accounting for the smooth property of interest rate, it is natural to assume that the central bank adjust the interest rate by

$$\begin{aligned}i_{t+1} =& \omega_{0,t} + \omega_{y,t}\mathbb{E}_t\left[y_{t+1}^{2\kappa_y-1}\left(1 + \frac{\gamma_y}{2} y_{t+1}^{\kappa_y}\right)\right] + \omega_{l,t}\mathbb{E}_t\left[l_{t+1}^{2\kappa_l-1}\left(1 + \frac{\gamma_l}{2} l_{t+1}^{\kappa_l}\right)\right] \\ &+ \omega_{\pi,t}\mathbb{E}_t\left[\left(\left(\pi_{t+1} - \pi^*_{t+1}\right)^{2\kappa_\pi-1}\left(1 + \frac{\gamma_\pi}{2}\left(\pi_{t+1} - \pi^*_{t+1}\right)^{\kappa_\pi}\right)\right)\right] + \rho_t i_t + e_{t+1}.\end{aligned} \tag{8}$$

where ρ_t is the smoothing parameter.

Apparently, when $\kappa_\pi = \kappa_y = \kappa_l = 1$ and $\gamma_\pi = \gamma_y = \gamma_l = 0$, the monetary policy in Eq. (8)

degenerates into the popular linear forward-looking monetary policy conduct as Taylor (1993) and Boivin (2006),

$$i_{t+1} = \omega_{0,t} + \omega_{\pi,t}\mathbb{E}_t\left[\pi_{t+1} - \pi^*_{t+1}\right] + \omega_{y,t}\mathbb{E}_t\left[y_{t+1}\right] + \omega_{l,t}\mathbb{E}_t\left[l_{t+1}\right] + \rho_t i_t + e_{t+1}. \tag{9}$$

In other words, the model in Eq. (8) is more general. As discussed in Section 2.1, the model here can be used to identify the central bank's preference and therefore capture the characteristics of monetary policy, like symmetric or zone-like preference.

Following Primiceri (2005), to estimate the autoregression coefficient, we do the following transformation,

$$\rho_t = \frac{1}{1+e^{-\tilde{\varrho}_t}}. \tag{10}$$

Besides, we rewrite the model and impose the evolution of time-varying parameters

$$\begin{aligned} i_{t+1} =& \omega_{0,t} + \omega_{y,t}\left(y_{t+1}^{2\kappa_y-1} + \frac{\gamma_y}{2}y_{t+1}^{3\kappa_y-1}\right) + \omega_{l,t}\left(l_{t+1}^{2\kappa_l-1}1 + \frac{\gamma_l}{2}l_{t+1}^{3\kappa_l-1}\right) \\ &+ \omega_{\pi,t}\left(\left(\pi_{t+1}-\pi^*_{t+1}\right)^{2\kappa_\pi-1} + \frac{\gamma_\pi}{2}\left(\pi_{t+1}-\pi^*_{t+1}\right)^{3\kappa_\pi-1}\right) + \rho_t i_t + \xi_t, \end{aligned} \tag{11}$$

$$\boldsymbol{\beta}_t = \boldsymbol{\beta}_{t-1} + \varpi_t, \varpi_t \sim N\left(0, \boldsymbol{\Sigma}\right), \tag{12}$$

where $\boldsymbol{\beta}_t = (\omega_{0,t}, \omega_{y,t}, \omega_{l,t}, \omega_{\pi,t}, \tilde{\varrho}_t)'$, $\boldsymbol{\Sigma} = diag\left(\sigma_0^2, \sigma_y^2, \sigma_l^2, \sigma_\pi^2, \sigma_\varrho^2\right)$, ϖ_t and ξ_t are mutually independent,

$$\begin{aligned} \xi_t =& \omega_{y,t}\left(\mathbb{E}_t\left[y_{t+1}^{2\kappa_y-1}\left(1+\frac{\gamma_y}{2}y_{t+1}^{\kappa_y}\right)\right] - y_{t+1}^{2\kappa_y-1}\left(1+\frac{\gamma_y}{2}y_{t+1}^{\kappa_y}\right)\right) \\ &+ \omega_{l,t}\left(\mathbb{E}_t\left[l_{t+1}^{2\kappa_l-1}\left(1+\frac{\gamma_l}{2}l_{t+1}^{\kappa_l}\right)\right] - l_{t+1}^{2\kappa_l-1}\left(1+\frac{\gamma_l}{2}l_{t+1}^{\kappa_l}\right)\right) \\ &+ \omega_{\pi,t}\left(\mathbb{E}_t\left[\left(\pi_{t+1}-\pi^*_{t+1}\right)^{2\kappa_\pi-1}\left(1+\frac{\gamma_\pi}{2}\left(\pi_{t+1}-\pi^*_{t+1}\right)^{\kappa_\pi}\right)\right]\right. \\ &\left.- \left(\pi_{t+1}-\pi^*_{t+1}\right)^{2\kappa_\pi-1}\left(1+\frac{\gamma_\pi}{2}\left(\pi_{t+1}-\pi^*_{t+1}\right)^{\kappa_\pi}\right)\right). \end{aligned} \tag{13}$$

Sims and Zha (2001) and Sims and Zha (2006) have highlighted the significant heteroscedasticity of the variance of ζ_t. To account for this, we approximate the distribution of ξ_t using a GARCH(1,1) process, following Kim and Nelson (2006).

$$\xi_t | \mathcal{I}_{t-1} \sim N\left(0, \sigma^2_{\xi,t}\right), \tag{14}$$

$$\sigma^2_{\xi,t} = \alpha_0 + \alpha_1\xi^2_{t-1} + \alpha_2\sigma^2_{\xi,t-1}, \tag{15}$$

where $\mathcal{I}_{t-1}$ is the informaton set up to time $t-1$.

In the model, the parameters of interest are $\left\{\alpha_0, \alpha_1, \alpha_2, \sigma_0^2, \sigma_y^2, \sigma_l^2, \sigma_\pi^2, \sigma_\varrho^2, \gamma_\pi, \gamma_y, \gamma_l\right\}$. However, due to correlation betweent ξ_t and the regressors in Eq. (11), there may exit endogeneity and hence estimates may be biased. To address this issue, we use the Heckman-type two-stage maximum likelihood estimation method described in Section 3.1, as recommended by Kim and Nelson (2006), to solve the endogeneity problem.

3 Estimation Methodology

3.1 Estimation

As mentioned earlier, it is important to address the issue of endogeneity and obtain unbiased estimates. To tackle this, we use the inflation gap $\pi - \pi^*$ as an example, follow the approach of Kim and Nelson (2006) and introduce instrumental variables denoted as Z_t. These variables are assumed to satisfy:

$$\pi_{t+1} - \pi^*_{t+1} = Z_t \phi^\pi_t + \varepsilon^\pi_t, \tag{16}$$

$$\phi^\pi_t = \phi^\pi_{t-1} + \varpi^\pi_t, \varpi^\pi_t \sim N\left(0, \sigma^2_{\phi,\pi}\right), \varepsilon^\pi_t \sim N\left(0, \sigma^2_{\varepsilon,\pi,t}\right), \tag{17}$$

$$\sigma^2_{\varepsilon,\pi,t} = a^\pi_0 + a^\pi_1 \sigma^2_{\varepsilon,\pi,t-1} + a^\pi_2 \varepsilon^{\pi 2}_{t-1}. \tag{18}$$

The model in Eq. (16) - Eq. (18) can be estimated via the Kalman filter. Specifically, we define

$$Z_t = \left(Z'_{t-1}, Z'_{t-2}, Z'_{t-3}, Z'_{t-4}\right)', \tilde{Z}_{t-j} = \left(i_{t-j}, \pi_{t-j} - \pi^*_{t-j}, y_{t-j}, l_{t-j}, m2_{t-j}\right)',$$

where $m2_{t-j}$ is the growth of M2. To mitigate endogeneity, the regressors are partitioned into two components, i.e., predicted parts and prediction errors. The prediction error components, denoted as $\varepsilon_{\pi,t|t-1}$, are retained after applying the Kalman filter. Standardized prediction errors $\varepsilon^*_{\pi,t}$ can be obtained as follows:

$$\varepsilon_{\pi,t|t-1} = \sigma^{1/2}_{\varepsilon,\pi,t|t-1} \varepsilon^*_{\pi,t}, \varepsilon^*_t \sim N(0,1),$$

where the conditional covariance $\sigma^{1/2}_{\phi,\pi,t|t-1}$ is the by-product of the Kalman filter. Further, we run the same procedure for output gap y_t and leverage gap l_t, we then rewrite ξ_t as

$$\xi_t = c_1 \sigma_{\xi,t} \varepsilon^*_{\pi,t} + c_2 \sigma_{\xi,t} \varepsilon^*_{y,t} + c_3 \sigma_{\xi,t} \varepsilon^*_{l,t} + \xi^*_t, \xi^*_t \sim N\left(0, \left(1 - c_1^2 - c_2^2 - c_3^2\right) \sigma^2_{\xi,t}\right).$$

Finally, we can rewrite the model in Eq. (11) as

$$\begin{aligned} i_{t+1} =& \omega_{0,t} + \omega_{y,t} \left(y^{2\kappa_y - 1}_{t+1} + \frac{\gamma_y}{2} y^{3\kappa_y - 1}_{t+1}\right) + \omega_{l,t} \left(l^{2\kappa_l - 1}_{t+1} 1 + \frac{\gamma_l}{2} l^{3\kappa_l - 1}_{t+1}\right) \\ &+ \omega_{\pi,t} \left(\left(\pi_{t+1} - \pi^*_{t+1}\right)^{2\kappa_\pi - 1} + \frac{\gamma_\pi}{2} \left(\pi_{t+1} - \pi^*_{t+1}\right)^{3\kappa_\pi - 1}\right) + \frac{1}{1 + e^{-\tilde{\varrho}_t}} i_t \\ &+ c_1 \sigma_{\xi,t} \varepsilon^*_{\pi,t} + c_2 \sigma_{\xi,t} \varepsilon^*_{y,t} + c_3 \sigma_{\xi,t} \varepsilon^*_{l,t} + \xi^*_t, \xi^*_t \sim N\left(0, \left(1 - c_1^2 - c_2^2 - c_3^2\right) \sigma^2_{\xi,t}\right). \end{aligned} \tag{19}$$

We can find that there exists nonlinearity in Eq. (19). We use the Taylor expansion to deal with this problem. Denote

$$f\left(t;\tilde{\varrho}_t\right)=\frac{1}{1+e^{-\tilde{\varrho}_t}}i_t,$$

and by taking the Taylor expansion with respect to $\tilde{\varrho}_t$ around $\tilde{\varrho}_t=\tilde{\varrho}_{t|t}=\mathbb{E}_t\left(\tilde{\varrho}_t\right)$, we can have

$$f\left(t;\tilde{\varrho}_t\right)=f\left(t;\tilde{\varrho}_{t|t}\right)+\frac{\partial f\left(t;\tilde{\varrho}_t\right)}{\partial\tilde{\varrho}_t}\left(\tilde{\varrho}_t-\tilde{\varrho}_{t|t}\right).$$

Therefore, the model can be transformed into a linear form,

$$Y_t=\boldsymbol{X}_t'\boldsymbol{\beta}_t+c_1\sigma_{\xi,t}\varepsilon^*_{\pi,t}+c_2\sigma_{\xi,t}\varepsilon^*_{y,t}+c_3\sigma_{\xi,t}\varepsilon^*_{l,t}+\xi^*_t,$$

where

$$Y_t=i_{t+1}-\frac{i_t}{1+e^{-\tilde{\varrho}_{t|t}}}+\frac{i_t}{\left(1+e^{-\tilde{\rho}_{t|t}}\right)^2}e^{-\tilde{\varrho}_{t|t}}\tilde{\varrho}_{t|t},$$

$$\boldsymbol{X}_t=\left(\begin{array}{c}1\\ y_{t+1}^{2\kappa_y-1}+\frac{\gamma_y}{2}y_{t+1}^{3\kappa_y-1}\\ l_{t+1}^{2\kappa_l-1}1+\frac{\gamma_l}{2}l_{t+1}^{3\kappa_l-1}\\ \left(\pi_{t+1}-\pi^*_{t+1}\right)^{2\kappa_\pi-1}+\frac{\gamma_\pi}{2}\left(\pi_{t+1}-\pi^*_{t+1}\right)^{3\kappa_\pi-1}\\ \frac{i_{t-1}}{\left(1+e^{-\tilde{\varrho}_{t|t}}\right)^2}e^{-\tilde{\varrho}_{t|t}}\end{array}\right).$$

Then the model can be rewritten in a state-space form

$$Y_t=\tilde{\boldsymbol{X}}_t'\tilde{\boldsymbol{\beta}}_t+c_1\sigma_{\xi,t}\varepsilon^*_{\pi,t}+c_2\sigma_{\xi,t}\varepsilon^*_{y,t}+c_3\sigma_{\xi,t}\varepsilon^*_{l,t}+\xi^*_t, \tag{20}$$

$$\tilde{\boldsymbol{\beta}}_t=G\tilde{\boldsymbol{\beta}}_{t-1}+\tilde{\varpi}_t, \tag{21}$$

$$\sigma^2_{\xi,t}=\alpha_0+\alpha_1\xi^2_{t-1}+\alpha_2\sigma^2_{\xi,t-1}, \tag{22}$$

where $\tilde{\boldsymbol{X}}_t=\left(\boldsymbol{X}_t',1\right)'$, $\tilde{\boldsymbol{\beta}}_t=\left(\boldsymbol{\beta}_t',\xi^*_t\right)'$, $G=\left(\begin{array}{cc}I_5&0\\0&0\end{array}\right)$, $\tilde{\varpi}_t=\left(\varpi_t',\xi^*_t\right)'$,

$$\tilde{\varpi}_t\sim N\left(\mathbf{0},\left(\begin{array}{cc}\boldsymbol{\Sigma}&0\\0&\left(1-\rho^2\right)\sigma^2_{e,t}\end{array}\right)\right),$$

where $\Sigma=diag\left(\sigma^2_0,\sigma^2_y,\sigma^2_l,\sigma^2_\pi,\sigma^2_\varrho\right)$. After removing the endogeneity, the parameters we need to estimate in the model are $\boldsymbol{\Theta}=\left(\alpha_0,\alpha_1,\alpha_2,\gamma_\pi,\gamma_y,\gamma_l,\sigma^2_0,\sigma^2_y,\sigma^2_l,\sigma^2_\pi,\sigma^2_\varrho,c_1,c_2,c_3\right)'$. The model defined in Eq. (20) to Eq. (22) can be estimated by Kalman filter.

3.2 Model selection

We aim to comprehensively investigate the preferences of the People's Bank of China (PBoC), with a focus on exploring potential asymmetries and zone-like characteristics. To achieve this, we consider all possible model specifications outlined in Tables 2 and 3, resulting in a total of 64 different models. Specifically, we pre-specify integer values for the κ parameters, ranging from 0 to 3, and estimate the remaining parameters as detailed in Section Section 3.1.

In the absence of a general model specification that permits nesting among the 64 models under consideration, conventional methods like the F-test or likelihood ratio test are not applicable for identifying the optimal model. In line with Riboni and Ruge-Murcia (2023), we employ AIC to select the model that most effectively captures the underlying preferences. By adopting this rigorous approach, we aim to shed light on the nuances of the PBoC's preferences and enhance our understanding of their implications for economic outcomes. AIC is calculated as follows:

$$AIC = -2 \ln L \left(Data | \, \mathbf{\Theta}, M_p \right) + 2k \tag{23}$$

where $L \left(Data | \, \mathbf{\Theta}, M_p \right)$ represents the likelihood for model p, which is obtained as a by-product of the Kalman filter. The variable k is the number of parameters in the model. The model with the lowest AIC value is preferred, as it indicates the best balance between model complexity and goodness of fit.

4 Data

The dataset used covers the period from 1996Q1 to 2022Q4. Each variable was processed using specific filtering methods and sourced from various data repositories, as summarized below:

(i) Nominal interest rate i_t: We use the quarterly interbank lending rate as a proxy for the nominal interest rate. This choice is based on the interbank lending rate's large market volume, high transaction share, and stability, which render it a more precise indicator of the cost of funds than the repo rate. The quarterly rate is derived by averaging the monthly interbank lending rates over a three-month period. The data is obtained from the official website of the People's Bank of China.

(ii) Inflation gap $\pi_t - \pi_t^*$: We use the monthly Consumer Price Index (CPI) for China, sourced from the National Bureau of Statistics, as a proxy for the inflation level. The CPI is selected due to its strong connection to everyday life and its interpretability compared to other indices such as the Producer Price Index (PPI) or the GDP deflator. The inflation gap is calculated by subtracting the inflation target rate from the actual inflation rate. For the inflation target rate, we rely on the figure published in the report by the Premier of the State Council, which is widely recognized as an authoritative measure.

(iii) Output gap y_t: The proxy variable for the output gap is derived from quarterly GDP data. We begin by calculating real GDP using the GDP levels and their cumulative real growth rates. Subsequently, we apply seasonal adjustments to the real GDP figures. Finally, the output gap proxy is obtained through Hodrick-Prescott (HP) filtering of the seasonally adjusted real GDP.

(iv) Credit leverage gap l_t: The Credit-to-GDP gap, commonly referred to as the Basel III countercyclical capital buffer indicator, measures the deviation of the credit-to-GDP ratio from its long-term trend. This trend is typically estimated using the Hodrick-Prescott (HP) filter. The credit leverage gap serves as a proxy for systemic risk and has become a focal point in the central bank's monetary policy objectives for two primary reasons. First, as leverage levels in China have escalated, the central bank has shifted its emphasis from traditional goals such as economic growth and inflation towards addressing financial risk and leverage. This shift aims to mitigate systemic risks. Second, recent studies (Chen and Dai, 2018; Dong et al., 2021) suggest that China's monetary policy has increasingly prioritized leverage targets. Consequently, we incorprate the credit leverage gap in the monetary policy rule, reflecting its growing importance.

(iv) The growth of $M2$: The growth of $M2$ is the difference between two subsequent values of $M2$.

5 Empirical results

In this section, we apply our proposed model and estimation strategy to explore the asymmetric and zone-like preferences of the PBoC. We begin by estimating all 64 models based on the loss function forms outlined in Tables 2 and 3. After obtaining the estimates, we compute AIC for each model and select the one that best captures the nuances of the PBoC's preferences. We specifically focus on comparing the chosen model with the linear benchmark model, where $\gamma_\pi = \gamma_l = \gamma_y = 0$ and $\kappa_\pi = \kappa_l = \kappa_y = 1$, to assess their relative performance.

5.1 Model selection and estimation

We estimate 64 models with time-varying parameters using the strategies outlined in Section 3.1. After completing model estimation, we calculate AIC values, as explained in Section 3. The AIC values are displayed in Figure 2.

To visualize the performance of each model, Panel (A) of Figure 2 presents a 4×4 heatmap of AIC values. Each cell corresponds to a specific combination of κ and γ values for the output and leverage gaps, with $\kappa_\pi = 1$ and $\gamma_\pi \to 0$. Panels (B), (C), and (D) further explore the impact of κ_π by showing heatmaps for $\kappa_\pi = 1, 2$, and 3, respectively. In these panels, κ_y and κ_l are varied in the same manner as in Panel (A).

Our analysis reveals two key findings. First, the AIC values across all models vary significantly, ranging from a maximum of 345.74 to a minimum of 149.95. Compared to the classic linear model (AIC = 157.72), the parameter combination of $\kappa_\pi = 3$, $\kappa_y = 1$, and $(\kappa_l = 1, \gamma_l \to 0)$ yields the lowest AIC value. Second, the loss function supported by AIC reveals pronounced nonlinearity. The corresponding loss functions, calculated without time-varying weights as per equations (24) - (26), are shown in Figure 3. The figure indicates that the PBoC demonstrates asymmetric inertia in its response to the inflation gap, exhibits asymmetrical reactions to the output gap, and responds linearly to the leverage gap.

$$\text{Inflation gap: } \frac{1}{\kappa_\pi \gamma_\pi^2 \left(1-\rho_{t|t}\right)} \left[e^{\gamma_\pi \left(\pi_{t+1}-\pi_{t+1}^*\right)^{\kappa_\pi}} - \gamma_\pi \left(\pi_{t+1}-\pi_{t+1}^*\right)^{\kappa_\pi} - 1 \right], \tag{24}$$

$$\text{Output gap: } \frac{1}{\kappa_y \gamma_y^2} \left[e^{\gamma_y y_{t+1}^{\kappa_y}} - \gamma_y y_{t+1}^{\kappa_y} - 1 \right], \tag{25}$$

$$\text{Leverage gap: } l_{t+1}^2. \tag{26}$$

Table 1 presents the parameter estimates for the model selected based on AIC, with a comparison to the estimated linear monetary policy rule. The results reveal three key insights. First, both models show significant heteroscedasticity, as evidenced by the statistically significant GARCH(1,1) parameters. Second, the standard deviation of the time evolution of parameters varies between models, with $\omega_{y,t}$ showing the highest variability, reflecting significant fluctuations in the output gap parameters. Third, the asymmetric parameters γ_π and γ_y are statistically significant and greater than zero, confirming asymmetric losses for inflation and the output gap. The next section will delve deeper into PBoC's preferences using the selected nonlinear model.

Table 1: **The parameters estimated under the linear and selected models**

	Selected model ($\kappa_\pi = 3, \kappa_y = 1$)		Linear model	
	Estimates	Standard error	Estimates	Standard error
α_0	0.0000	0.0000	0.0000	0.0000
α_1	0.7507	0.0752	0.8992	0.0348
α_2	0.2493	0.0752	0.1008	0.0348
σ_0	0.0035	0.0281	0.0000	0.0100
σ_y	0.0264	0.0162	0.0129	0.0075
σ_l	0.0008	0.0010	0.0000	0.0002
σ_π	0.0001	0.0000	0.0000	0.0013
σ_ϱ	0.0000	0.0762	0.0000	0.0013
γ_π	0.0077	0.0003	-	-
γ_y	0.2946	0.1437	-	-
c_1	-0.0063	0.0990	-0.0756	0.1059
c_2	-0.1093	0.0982	-0.0411	0.0975
c_3	-0.0323	0.1027	-0.0406	0.1068

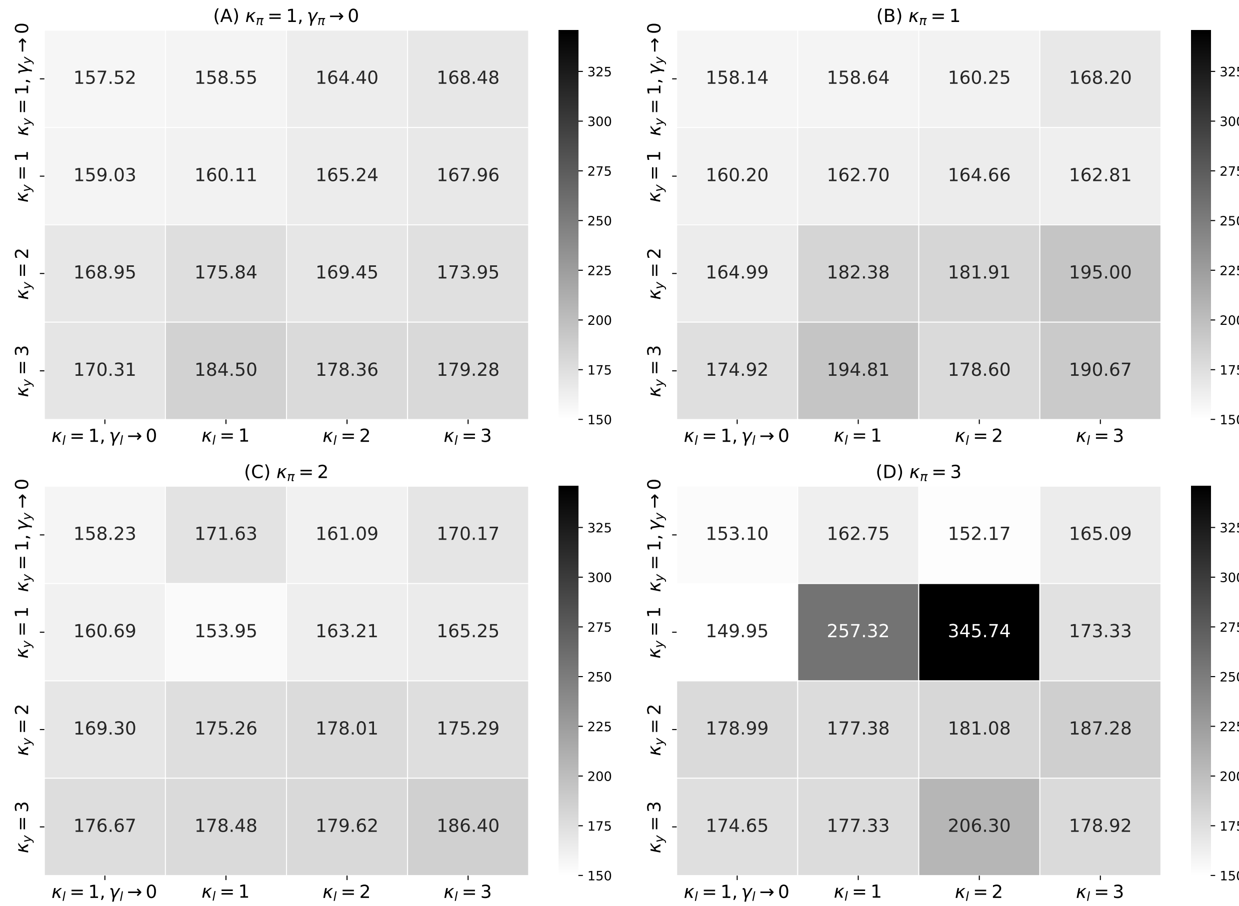

Figure 2: **The heatmaps of AIC of all model specifications**
Panel (A) presents a heatmap displaying a 4×4 matrix of AIC values for 16 combinations of $\kappa_y = 1, \gamma_y \to 0; \kappa_y = 1, 2, 3$ and $\kappa_l = 1, \gamma_l \to 0; \kappa_l = 1, 2, 3$, with $\kappa_\pi = 1$ and $\gamma_\pi \to 0$. Panels (B), (C), and (D) correspond to cases where κ_π equals 1, 2, and 3, respectively.

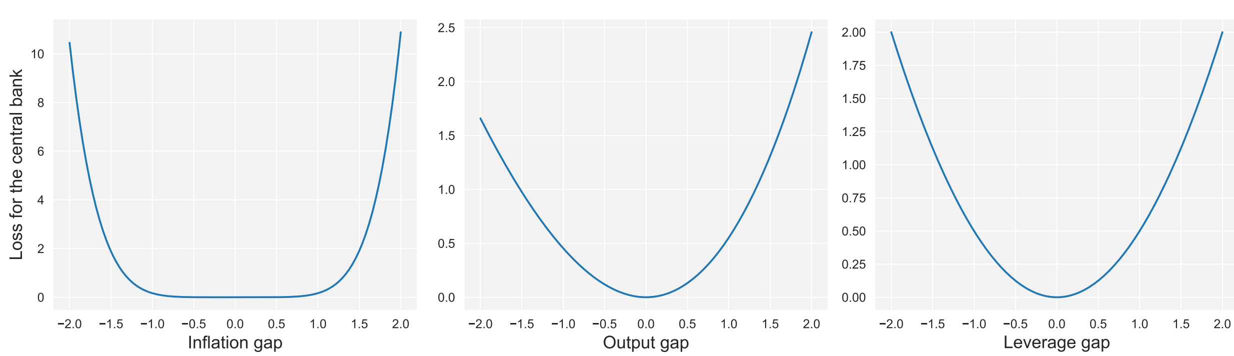

Figure 3: **The preference of the monetary authority in the selected model**

5.2 The time-varying characteristics of the central bank

In this section, we employ the Kalman filter to derive the time-varying parameters for both linear and selected nonlinear monetary policy rules. Using the estimation results presented in Table 1, we extract the time-varying parameters $\omega_{0,t}, \omega_{y,t}, \omega_{l,t}, \omega_{\pi,t}, \rho_t = \frac{1}{1+e^{-\varrho_t}}$, and ϱ_t for each period t, incorporating all available information up to that point. Figure 4 illustrates the evolution of these parameters, offering insights into how the PBoC dynamically responds to the inflation gap, output gap, and leverage gap throughout the sample period. For comparative purposes, we also present the time-varying parameters within the framework of linear monetary policy.

As depicted in Panel (A) of Figure 4, the trends of equilibrium interest rates, denoted as $\frac{\omega_{0,t|t}}{1-\rho_{t|t}}$, are strikingly similar under both linear and nonlinear monetary policy rules. Notably, the equilibrium interest rate in the selected nonlinear monetary policy is consistently lower than that in the linear rules. Additionally, the rate in the linear model demonstrates greater volatility compared to its nonlinear counterpart. The equilibrium interest rate serves as a fundamental benchmark for the PBoC's policy rate and plays a pivotal role in shaping monetary policy. From 2001 to 2008, a decline in the equilibrium interest rate suggests a shift towards looser monetary policies aimed at stimulating economic recovery. In contrast, beginning in 2008, the equilibrium interest rate started to rise. This upward trend has persisted since the Subprime Mortgage Crisis of 2008, reflecting a increased cost of financing in the market.

Panel (B) of Figure 4 illustrates that the output gap coefficient is generally positive in both the linear and nonlinear model ($\kappa_y = 1, \gamma_y > 0$), indicating a counter-cyclical monetary policy approach by the PBoC. This implies that when there is a negative economic deviation, the PBoC adopts a stimulative policy by lowering interest rates. Conversely, during a positive deviation, it tightens policy by raising interest rates. Prior to 2019, the coefficient was predominantly above zero, indicating the PBoC's preference to prevent an overheated economy rather than mitigate an economic downturn. However, a significant shift has occurred since 2020 as the coefficient turned negative, reflecting the impact of the COVID-19 pandemic on China's economy. This suggests that in the face of substantial negative external shocks, the central bank becomes more proactive in averting a recession. The dynamic nature of monetary policy underscores its adaptability in response to macroeconomic fluctuations. The transition from positive to negative values highlights a potential shift in China's macroeconomic policies from counter-cyclical to pro-cyclical regulation, aligning with prevailing economic conditions to maintain stable growth.

Panel (C) of Figure 4illustrates the evolution of credit leverage gap coefficients over time within both nonlinear and linear monetary policy frameworks. In the nonlinear model, these coefficients have generally increased, whereas in the linear model, they initially decreased before rising post-2008. The response to leverage gap in the nonlinear model ($\kappa_l = 1, \gamma_y \to 0$) is the same as the linear one. Before 2005, the coefficients in the nonlinear framework were relatively small and occasionally negative, indicating a pro-cyclical regulatory stance by the People's Bank of China

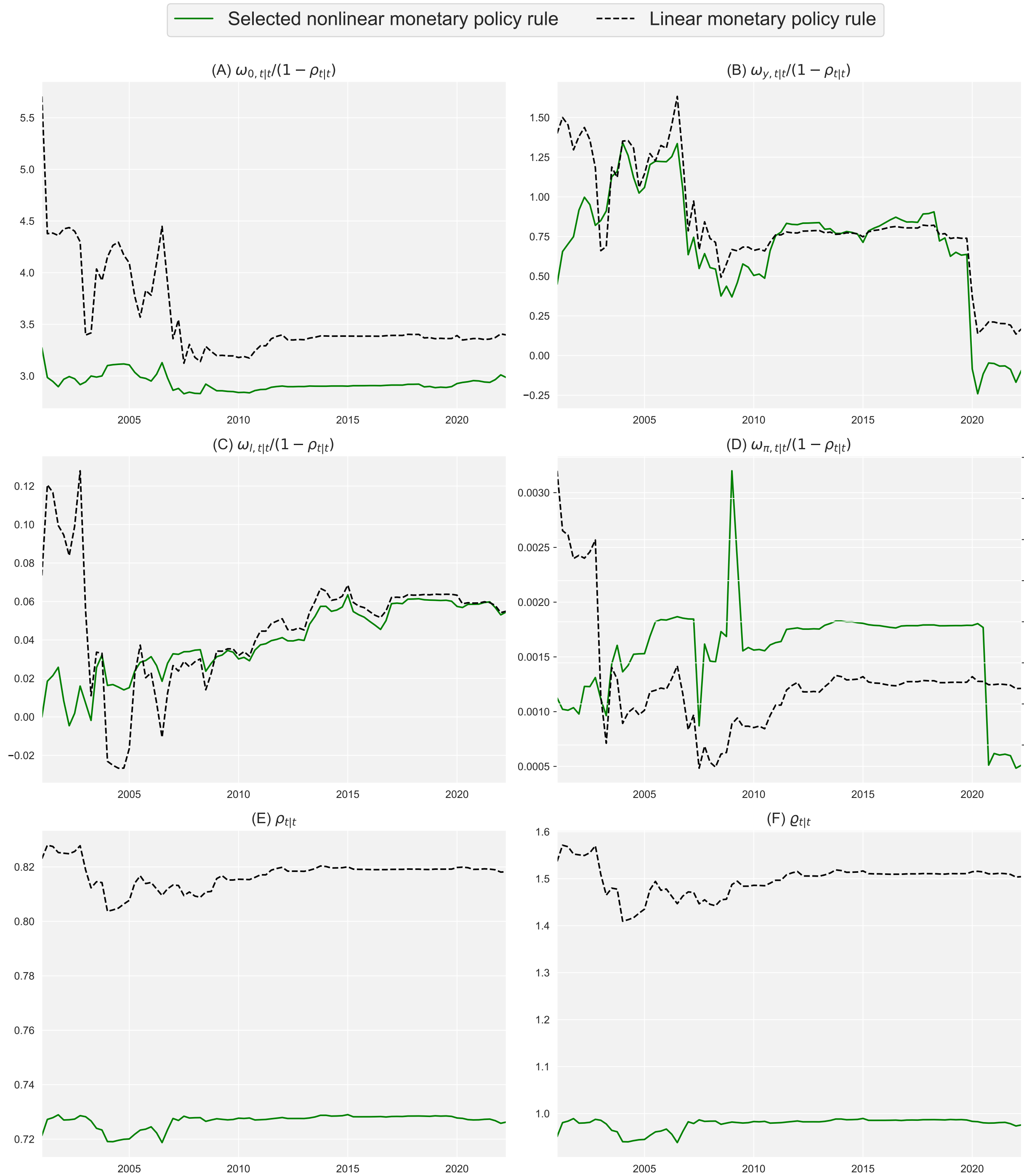

Figure 4: **Time-varying responses in linear and selected nonlinear monetary policy rules** This figure displays the time-varying parameters $\frac{\omega_{0,t|t}}{1-\rho_{t|t}}$, $\frac{\omega_{y,t|t}}{1-\rho_{t|t}}$, $\frac{\omega_{l,t|t}}{1-\rho_{t|t}}$, $\frac{\omega_{\pi,t|t}}{1-\rho_{t|t}}$, $\rho_{t|t} = \frac{1}{1+e^{-\varrho_{t|t}}}$, and $\varrho_{t|t}$ estimated using the Kalman filter, as shown in Panels (A) to (F). The nonlinear model captures the monetary policy conduct. The notation "$t|t$" indicates the estimates obtained with data available up to time t. Panel (D) compares the nonlinear model (left axis) to the linear model (right axis).

(PBoC). This approach can be attributed to the low levels of credit leverage in China during this period, which diminished the need for counter-cyclical regulation. Conversely, the linear model exhibited significant volatility, with coefficients peaking at 13 % in 2002Q4 and dropping to -2% in 2004Q3, continuing to fluctuate until 2007. From 2007 onwards, both models show a similar upward trend in response to the leverage gap. The increasing coefficients reflect the central bank's heightened focus on leverage regulation, adopting a more robust counter-cyclical approach due to the rising macro leverage ratio in China. Counter-cyclical regulation reached its peak at 6.34% in the nonlinear model and 6.85% in the linear model by 2015Q1, maintaining a relatively high level through 2022. This underscores the elevated leverage risk and the ongoing necessity for strong counter-cyclical measures. In summary, China's monetary policy demonstrates a strong capacity for timely adjustments in regulating the leverage cycle and responding to evolving economic conditions and requirements. In summary, China's monetary policy exhibits a strong capacity for timely adjustments in regulating the leverage cycle, effectively responding to evolving economic conditions and requirements.

Panel (D) of Figure 4 demonstrates that the estimates under both monetary policy rules are consistently positive. In the context of a linear monetary policy rule, these positive values suggest a counter-cyclical strategy by the central bank in managing inflation targets. Specifically, the PBoC adopts a tightening stance to mitigate risks when inflation rises, signaling an overheated economy, and eases policy when inflation declines. The coefficients decrease from a peak of 1.07 in 2001Q1 to 0.34 by 2007Q3. Thereafter, they exhibit an upward trend, reaching 0.538 by 2020Q4. In the nonlinear monetary policy rule, the PBoC's loss function concerning the inflation gap ($\kappa_\pi = 3, \gamma_\pi > 0$) is non-quadratic. Consequently, the time-varying coefficient cannot straightforwardly represent the PBoC's response to the inflation gap. Nevertheless, we observe a sharp increase in the coefficients during 2009Q1, attributed to the financial crisis, followed by a significant decline in 2020Q4 due to the pandemic.

The examination of the interest rate smoothing coefficients provides valuable insights into the PBoC's monetary policy strategies over time. As depicted in Panel (E) and (F) of Figure 4, the trends in parameter estimates for both linear and nonlinear models are generally align, although the coefficients in the nonlinear model are significantly smaller than those in the linear model. With all coefficients in both models exceeding 0.7, it is clear that both nonlinear and linear monetary policy rules aim to maintain a steady course, resulting in relatively smaller coefficients (scaled by $1-\varrho_{t|t}$) for inflation, output, and credit targets. In both models, the coefficients fluctuate prior to 2007. After 2007, the smoothing coefficients exhibit an upward trend, increasing slightly from 0.723 (0.812) to around 0.726 (0.828) in the nonlinear (linear) monetary policy rule. These temporal variations in smoothing coefficients over time reflect the central bank's strategies in response to changing economic conditions, underscoring its commitment to maintaining financial market stability while addressing economic crises and recoveries.

5.3 The time-varying losses and responses of the central bank

In the following analysis, we aim to investigate the time-varying preferences of the monetary authority by estimating the approximate loss surface associated with different economic gaps over time. We interpret $\omega_{y,t}$, $\omega_{l,t}$, and $\omega_{\pi,t}$ in equation (8) as the relative weights assigned to the losses incurred from deviations from policy targets. Accordingly, we calculate the relative approximated losses due to inflation ($\kappa_\pi = 3$), output ($\kappa_y = 1$), and leverage ($\kappa_l = 0$, $\gamma_l \to 0$) gaps using the following expressions:

$$
\begin{aligned}
\text{Inflation gap: } & \frac{\omega_{\pi,t|t}}{\kappa_\pi \gamma_\pi^2 \left(1-\rho_{t|t}\right)} \left[e^{\gamma_\pi \left(\pi_{t+1}-\pi^*_{t+1}\right)^{\kappa_\pi}} - \gamma_\pi \left(\pi_{t+1}-\pi^*_{t+1}\right)^{\kappa_\pi} - 1 \right], \\
\text{Output gap: } & \frac{\omega_{y,t|t}}{\kappa_y \gamma_y^2 \left(1-\rho_{t|t}\right)} \left[e^{\gamma_y y_{t+1}^{\kappa_y}} - \gamma_y y_{t+1}^{\kappa_y} - 1 \right], \\
\text{Leverage gap: } & \frac{\omega_{l,t|t}}{\left(1-\rho_{t|t}\right)} l_{t+1}^2,
\end{aligned}
$$

which are summarized in Figure 5. Additionally, we present the time-varying response of the PBoC to gaps in inflation, output, and leverage in Figure 6, which are derived as follows:

$$
\begin{aligned}
\text{Inflation gap: } & \frac{\omega_{\pi,t|t}}{1-\rho_{t|t}} \left[\left(\pi_{t+1}-\pi^*_{t+1}\right)^{2\kappa_\pi - 1} + \frac{\gamma_\pi}{2} \left(\pi_{t+1}-\pi^*_{t+1}\right)^{3\kappa_\pi - 1} \right], \\
\text{Output gap: } & \frac{\omega_{y,t|t}}{1-\rho_{t|t}} \left(y_{t+1}^{2\kappa_y - 1} + \frac{\gamma_y}{2} y_{t+1}^{3\kappa_y - 1} \right), \\
\text{Leverage gap: } & \frac{\omega_{l,t|t}}{1-\rho_{t|t}} l_{t+1}.
\end{aligned}
$$

A closer examination of Figures 5 and 6 reveals three significant observations.

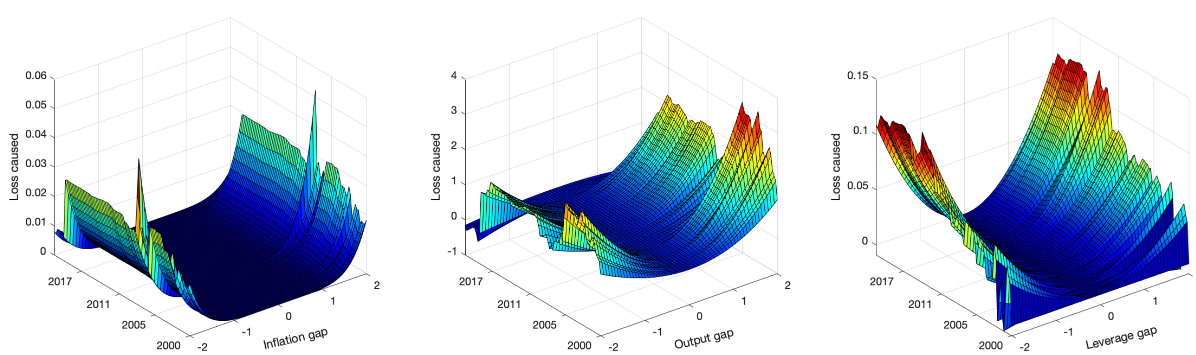

Figure 5: **The time-varying relative loss caused by inflation, output and leverage gaps**

First, the analysis of the loss function associated with the inflation gap reveals an apparent inertia with a slightly asymmetrical pattern, as illustrated in Figures 3 and 5. These figures

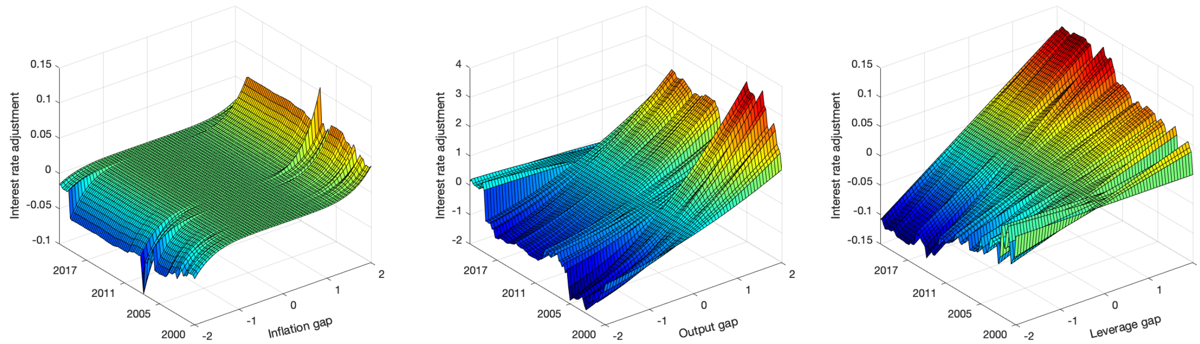

Figure 6: **The time-varying responses of monetary policy to inflation, output and leverage gaps**

highlight the monetary authority's inertial approach to addressing inflation shocks. Specifically, the PBoC tends to refrain from intervention unless inflation deviates by more than 1% from the target, irrespective of the direction of this deviation. However, once the deviation surpasses 1%, the central bank engages in asymmetrical counter-cyclical regulation, suggesting an inertial zone within approximately a (-1, 1) deviation range for managing inflation through monetary policy. Furthermore, the PBoC exhibits a slightly greater aversion to high inflation levels compared to low inflation levels, as indicated by $\gamma_\pi > 0$. The response to inflation gaps, depicted in Figure 6, indicates that a 1% increase in inflation above the target results in an interest rate hike ranging from 0.05% to 0.3% over time. Conversely, a 1% decrease below the target leads to an interest rate reduction ranging from 0.04% to 0.3% over time. Importantly, due to the COVID-19, the PBoC's counter-cyclical regulation has undergone significant changes and has become more moderate since 2020Q4. This pattern suggests that the PBoC's monetary policy response to inflation is relatively moderate. The presence of zone-like preferences indicates that the central bank maintains a clear policy boundary when regulating inflation.

Second, with respect to the output gap, the loss function of the PBoC exhibits an asymmetric characteristic, indicating a stronger aversion to economic overheating than to recession, as illustrated in Figure 3. The time-varying relative weights, denoted by $\frac{\omega_{y,t|t}}{(1-\rho_{t|t})}$, reveal that the PBoC's losses have fluctuated and turned negative—indicating gains—since 2020Q1, primarily due to the impact of the COVID-19 pandemic. In alignment with these time-varying losses, the responses to the output gaps suggest that monetary policy followed to an asymmetric counter-cyclical stance for managing output gaps until 2020Q1, after which it shifted to a pro-cyclical approach. Unlike inflation regulation, there is no "inertia zone" observed in this context. The regulatory force applied to mitigate positive output gaps is more strong than that for negative gaps of equivalent magnitude, reflecting the asymmetry in the PBoC's loss function concerning the output gap. These findings imply that China has prioritized maintaining stable economic growth over strict economic cycle regulation.

Third, for the leverage gaps, the PBoC employs a symmetrical regulatory approach in absence of inertia. This implies that the central bank intervenes with equal intensity regardless of whether the leverage level deviates upward or downward. As illustrated in Figure 5 and Figure 6, earlier monetary policies did not explicitly show a regulatory stance for leverage targets. This observation is consistent with empirical findings indicating that prior to 2005, both time-varying losses and policy responses were minimal and occasionally reversed direction. However, from 2005 onwards, there has been an noticeable increase in relative weights, $\frac{\omega_{l,t|t}}{(1-\rho_{t|t})}$, reflecting a stronger focus on mitigating excessive credit growth. During this period, the PBoC implements a counter-cyclical framework. Consequently, the time-varying losses associated with the leverage gap have increased, as depicted in Figure 5. Correspondingly, the intensity of policy interventions has also risen over time, as indicated by Figure 6.

6 Robustness

In this section, we perform a robustness check by comparing the proposed model specifications to models with constant parameters and time-varying parameter models that exclude leverage gaps. The AIC values for all model specifications are presented in Figures 7 and 8. The results demonstrate that the AIC values for these alternative models are consistently higher than the selected nonlinear monetary policy model in the previous sections. Specifically, the lowest AIC value for the model with constant parameters is 154.95, while the lowest AIC value for the time-varying parameter models without leverage gaps is 153.31. These findings indicate that the proposed nonlinear policy model is a more suitable choice, as it achieves a lower AIC value compared to the alternatives considered.

7 Conclusion

We examine the time-varying asymmetric and zone-like preferences in the monetary policy response function of the People's Bank of China (PBoC). We hypothesize that the priority assigned to different policy objectives within the PBoC's loss function evolves over time. Under this assumption, the central bank minimizes its losses by deriving an optimal forward-looking monetary policy rule characterized by time-varying parameters.

Our analysis considers four distinct types of losses related to inflation, output, and leverage, resulting in a total of 64 unique models. We extend a classic maximum likelihood estimation strategy to estimate these models and employ the AIC to identify the most suitable model. We compare the selected model against time-varying parameter models without a leverage target and

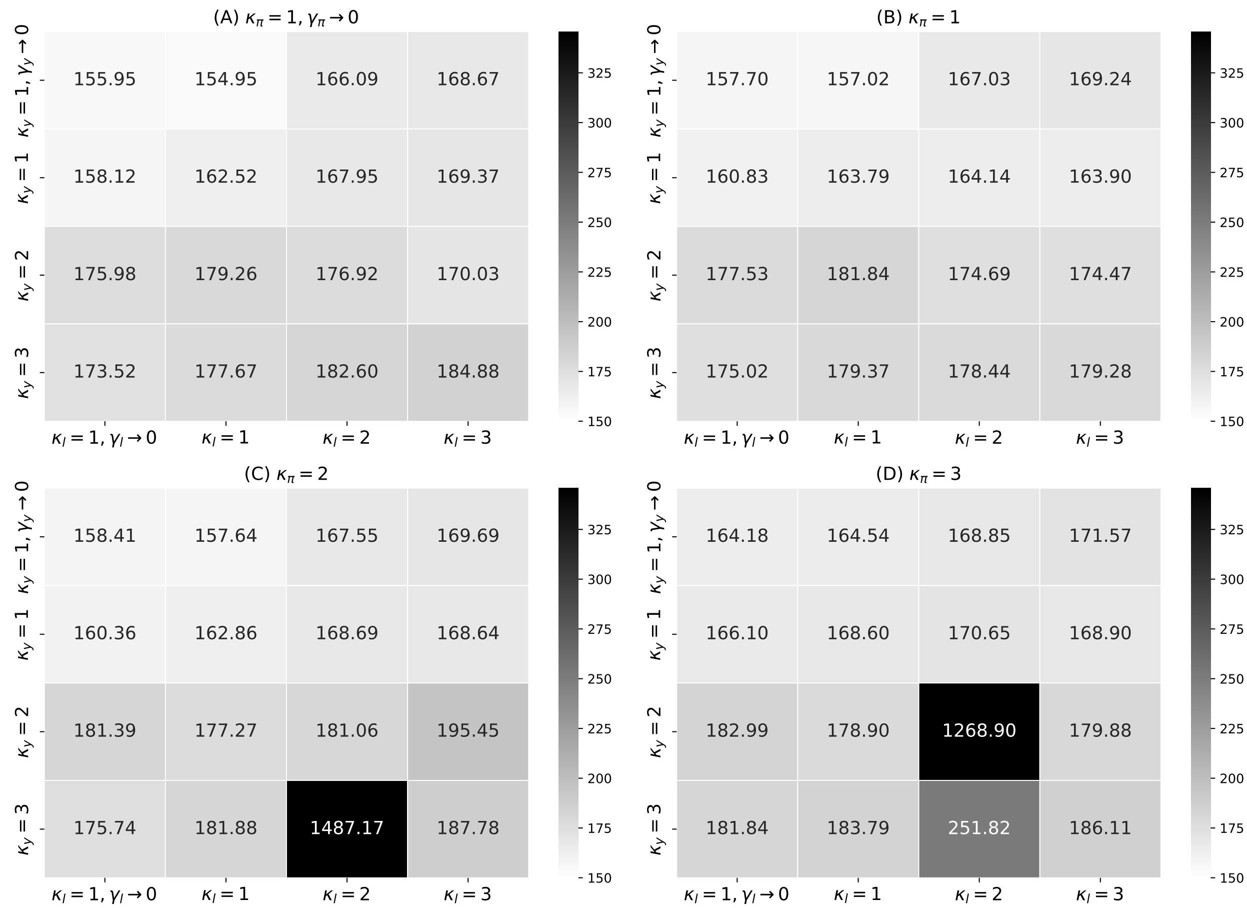

Figure 7: **The heatmaps of AIC of all model specifications with constant parameters** Panel (A) presents a heatmap displaying a 4×4 matrix of AIC for 16 combinations of $\kappa_y = 1, \gamma_y \to 0; \kappa_y = 1, 2, 3$ and $\kappa_l = 1, \gamma_l \to 0; \kappa_l = 1, 2, 3$, with $\kappa_\pi = 1$ and $\gamma_\pi \to 0$. Panels (B), (C), and (D) correspond to cases where κ_π equals 1, 2, and 3, respectively.

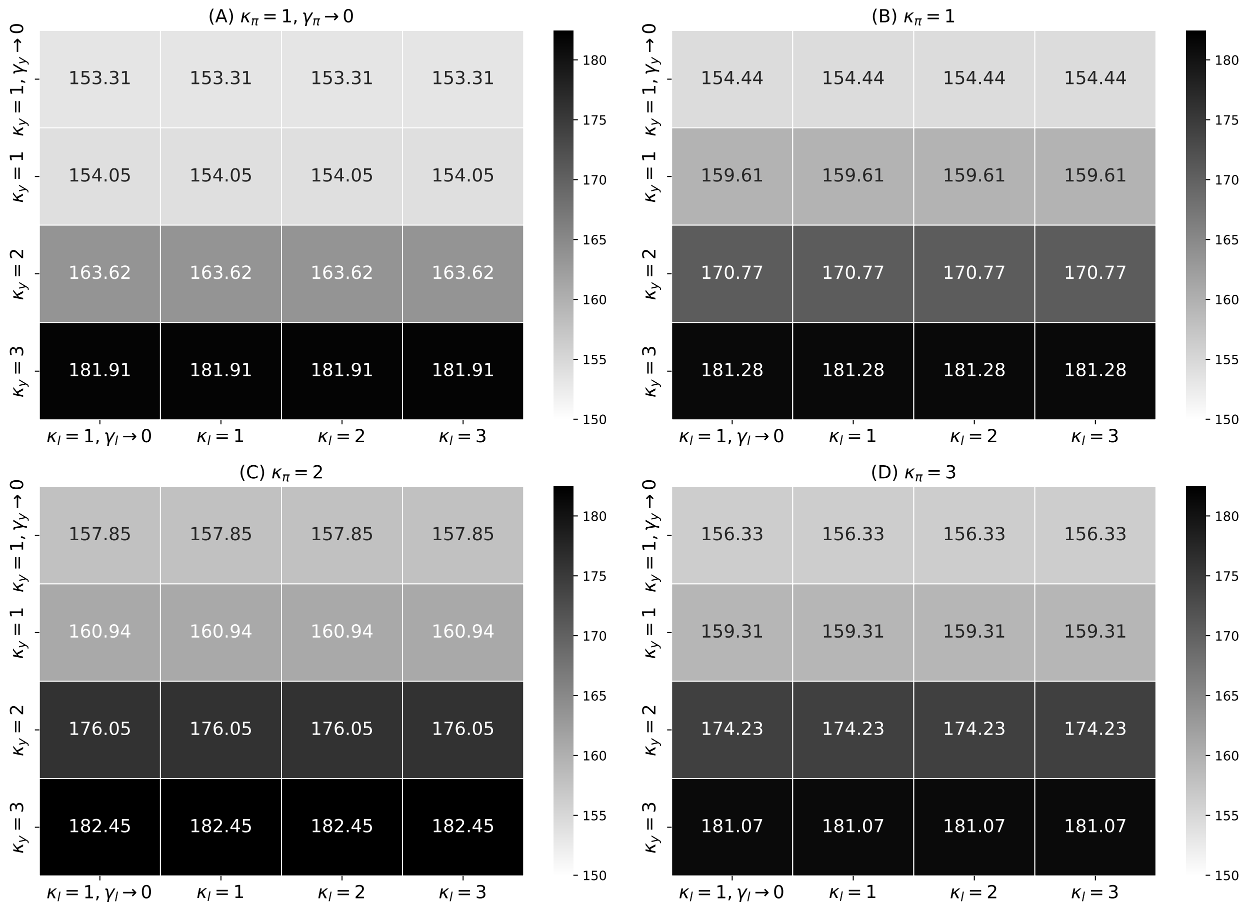

Figure 8: **The heatmaps of AIC of all model specifications without leverage gaps** Panel (A) presents a heatmap displaying a 4 × 4 matrix of AIC for 16 combinations of $\kappa_y = 1, \gamma_y \to 0; \kappa_y = 1, 2, 3$ and $\kappa_l = 1, \gamma_l \to 0; \kappa_l = 1, 2, 3,$ with $\kappa_\pi = 1$ and $\gamma_\pi \to 0$. Panels (B), (C), and (D) correspond to cases where κ_π equals 1, 2, and 3, respectively.

models with constant parameters. AIC indicates that our proposed model has the lowest value, thus identifying it as the best fit.

Upon further examination of the time-varying policy reactions, we derive three key insights. First, our findings reveal that the PBoC adopts an inertial approach to inflation gaps, intervening only when inflation deviates more than 1% from the target. Within the "inert zone" (-1%, 1%), the central bank refrains from intervention. The PBoC exhibits a slightly greater concern for high inflation compared to low inflation. A 1% increase above the target prompts an interest rate hike ranging from 0.05% to 0.3%, whereas a 1% decrease results in a reduction between 0.04% and 0.3%. Since late 2020, influenced by COVID-19, the PBoC's counter-cyclical measures have become more moderate, indicating a cautious monetary policy with defined boundaries for regulating inflation.

Second, the PBoC demonstrates a stronger aversion to economic overheating than to recession. Since early 2020, due to COVID-19, the PBoC's losses have fluctuated, occasionally turning into gains. Prior to 2020, monetary policy was counter-cyclical but shifted to a pro-cyclical stance thereafter. Unlike inflation control, there is no "inertia zone" for output gaps. The PBoC applies more regulatory force to curb positive output gaps than negative ones of equivalent magnitude, underscoring its asymmetric loss function. This suggests that China prioritizes stable economic growth over strict cycle regulation.

Third, the PBoC employs a linear regulatory approach to leverage gaps, intervening equally whether leverage rises or falls. Before 2005, monetary policies did not explicitly target leverage, exhibiting minimal and sometimes reversed responses. However, since 2005, there has been a noticeable shift towards controlling credit growth, evidenced by increased policy focus and intervention intensity. This transition is reflected in rising time-varying losses and more active policy measures.

In summary, empirical results and analysis underscore the flexibility and advantages of our model and estimation framework. Our study highlights the dynamic nature of the PBoC's monetary policy, emphasizing its evolving priorities and strategic interventions across different economic conditions.

Table 2: Specifications of the loss function on inflation gap, output gap and leverage gap

The specifications of the preference towards to output gap (I), leverage gap (II) and inflation gap (III) given different sets of parameters.

		$\kappa_\pi = 1, \gamma_\pi \to 0$	$\kappa_\pi = 1$	$\kappa_\pi = 2$	$\kappa_\pi = 3$
$\kappa_y = 1$ $\gamma_y \to 0$	$\kappa_l = 1$ $\gamma_l \to 0$	I: Quadratic II: Quadratic III: Quadratic	I: Quadratic II: Quadratic III: Asymmetric	I: Quadratic II: Quadratic III: Symmetrically inert	I: Quadratic II: Quadratic III: Asymmetrically inert
	κ_l=1	I: Quadratic II: Asymmetric III: Quadratic	I: Quadratic II: Asymmetric III: Asymmetric	I: Quadratic II: Asymmetric III: Symmetrically inert	I: Quadratic II: Asymmetric III: Asymmetrically inert
	$\kappa_l = 2$	I: Quadratic II: Symmetrically inert III: Quadratic	I: Quadratic II: Symmetrically inert III: Asymmetric	I: Quadratic II: Symmetrically inert III: Symmetrically inert	I: Quadratic II: Symmetrically inert III: Asymmetrically inert
	$\kappa_l = 3$	I: Quadratic II: Asymmetrically inert III: Quadratic	I: Quadratic II: Asymmetrically inert III: Asymmetric	I: Quadratic II: Asymmetrically inert III: Symmetrically inert	I: Quadratic II: Asymmetrically inert III: Asymmetrically inert
κ_y=1	$\kappa_l = 1$ $\gamma_l \to 0$	I: Asymmetric II: Quadratic III: Quadratic	I: Asymmetric II: Quadratic III: Asymmetric	I: Asymmetric II: Quadratic III: Symmetrically inert	I: Asymmetric II: Quadratic III: Asymmetrically inert
	κ_l=1	I: Asymmetric II: Asymmetric III: Quadratic	I: Asymmetric II: Asymmetric III: Asymmetric	I: Asymmetric II: Asymmetric III: Symmetrically inert	I: Asymmetric II: Asymmetric III: Asymmetrically inert
	$\kappa_l = 2$	I: Asymmetric II: Symmetrically inert III: Quadratic	I: Asymmetric II: Symmetrically inert III: Asymmetric	I: Asymmetric II: Symmetrically inert III: Symmetrically inert	I: Asymmetric II: Symmetrically inert III: Asymmetrically inert
	$\kappa_l = 3$	I: Asymmetric II: Asymmetrically inert III: Quadratic	I: Asymmetric II: Asymmetrically inert III: Asymmetric	I: Asymmetric II: Asymmetrically inert III: Symmetrically inert	I: Asymmetric II: Asymmetrically inert III: Asymmetrically inert

Table 3: Specifications of the loss function on inflation gap, output gap and leverage gap (Continued)

The specifications of the preference towards to output gap (I), leverage gap (II) and inflation gap (III) given different sets of parameters.

		$\kappa_\pi = 1, \gamma_\pi \to 0$	$\kappa_\pi = 1$	$\kappa_\pi = 2$	$\kappa_\pi = 3$
κ_y=2	$\kappa_l = 1$ $\gamma_l \to 0$	I: Symmetrically inert II: Quadratic III: Quadratic	I: Symmetrically inert II: Quadratic III: Asymmetric	I: Symmetrically inert II: Quadratic III: Symmetrically inert	I: Symmetrically inert II: Quadratic III: Asymmetrically inert
	κ_l=1	I: Symmetrically inert II: Asymmetric III: Quadratic	I: Symmetrically inert II: Asymmetric III: Asymmetric	I: Symmetrically inert II: Asymmetric III: Symmetrically inert	I: Symmetrically inert II: Asymmetric III: Asymmetrically inert
	$\kappa_l = 2$	I: Symmetrically inert II: Symmetrically inert III: Quadratic	I: Symmetrically inert II: Symmetrically inert III: Asymmetric	I: Symmetrically inert II: Symmetrically inert III: Symmetrically inert	I: Symmetrically inert II: Symmetrically inert III: Asymmetrically inert
	$\kappa_l = 3$	I: Symmetrically inert II: Asymmetrically inert III: Quadratic	I: Symmetrically inert II: Asymmetrically inert III: Asymmetric	I: Symmetrically inert II: Asymmetrically inert III: Symmetrically inert	I: Symmetrically inert II: Asymmetrically inert III: Asymmetrically inert
$\kappa_y = 3$	$\kappa_l = 1$ $\gamma_l \to 0$	I: Asymmetrically inert II: Quadratic III: Quadratic	I: Asymmetrically inert II: Quadratic III: Asymmetric	I: Asymmetrically inert II: Quadratic III: Symmetrically inert	I: Asymmetrically inert II: Quadratic III: Asymmetrically inert
	κ_l=1	I: Asymmetrically inert II: Asymmetric III: Quadratic	I: Asymmetrically inert II: Asymmetric III: Asymmetric	I: Asymmetrically inert II: Asymmetric III: Symmetrically inert	I: Asymmetrically inert II: Asymmetric III: Asymmetrically inert
	$\kappa_l = 2$	I: Asymmetrically inert II: Symmetrically inert III: Quadratic	I: Asymmetrically inert II: Symmetrically inert III: Asymmetric	I: Asymmetrically inert II: Symmetrically inert III: Symmetrically inert	I: Asymmetrically inert II: Symmetrically inert III: Asymmetrically inert
	$\kappa_l = 3$	I: Asymmetrically inert II: Asymmetrically inert III: Quadratic	I: Asymmetrically inert II: Asymmetrically inert III: Asymmetric	I: Asymmetrically inert II: Asymmetrically inert III: Symmetrically inert	I: Asymmetrically inert II: Asymmetrically inert III: Asymmetrically inert

Appendix A: The derivation of the optimal interest rate for the central bank

The FOCs in Eq. (5) can be derived as below. First, we can find that

$$\begin{aligned}
\frac{\partial L_t}{\partial i_t} =& \tilde{w}_{i,t}\left(i_t - i_t^*\right) \\
& - \mathcal{G}\left(\pi_t - \pi_t^*; \kappa_\pi, \gamma_\pi\right)\left(\pi_t - \pi_t^*\right)\lambda\theta_1 \\
& - \tilde{w}_{y,t}\mathcal{G}\left(y_t; \kappa_y, \gamma_y\right) y_t \theta_1 \\
& - \tilde{w}_{l,t}\mathcal{G}\left(l_t; \kappa_l, \gamma_l\right) l_t \left(k_1 + \theta_1 k_2\right) \\
\frac{\partial L_{t+\tau}}{\partial i_t} =& 0, \text{ for } \tau \geq 1.
\end{aligned}$$

where $\mathcal{G}\left(x; \kappa, \gamma\right) = \frac{x^{\kappa-2}\left(e^{\gamma x^\kappa}-1\right)}{\gamma}$. Therefore,

$$\begin{aligned}
& \mathbb{E}_{t-1}\left[\frac{\partial L_t}{\partial i_t} + \sum_{\tau=1} \delta^\tau \frac{\partial L_{t+\tau}}{\partial i_t}\right] \\
=& -\theta_1 \mathbb{E}_{t-1}\left[\tilde{w}_{y,t}\mathcal{G}\left(y_t; \kappa_y, \gamma_y\right) y_t\right] - \left(k_1 + \theta_1 k_2\right)\mathbb{E}_{t-1}\left[\tilde{w}_{l,t}\mathcal{G}\left(l_t; \kappa_l, \gamma_l\right) l_t\right] + \mathbb{E}_{t-1}\left[\tilde{w}_{i,t}\left(i_t - i_t^*\right)\right] \\
& - \lambda\theta_1 \mathbb{E}_{t-1}\left[\mathcal{G}\left(\pi_t - \pi_t^*; \kappa_\pi, \gamma_\pi\right)\left(\pi_t - \pi_t^*\right)\right] = 0,
\end{aligned}$$

and since $\tilde{w}_{y,t}$, $\tilde{w}_{l,t}$, and $\tilde{w}_{i,t}$ are relative and time-varying and independent of $\left(\pi_t - \pi_t^*\right), y_t$ and l_t, we have

$$\begin{aligned}
\mathbb{E}_{t-1}\left[i_t\right] =& \mathbb{E}_{t-1}\left[i_t^*\right] + \mathbb{E}_{t-1}\left[\frac{\tilde{w}_{y,t}\theta_1}{\tilde{w}_{i,t}}\right]\mathbb{E}_{t-1}\left[\mathcal{G}\left(y_t; \kappa_y, \gamma_y\right) y_t\right] + \mathbb{E}_{t-1}\left[\frac{\tilde{w}_{l,t}\left(k_1 + \theta_1 k_2\right)}{\tilde{w}_{i,t}}\right]\mathbb{E}_{t-1}\left[\mathcal{G}\left(l_t; \kappa_l, \gamma_l\right) l_t\right] \\
& + \mathbb{E}_{t-1}\left[\frac{\lambda\theta_1}{\tilde{w}_{i,t}}\right]\mathbb{E}_{t-1}\left[\mathcal{G}\left(\pi_t - \pi_t^*; \kappa_\pi, \gamma_\pi\right)\left(\pi_t - \pi_t^*\right)\right].
\end{aligned}$$

Let $\omega_{0,t} = \mathbb{E}_t\left[i_{t+1}^*\right]$, $\omega_{y,t} = \mathbb{E}_t\left[\frac{\tilde{w}_{y,t+1}\theta_1}{\tilde{w}_{i,t+1}}\right]$, $\omega_{l,t} = \mathbb{E}_t\left[\frac{\tilde{w}_{l,t+1}(k_1+\theta_1 k_2)}{\tilde{w}_{i,t+1}}\right]$ $\omega_{\pi,t} = \mathbb{E}_t\left[\frac{\lambda\theta_1}{\tilde{w}_{i,t+1}}\right]$, and $\hat{i}_t = \mathbb{E}_t\left[i_{t+1}\right]$, we can have,

$$\begin{aligned}
\hat{i}_t =& \omega_{0,t} + \omega_{y,t}\mathbb{E}_t\left[\mathcal{G}\left(y_{t+1}; \kappa_y, \gamma_y\right) y_{t+1}\right] + \omega_{l,t}\mathbb{E}_t\left[\mathcal{G}\left(l_{t+1}; \kappa_l, \gamma_l\right) l_{t+1}\right] \\
& + \omega_{\pi,t}\mathbb{E}_t\left[\mathcal{G}\left(\pi_{t+1} - \pi_{t+1}^*; \kappa_\pi, \gamma_\pi\right)\left(\pi_{t+1} - \pi_{t+1}^*\right)\right].
\end{aligned}$$

References

Adrian, T., N. Boyarchenko, and D. Giannone (2019). Vulnerable growth. *American Economic Review 109*(4), 1263–1289.

Auclert, A. (2019). Monetary policy and the redistribution channel. *American Economic Review 109*(6), 2333–2367.

Baele, L., G. Bekaert, S. Cho, K. Inghelbrecht, and A. Moreno (2015). Macroeconomic regimes. *Journal of Monetary Economics 70*, 51–71.

Bartscher, A. K., M. Kuhn, M. Schularick, and U. Steins (2020). Modigliani meets minsky: Inequality, debt, and financial fragility in america, 1950-2016.

Benigno, P. and L. Rossi (2021). Asymmetries in monetary policy. *European economic review 140*, 103945.

Bianchi, F., M. Lettau, and S. C. Ludvigson (2022). Monetary policy and asset valuation. *The Journal of Finance 77*(2), 967–1017.

Blanchard, O. (2019). Public debt and low interest rates. *American Economic Review 109*(4), 1197–1229.

Boinet, V. and C. Martin (2008). Targets, zones, and asymmetries: a flexible nonlinear model of recent uk monetary policy. *Oxford Economic Papers 60*(3), 423–439.

Boivin, J. (2006). Has u.s. monetary policy changed? evidence from drifting coefficients and real-time data. *Journal of Money, Credit, and Banking 38*, 1149 – 1173.

Borio, C. E. and P. W. Lowe (2002). Asset prices, financial and monetary stability: exploring the nexus.

Bruno, V. and H. S. Shin (2015). Capital flows and the risk-taking channel of monetary policy. *Journal of monetary economics 71*, 119–132.

Castro, V. (2011). Can central banksâ€™ monetary policy be described by a linear (augmented) taylor rule or by a nonlinear rule? *Journal of Financial Stability 7*(4), 228–246.

Chen, C. and M. Dai (2018). Monetary policy, leverage cycle, and house price fluctuation. *Economic Research Journal 53*(9), 52–67.

Cogley, T. and T. J. Sargent (2005). Drifts and volatilities: monetary policies and outcomes in the post wwii us. *Review of Economic dynamics 8*(2), 262–302.

Dong, B., H. Xu, and X. Tan (2021). Can monetary policy reconcile sustaining steady growth with preventing risks in china? an analysis based on dynamic stochastic general equilibrium modeling. *Journal of Financial Research 490*(4), 19–37.

Drehmann, M. and K. Tsatsaronis (2014). The credit-to-gdp gap and countercyclical capital buffers: questions and answers. *BIS Quarterly Review March*.

Filardo, A., P. Hubert, and P. Rungcharoenkitkul (2022). Monetary policy reaction function and the financial cycle. *Journal of Banking and Finance 142*, 106536.

Gambacorta, L. and F. M. Signoretti (2014). Should monetary policy lean against the wind?: An analysis based on a dsge model with banking. *Journal of Economic Dynamics and Control 43*, 146–174.

Giannoni, M. P. and M. Woodford (2017). Optimal target criteria for stabilization policy. *Journal of Economic Theory 168*, 55–106.

Gourinchas, P.-O. and H. Rey (2019). Global real rates: A secular approach.

Gross, I. and J. Hansen (2021). Optimal policy design in nonlinear dsge models: An n-order accurate approximation. *European Economic Review 140*, 103918.

Kim, C.-J. and C. R. Nelson (2006). Estimation of a forward-looking monetary policy rule: A time-varying parameter model using ex post data. *Journal of Monetary Economics 53*(8), 1949–1966.

Nakajima, J. and M. West (2013). Bayesian analysis of latent threshold dynamic models. *Journal of Business & Economic Statistics 31*(2), 151–164.

Orphanides, A. and V. Wieland (2000). Inflation zone targeting. *European Economic Review 44*(7), 1351–1387.

Primiceri, G. E. (2005). Time varying structural vector autoregressions and monetary policy. *The Review of Economic Studies*.

Riboni, A. and F. Ruge-Murcia (2023). The power of the federal reserve chair. *International Economic Review 64*(2), 727–756.

Robert Nobay, A. and D. A. Peel (2003). Optimal discretionary monetary policy in a model of asymmetric central bank preferences. *The Economic Journal 113*(489), 657–665.

Ruge-Murcia, F. J. (2003). Inflation targeting under asymmetric preferences. *Journal of Money, Credit and Banking*, 763–785.

Shapiro, A. H. and D. J. Wilson (2022). Taking the fed at its word: A new approach to estimating central bank objectives using text analysis. *The Review of Economic Studies 89*(5), 2768–2805.

Silvo, A. (2019). The interaction of monetary and macroprudential policies. *Journal of Money, Credit and Banking 51*(4), 859–894.

Sims, C. A. and T. Zha (2001). Stability and instability in us monetary policy behavior. *Princeton University*.

Sims, C. A. and T. Zha (2006). Were there regime switches in us monetary policy? *American Economic Review 96*(1), 54–81.

Surico, P. (2007). The fed's monetary policy rule and us inflation: The case of asymmetric preferences. *Journal of Economic Dynamics and Control 31*(1), 305–324.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester conference series on public policy*, Volume 39, pp. 195–214. Elsevier.

Woodford, M. and C. E. Walsh (2005). Interest and prices: Foundations of a theory of monetary policy. *Macroeconomic Dynamics 9*(3), 462–468.