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ASYMMETRIC MONETARY POLICY RULES AND THE ACHIEVEMENT OF THE INFLATION TARGET: THE CASE OF CHILE

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Resumen

El objetivo del presente trabajo es contrastar si la respuesta de política monetaria del Banco Central de Chile (BCCh) depende del estado actual de la economía. Para ello, se estiman modelos de umbral para la regla de política del BCCh que permite la existencia de dos regímenes dependiendo de si la brecha, el desvío de la inflación o el crecimiento del PIB están en niveles por sobre o debajo de un valor de umbral. También se evalúa los posibles efectos de las reglas estimadas en el logro de la meta de inflación. Para ello, se realizan simulaciones en base a un modelo neokeynesiano estándar sujeto a cambios endógenos de parámetros. Las estimaciones indican que la autoridad monetaria responde con mayor fuerza a desvíos de la inflación en períodos de alta actividad económica, pero de manera más débil a la brecha de producto. También se encuentra evidencia estadística de que el BCCh reacciona de manera más rápida moviendo su instrumento de política cuando la economía se encuentra en un período de expansión. Estos resultados son robustos a la estimación con umbral desconocido y con datos en tiempo real. Ejercicios de simulación revelan que la regla de política estimada puede inducir un comportamiento asimétrico de la inflación y con un sesgo negativo.

Abstract

The purpose of this paper is to test empirically whether the Central Bank of Chile (CBC) has a monetary policy reaction that changes depending on the actual state of the economy. For that, we estimate a threshold model for the CBC's policy rule that allows the existence of two policy regimes according to whether the output gap, the inflation deviation or the GDP growth is above or below a threshold value. Also, we assess the possible effects of estimated monetary policy rules in the achievement of the inflation target by simulating a standard New Keynesian Model with endogenous switching parameters. Estimations show that the monetary authority responds strongly to inflation deviations but weakly to the output gap when the gap is larger than a specific threshold value. Furthermore, there is statistical evidence that the CBC reacts faster moving the interest rate under expansion periods. These results are robust when assuming an unknown threshold value and to real-time estimation. Simulations reveal that the estimated monetary policy rule may induce an asymmetric behavior in the inflation rate and a small negative inflation bias.

I would like to thank Klaus Schmidt-Hebbel, Patricio Jaramillo and an anonymous referee for helpful suggestions. The views and conclusions presented in the paper are exclusively those of the author and do not reflect the position of the Central Bank of Chile or of the Board members. Email: fgredig@bcentral.cl.

1 Introduction

Since Taylor (1993), the standard way to characterize and analyze CBs' behavior is through a linear function of a short–term interest rate (usually the CB's monetary policy rate) linked to the inflation deviation from the inflation target and the output gap, the so-called Taylor rule. Taylor rules are directly related to CBs' legal mandates. In general, the main objective of CBs is ensuring price stability, but when this is achieved, real purposes like smoothing cyclical output fluctuations can be considered. Besides their good empirical performance, Taylor rules have strong theoretical support. Under a quadratic central bank loss function and a linear dynamic structure of the economy, the optimal adjustment in the monetary policy instrument can be described by a Taylor rule. However, these assumptions exclude the possibility of asymmetries in policymakers' preferences with respect to inflation deviations and the output gap, or the existence of nonlinearities in the equations that describe the economy's dynamics. In both cases, the linear quadratic paradigm dissapears and nonlinear monetary policy reactions arise. For example, monetary authorities may dislike positive inflation deviations more than negative ones, or make more efforts to reduce the output gap when the inflation goal has been achieved. Possibly people dislike unemployment more than inflation, especially when inflation rates are low; then, during recessions they prefer a little more inflation in the short–run to reduce unemployment rates that is larger than the little less inflation they would want to increase unemployment during booms. Since CBs respond for their actions to the political power –and, therefore, in an indirect way to the population– policymakers may reflect part of these preferences. In this line, Blinder (1998) suggests that political demands may lead to an asymmetric CB behavior.[1] In the case of Chile, the Basic Constitutional Act of the Central Bank establishes that "The Bank shall inform the President of the Republic and the Senate with regard to the policies and regulations of general applicability issued by the Bank in the performance of its duties" (Section 4), and "the Board shall consider the general orientation of the Government's economic policies" (Section 6).

The previous discussion has a direct link with the achievement of the inflation target. Under an asymmetric monetary policy rule, the inflation level can be different, in average, from the target even if authorities try to achieve the target levels of inflation and output in the long–run. Over the period of study, the inflation rate has been, in average, lower than the inflation target. As we will see, the existence of an asymmetric CBC's policy rule may explain in part this result.

The purpose of this paper is to test empirically whether the Central Bank of Chile (CBC) has a monetary policy reaction that changes depending on the actual state of the economy,

[1] "In most situations, the central bank will take far more political heat when it tightens pre-emptively to avoid higher inflation than when it eases pre-emptively to avoid higher unemployment."

in particular the actual output gap, the actual inflation deviation from the inflation target or the GDP growth rate. For that, we estimate a threshold model for the CBC's policy rule that allows the existence of two policy regimes according to whether the output gap, the inflation deviation or the GDP growth rate is above or below a threshold value. For the threshold value, we assume two alternatives: a known value and an unknown value. In the latter case, we follow the GMM method proposed by Caner and Hansen (2004) that allows estimating sample splitting models with endogenous control variables and testing linearity by bootstrap. Also, we assess the possible effects of estimated monetary policy rules in the achievement of the inflation target by simulating a standard New Keynesian Model (NKM) with endogenous switching parameters. Our results reveal that it is not possible to reject an asymmetric behavior of the CBC. Estimations show that the monetary authority responds strongly to inflation deviations but weakly to the output gap when the gap is larger than a specific threshold value. Furthermore, there is statistical evidence that the CBC reacts faster moving the interest rate under expansion periods. These results are robust when assuming an unknown threshold value and to real–time estimation. Nonlinearities due to other states of the economy, as actual inflation deviation or GDP growth, are not robust to unknown threshold and real–time estimation. Simulations reveal that the estimated monetary policy rule may induce an asymmetric behavior in the inflation rate and a small negative inflation bias. The faster response of the CBC under expansion periods (associated to high inflation level periods) explains this result.

There is growing work in the literature that explores both the existence and the effects of asymmetries or nonlinearities in monetary policy rules. Surico (2007) shows that if the CB has a cubic specification for the loss function and acts under discretion in a standard NKM, then the optimal monetary policy rule must add squared terms of both the inflation deviation and the output gap. Using U.S data, he finds asymmetric preferences of the Fed with respect to the output gap in the pre-Volcker era. Under this period, that kind of preferences induced stronger reactions to output contractions than expansions of the same magnitude. Assuming a linex function for the CB's loss function[2] –that allows for asymmetric CB preferences– and allowing for nonlinearities in the AS curve, Dolado et al. (2004) find that the optimal monetary policy rule must include the conditional variance of inflation (prudent behavior). However, their model induces asymmetric responses only when the AS curve is nonlinear. Their empirical estimations for the U.S. suggest the existence of a nonlinear Fed's monetary policy reaction during the Volcker-Greenspan period (post–1982) driven by asymmetric preferences regarding inflation deviations instead of convexity in the AS curve. According to this result, over this

[2] The linex central bank loss function coresponds to: $L_t = \frac{e^{\alpha(\pi_t-\pi^*)}-\alpha(\pi_t-\pi^*)-1}{\alpha^2} + \lambda\left[\frac{e^{(\gamma y_t)}-\gamma(y_t)-1}{\gamma^2}\right] + \frac{\mu}{2}(i_t - i^*)^2$.

period the Fed would have weighted more severely positive inflation deviations than negative ones. For the previous Burns-Miller period (pre-1979), their estimations do not reject the existence of quadratic preferences.

Theoretical effects of asymmetric preferences on monetary policy rules have been explored in Cukierman (2000), Ruge-Murcia (2002), and Surico (2007), among others. When CBs are concerned more about negative output gaps (or positive unemployment rate deviations from the natural rate) and there is uncertainty about the future state of the economy, an inflation bias arises even when monetary authorities target output or unemployment at potential levels. When the linex function is assumed for the loss function, the larger the volatility of output (or unemployment), the larger the inflation bias. Cukierman and Gerlach (2003) find that the inflation bias was important in the period 1971-1985 for a sample of 21 OECD countries, but this was not significant in the period 1986-2000. In a similar study, Doyle and Falk (2006) arrive to the same conclusions. Ruge-Murcia (2004) finds empirical support for the inflation bias in the United States and France, suggesting that their respective CBs weight more severely positive than negative unemployment deviations from the natural level. However, empirical support is not found for Canada, Italy, and the U.K. Surico (2004) estimates a statistically significant 1-percent inflation bias in the U.S. for the pre-1979 period, whereas no significant inflation bias is found for the post-1982 period.

Dolado et al. (2005) show that an asymmetric optimal monetary policy rule arises in the presence of nonlinearities in the Phillips curve and quadratic CBs' preferences.[3] This rule adds an interaction term of inflation and output gap to the standard Taylor rule, which leads CBs to react more severely to positive (negative) than negative (positive) inflation deviations when the Phillips curve is convex (concave). Their empirical estimations suggest that after the 1980s four European CBs (UK, Germany, Spain, and ECB) have shown more concern about positive than negative deviations from the inflation target. However, they cannot reject the existence of a linear Phillips curve –and therefore, a symmetrical monetary policy rule– a result in line with Dolado, et al. (2003), referred to above.

There are many other empirical studies that focus on testing nonlinear and/or asymmetric monetary policy rules. Surico (2003) finds that the ECB and the Fed respond asymmetrically to the output gap –stronger reaction to positive than negative deviations– during the period 1997:07–2002:10, but a linear response to inflation deviations. Karagedikli and Lees (2004) find that the central bank of New Zealand behaves symmetrically during the inflation-targeting period, whereas the Reserve Bank of Australia weights contractions more than expansions of the same magnitude. Bec et al. (2002), using a threshold model for the Taylor rule, do not

[3] According to the most popular theories, nonlinearities in the AS or Phillips curve can arise due to downward nominal wage rigidities (Baily, 1978) or money illusion in part of the workers (Akerlof et al., 1996).

reject the existence of asymmetries in the Taylor rule for the U.S, Germany, and France over the 1982:10–1998:8 period. While the Bundesbank reacted more agresively to both output gap and inflation deviations during expansions than recessions, the Fed only cared about inflation during booms. On the other hand, they find that the Bank of France weights inflation deviations more in recessions than expansions, but puts no weight to output gap either in downturns or in booms. In the same line, Taylor and Davradakis (2006) find statistical support to a nonlinear monetary policy reaction under the inflation-targeting period (from 1992:10 to 2003:01). During this period, above a threshold of 3.1% for the inflation rate, a standard forward-looking Taylor rule characterizes well the Bank of England's behavior, while below that threshold, the Bank seems to have left interest rates to be almost random, only with a weak concern about the output gap. Martin and Milas (2004) find that the Bank of England reacts more to positive than negative inflation deviations since the adoption of inflation targeting (IT) in 1992. For Chile, Gonzalez and Tejada (2006) estimate a flexible nonlinear form for the monetary policy reaction. Their estimations suggest that the Central Bank of Chile (CBC) reacts linearly to inflation deviations, but does not respond to them immediately during recessions.

The paper is structured as follows. Section 2 presents estimations of the CBC's monetary policy reaction assuming linearity in coefficients. Section 3 presents estimations of the CBC's monetary policy reaction allowing asymmetric responses according to the state of the economy. The section also includes a brief description of the estimation method for the case of unknown threshold value and real–time estimations to check how robust the results are. Section 4 presents simulations based on a standard NKM and the estimations for the CBC's monetary policy rule to assess the effect in the achievement of the inflation target. Section 5 concludes.

2 Standard monetary policy reaction

In a very influential work, Taylor (1993) shows that the Fed's behavior can be well characterized by linking the monetary policy instrument (Fed Funds Rate) with the lagged inflation deviation from its target and the output gap. After that, a growing empirical and theoretical research has studied what kind of rule "governs" CBs' behavior and whether this kind of rules are desirable to ensure price stabilization under rational expectation equilibrium models.

As an interpretation of their legal mandates, in practice CBs may be concerned about other objectives than inflation and the output gap, such as avoiding excessive interest rates movements and exchange rate fluctuations. CBs smooth interest rates to avoid disturbances in the financial system and amiliorate the effect of possible policy mistakes. The concern about exchange rates arises in highly dollarized countries (due to the balance sheet effect) and in economies with large levels of exchange-rate-to-inflation passthrough. Also, due to lags in monetary policy transmission, CBs behave in a forward-looking manner; and, therefore, usually target forecasts of variables instead of actual values. To the extent that actual values are good proxies for the expected ones, forward-looking rules nest linear especifications. The modified Taylor rule, due to Clarida et al. (2000), brings together the previous discussion:

$$r_t = \rho^r r_{t-1} + (1-\rho^r)\{\bar{r}_t + (\beta^\pi - 1)(\pi^e_{t+k,t} - \bar{\pi}_t) + \beta^x(y^e_{t+j,t} - \bar{y}^e_{t+j,t}) + \Gamma' c_t\} + \varepsilon_t, \quad (1)$$

where r_t corrresponds to the real monetary policy rate, ρ^r measures the interest rate smoothness of monetary policy, β^π is the CB's reaction to inflation rate deviations from the inflation target $(\pi^e_{t+k,t} - \bar{\pi}_t)$, β^x is the interest-rate response to output gap $(y^e_{t+j,t} - \bar{y}^e_{t+j,t})$, $\bar{r}_t$ is the natural real rate of interest, and ε_t is a residual term distributed with mean zero and variance σ^2_ε. Special attention is given to β^π, since a value of less (more) than one for this parameter would mean a destabilizing (stabilizing) rule.[4] $\pi^e_{t+k,t}$ is the expected inflation for period $t+k$ based on information in period t, $y^e_{t+j,t}$ $(\bar{y}^e_{t+j,t})$ is the expected log of actual (potential) GDP for period $t+j$ based on information in period t , and c_t is a vector of other CB targets.

Note that both the inflation target and the natural rate of interest can vary under this monetary policy rule. Chile had varying inflation targets since the adoption of the IT framework in 1990 until 1999 when the CBC announced a permanent inflation goal as a range from 2 to 4 percent over a medium-term horizon. At the moment of implementing IT, authorities chose a gradual process of inflation stabilization from annual inflation levels above twenty percent to inflation levels prevailing in industrial economies. Having in mind the high degree of price indexation and the possible adverse effects on output, during this disinflation period every year the CBC announced an annual end-of-year inflation goal for the next year, in general, somewhat lower than the previous one. Once low inflation levels were attained, the CBC established the permanent year-on-year inflation target, which started in 2001. With respect to the natural rate of interest, empirical evidence suggests that this rate can vary through time (Bomfim, 2001; Laubach and Williams, 2003; Clark and Kozicki, 2005). In particular, Tregan and Wu (2007) show that ignoring this fact and estimating monetary policy rules with a constant natural rate of interest can lead to an overestimation of both the interest-rate-smoothing parameter and the CB's response to inflation deviations.[5]

[4] A less than one β_π violates the so-called "Taylor principle", producing possible undesirable outcomes and multiplicity of bounded equilibria in rational equilibrium models.

[5] Estimations of monetary policy reactions for Chile (monthly data), assuming a constant natural rate of interest, yield interest-rate-smoothing parameters very close to one and inflation-response parameters much higher than 1.5 (the original Taylor's estimate), especially when estimates are based on real-time data.

Note that if we assume that $\bar{r}_t$ is very close to $\bar{r}_{t-1}$[6], (1) can be approximated as:

$$\hat{r}_t = \rho^r \hat{r}_{t-1} + (1-\rho^r)\{(\beta^\pi - 1)\hat{\pi}^e_{t+k,t} + \beta^x \hat{x}^e_{t+j,t} + \Gamma' c_t\} + \varepsilon_t, \tag{2}$$

where $\hat{r}_t$ is the interest rate gap, $\hat{\pi}_{t+k,t}$ the inflation deviation from the inflation target, and $\hat{x}^e_{t+j,t}$ the output gap. Following Clarida et al. (1997, 2000), we replace the expected terms ($\hat{\pi}^e_{t+k,t}$, $\beta^x \hat{x}^e_{t+j,t}$) by their effective ex–post values to estimate (2). This procedure generates residuals that are a linear combination of forecast errors and, therefore, orthogonal to variables in the information set in period t. Then, given an appropriate set of instruments, (2) is estimated by GMM.

Estimations are carried out using Chilean monthly data from January 1991 to March 2007. We consider a real interest rate as the monetary policy instrument instead of a nominal one, as during a large part of the sample monetary authorities targeted an inflation-indexed interest rate. From January 1991 to mid-1995 we use the PRBC90, an inflation-indexed promissory note issued by the CB; from May 1995 to August 2001, the official CBC's inflation-indexed monetary policy rate; and from then onwards we use the official CBC's nominal monetary policy rate less the one-year-ahead expected inflation from Consensus Forecasts.[7] The natural rate of interest is obtained from a multivariate filter model that includes a Phillips curve and an IS curve (as in Fuentes and Gredig, 2007). Monthly inflation targets are obtained by linearly interpolating official (midpoint) annual targets from reports to the Senate, and for actual inflation levels we use the annualized month-to-month variation of the CPIX1 price index.[8] The output gap is obtained from a multivariate filter model that includes a Phillips curve and The Okun's Law (as in Fuentes et al., 2007). GDP data is proxied by the IMACEC, a monthly indicator of economic activity that includes the principal activities conforming about 90% of the GDP. All estimations are carried out by the feasible two-step GMM estimator, with standard errors robust to heteroskedastic and autocorrelation. The set of instruments includes six lags of the interest rate gap, inflation deviations, output gap, real exchange rate gap, and oil price gap. We consider one period ahead for inflation expectations ($k = 1$) and the actual output gap ($j = 0$) as relevant variables in the monetary policy reaction.[9]

Table 1 shows estimations for the CBC's monetary policy response assuming symmetric behavior. In the first equation, the interest rate gap is linked to the lagged interest rate gap, the

[6] The natural interest rate should not vary so much from one period to the next, especially when considering high frequency data.

[7] Since after 2001 inflation expectations are well anchored and the inflation target is fixed, it is easier to change the actual nominal monetary policy rate to a real one than to do the opposite before 2001.

[8] CPIX1 inflation excludes oil, perishable goods, and some regulated utilities.

[9] Since during the most sample IMACEC data arrives with two-months lag, estimations consider two lags on gap estimates as actual values. Furthermore, this assumption improves estimations considerably.

inflation deviation and the output gap. The estimation yields a response to inflation deviations larger than one (1.07), meaning that the monetary policy has contributed to stabilizing inflation. The response to the output gap (0.49) has the expected positive sign and similar magnitude to the one proposed by Taylor (1993). The interest–rate–smoothing parameter (0.87) has also a large significance, indicating the CBC's preference for avoiding excessive fluctuations in interest rates. Since during the disinflation phase (1991-1999) the nominal exchange rate was managed inside a target band as a second anchor, the second equation adds the lagged real exchange rate gap ($c_t = r\hat{e}r_{t-1}$) as explanatory variable.[10] Although positive, estimations show no statistic significance in the CBC's response to real exchange rate deviations (β^{rer}).[11]

3 Asymmetric monetary policy reaction

Monetary authorities usually refer to monetary policy objectives in a symmetrical sense. The CBC, for example, explicitly announces a symmetric concern about inflation rate deviations from the target. An official CBC's document that describes the monetary policy in Chile says that "the CBC is more or less equally concerned about deviations in either direction. The Bank reacts equally swiftly and intensely to shocks pushing inflation under or over 3%."[12]

However, regarding the goals of monetary policy, it is natural to believe that conditionally to achieving the inflation target, monetary authorities are concerned more about the output gap if there is high unemployment. Alternatively, negative deviations are less hard to explain (politically) than positive deviations when the political power and the population are concerned more about unemployment than inflation. Then, monetary policy rules with asymmetrical responses to output gap and/or inflation deviations may arise in practice.

Theoretically, as we discussed above, the nonlinear structure of the economy or asymmetrical central bank's preferences produce asymmetries in the optimal monetary policy reaction. Regardless of that discussion, we postulate a monetary policy rule reacting in one way depending on whether a threshold variable is lesser than a specific value or in other way if it is greater. This kind of monetary policy reaction may be an optimal discretionary rule when the central bank has an asymmetric threshold loss function (as in Bec et al., 2002). The monetary policy rule we estimate is the following:

[10] The gap is estimated as the HP cyclical component of the real exchange rate. A positive deviation means an exchange rate depreciation from its trend.

[11] However, considering the 1991-1999 subperiod, a significant positive response to real exchange gap cannot be rejected if estimated.

[12] Central Bank of Chile (2007). "Central Bank of Chile: Monetary policy in an inflation targeting framework," page 17.

$$\hat{r}_t = \{\rho_1^r \hat{r}_{t-1} + (1-\rho_1^r)[(\beta_1^\pi - 1)\hat{\pi}^e_{t+k,t} + \beta_1^x \hat{x}^e_{t+j,t}]\} I_1(q_t \leq \tau) \quad (3)$$
$$+\{\rho_2^r \hat{r}_{t-1} + (1-\rho_2^r)[(\beta_2^\pi - 1)\hat{\pi}^e_{t+k,t} + \beta_2^x \hat{x}^e_{t+j,t}]\} I_2(q_t > \tau) + \varepsilon_t,$$

where $I_{1,2}(\cdot)$ are indicator functions that take a value equal to one if the condition in parentheses is true and zero otherwise. q_t is the threshold variable and τ the threshold value that can be known or estimated. We consider three observed threshold variables (q_t) related with actual economic development: the (third) lag of output gap ($q_t = \hat{x}$), the (first) lag of the 3-month-average inflation deviation ($q_t = \hat{\pi}$), and the 6-month-average GDP growth ($q_t = \hat{y}$). We postulate two possible regimes for central bank behavior depending on whether q_t is below (first regime) or above (second regime) the threshold value. Then, if we suppose $\tau = 0$ and the output gap as the threshold variable, the central bank may modify the magnitude (and the velocity) of its reaction to the output gap and/or inflation deviations during recessions, with respect to what it does in expansions. Alternatively, with the inflation deviation as the threshold variable, the central bank may react differently to output gap and inflation deviations if high-or low–inflation episodes occur. Empirically, we could find $\beta_1^x \neq \beta_2^x$, $\beta_1^\pi \neq \beta_2^\pi$, and $\rho_1^r \neq \rho_2^r$ in both cases.

3.1 Known threshold value

When τ is known, (3) can be estimated easily by splitting the sample according to the indicator function, which involves two possible regimes for central bank behavior. A natural value for both the output and the inflation deviation thresholds is zero ($\tau_x = 0$, $\tau_\pi = 0$), whereas for growth we use the sample mean, equal to 5.5% ($\tau_y = 5.5$). Since explanatory variables can be correlated with the error term (ε_t), we proceed as in the estimation of (1). Also, as estimations of (1) do not show a significant central bank response to the real exchange rate gap, we focus on lagged interest rate gap, output gap and inflation deviations as determinants of the monetary policy response. The results of these estimations are in Table 2.

The estimations show that the CBC responds asymmetrically to both the output gap and inflation deviations depending on the state of the business cycle –the output gap, inflation deviations or economic growth. Note that the three columns show a rejection at 5% significance –in the worst case– of the hipothesis of model linearity, i.e., that the coefficients of the first regime are jointly equal to the coefficients of the second regime.

When the output gap is considered as the threshold variable (first column), estimations show that the CBC responds more strongly to inflation deviations when the output gap is positive

(1.17 versus 0.88) but weaker to the output gap (0.40 versus 0.82). Tests of parameter equality support this finding at 5% significance in both cases. This means that the CBC worries more about the output gap in a recession period and cares more about inflation deviations during expansions; indeed, the Taylor principle prevails only under this second regime.[13] Also, note that under the second regime (recession) the bank reacts faster moving the interest rate, as the differences in the interest rate smoothing parameters between periods show (0.92 versus 0.84, significant at 1% level).

If inflation deviation is the relevant threshold variable (second column), estimations reveal a higher CBC's response to inflation deviations when actual inflation is above the inflation target midpoint (1.1 versus 0.88) but a lower response to output gap (0.54 versus 0.86). However, we do not reject tests of parameter equality for this case. Note that when the actual inflation deviation is positive, the interest-rate-smoothing parameter is lower than the one estimated under the first regime, when the actual deviations are negative (0.77 versus 0.97, difference significant at 1% level). This shows that although long-run responses to output gap and inflation deviations are similar, the CBC reacts by quickly adjusting the interest rate when the actual inflation rate evolves above its target but slowly in the contrary case.

If the GDP growth rate is considered as the threshold value (third column), the CBC reacts more strongly for both the output gap and inflation deviations when growth is above 5.5% than when it is below this rate. However, as the test of parameter equality reveals, only the difference in the response to inflation deviations shows statistic significance (1.56 versus 1.00). Contrary to the previous cases, the bank reacts slower when the economy grows faster (0.83 versus 0.97, difference significant at 1% level).

Summing up, estimations with a known threshold value support an asymmetric behavior of the CBC, depending on actual economic conditions like the output gap level, the inflation deviation from its target, and economic growth. However, the CBC's response to both the output gap and inflation deviations are different statistically only in the case when the output gap is considered as the threshold variable, being stronger under recession with respect to the output gap, and stronger in expansions with respect to inflation deviations. Also, estimations show that even though long-run responses to output gap and inflation deviations may be similar, the CBC modifies how fast the interest rate reacts —changing the interest-rate-smoothing parameter— depending on the actual regime or state of the economy.

[13] Davig and Leeper (2006) show that a switching monetary policy rule can satisfy the Taylor principle in the long-run even if that policy deviates largely from it for brief periods or shortly for prolonged periods; then, this result does not produce multiple rational expectations equilibria necessarily.

3.2 Unknown threshold value

Although we have taken plausible values for τ regarding each threshold variable, we really do not know at which value authorities shift their policy response. Following Caner and Hansen (2004) we obtain an estimate of the threshold value (τ^*) by finding the value of τ that minimizes the sum of squared residuals of (3). The method is based on a two-stage least squares procedure that allows for endogenous explanatory variables and an exogenous threshold variable. Once we obtain τ^*, parameters can be estimated by GMM splitting the sample into two regimes using the indicator functions $I_1(q_t \leq \tau^*)$, $I_2(q_t > \tau^*)$. To test model linearity (H_0: $\theta_1 = \theta_2$ vs. H_0: $\theta_1 \neq \theta_2$)[14], Hansen and Caner (2004) propose using the SupW statistic. Since under the null hypothesis the threshold parameter is not identified, this statistic has a non-conventional distribution that can be replicated by bootstrap. The SupW statistic is obtained by finding the threshold value (τ) that maximizes the Wald statistic for H_0 :

$$W_n(\tau) = (\hat{\theta}_1(\tau) - \hat{\theta}_2(\tau))'(\hat{V}_1(\tau) + \hat{V}_2(\tau))^{-1}(\hat{\theta}_1(\tau) - \hat{\theta}_2(\tau)), \tag{4}$$

where $\hat{V}_1(\tau)$ and $\hat{V}_2(\tau)$ are the variance covariance matrices of $\hat{\theta}_1(\tau)$ and $\hat{\theta}_2(\tau)$, respectively. The SupW statistic is contrasted with the resulting statistics from artificial data (SupW*) to obtain the p-value of the test:

$$\frac{1}{B} I_{pv}(SupW^* > SupW), \tag{5}$$

where B is the number of bootstrap replications and I_{pv} is an indicator function that takes a value of one if the condition prevails and zero otherwise.[15]

As in the case with known threshold values, estimations show an asymmetric behavior of the CBC depending on the actual state of the economy. For each threshold variable considered, SupW tests reject the linear model at least at the 10% significance level (see Table 3). The estimated threshold values are 1.1%, 0.36%, and 4.6% for the output gap, the inflation deviation, and the GDP growth rate, respectively. Note that the confidence intervals contain the imposed threshold levels in the known case, excepting when the GDP growth is considered as threshold variable. In general, estimations are very similar to the ones obtained assuming known values for threshold variables, excepting that now the response to the inflation deviation does not differ statistically depending on whether the actual rate of GDP growth is above or below the

[14] where $\theta_1 = [\beta_1^\pi \ \beta_1^x \ \rho_1^r]'$, $\theta_2 = [\beta_2^\pi \ \beta_2^x \ \rho_2^r]'$. The null hypothesis corresponds to the joint test of equality of parameters between both regimes.

[15] See Caner and Hansen (2004) for details about asymptotic distribution of the test and the bootstrap procedure.

estimated threshold value.

Summarizing, estimations with unknown threshold values show, as in the case of known ones, empirical support to an asymmetric behavior of the CBC. The estimation of threshold values reveals that the CBC is more concerned about inflation deviations and less to the output gap when the actual gap is greater that 1.1%. Furthermore, under those circumstances the central bank reacts faster in comparison with recession periods. When the inflation deviation and economic growth are considered as threshold values, the asymmetric behavior of the CBC is given fundamentally by differences in the interest-rate-smoothing parameter.

3.3 Robustness of results: real-time estimation

In practice, central banks take decisions based on the information available at that moment. Although ex-post estimation of central bank's monetary policy reactions is standard in the literature and suitable for DSGE analysis, it may yield a misleading picture regarding central bank intentions.[16] In this section we explore whether previous results are robust when estimations are carried out with real-time data.

In line with CBC's monetary police in practice, the monetary policy reaction includes the expected twelve-month inflation (one year ahead) instead of annualized month-to-month inflation.[17] We focus on the output gap and the inflation deviation responses, and the interest-rate-smoothing parameter, ignoring other possible determinants of the policy rule.

Estimations are carried out using monthly data for Chile from July 1993 to March 2007.[18] Real-time estimates for both output gap and neutral interest rate are the real-time counterparts of the ex-post estimates used in the standard estimation. Expected inflation is taken from Consensus Forecasts (as a proxy of CBC's own forecasts). The rest of the variables are the same used in the ex-post estimation. Since endogeneity problems may arise, parameters of the monetary policy reaction are estimated by GMM using the same set of instruments as in the ex-post estimation.[19]

Table 4 presents the real-time estimation of the CBC's monetary policy reaction with known threshold values. Conclusions are basically the same as those obtained in the ex-post estimation. The asymmetric behavior cannot be rejected for any considered threshold variable. When

[16] Orphanides (2001) discusses in detail about the drawbacks when estimating taylor rules with ex-post data. Gerdesmeier and Roffia (2004) present empirical evidence for the Euro Area.

[17] It would be desirable to use an expected inflation 12-24 month ahead, since that was the explicit CBC's monetary policy horizon during the baseline sample of this study. Unfortunately, only since 2000 we could construct a proxy for that information based on the Survey of Economic Expectations carried out by the CBC.

[18] Availability of inflation forecast data restricts the sample to this period. This means about thirty observations less in comparison with ex-post estimations.

[19] Endogeneity may arise since actual monetary policy shocks modify expectations immediately.

the output gap is considered as the threshold variable, the CBC's response to inflation deviations is larger when the output gap is positive, while the response to output gap is weaker. However, only for this second case is that difference statistically significant. With the inflation deviation as the threshold variable, both responses to output gap and inflation deviations do not show statistical differences if inflation deviations are positive or negative. This also happens when GDP growth is the threshold variable. Note that the Taylor principle prevails across all estimations and regimes considered. Since in practice the CBs target directly inflation forecast, this result is not uncommon in the literature.[20]

Estimations with unknown threshold values and real–time data confirm, in general, previous results. Note that confidence intervals for threshold values are similar to the estimated with ex–post data. However the SupW test cannot reject the linear model when the output gap is considered as the threshold variable (Table 5).

4 Monetary policy reaction and inflation bias

Asymmetric monetary rules may produce an inflation bias, as Cukierman (2000) shows when central banks are concerned more about negative output gaps and there is uncertainty about the economic development in the future, for example. Since our estimations show that we cannot reject an asymmetric monetary rule for the CBC, this might have an effect on the achievement of the inflation target in the long–run. To evaluate the possible effects on inflation behavior, we simulate artificial inflation series from a standard NKM framework that includes switching parameters in the monetary policy reaction according to two regimes ($s = 1, 2$):

$$x_t = E_t x_{t+1} - \sigma^{-1}(\hat{\imath}_t - E_t \hat{\pi}_{t+1}) + u_t^x$$

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa x_t + u_t^{\pi}$$

$$\hat{\imath}_t = \rho_s \hat{\imath}_{t-1} + (1 - \rho_s)[\beta_s^{\pi} E_t \hat{\pi}_{t+1} + \beta_s^x x_t] + u_t^i,$$

where the first equation corresponds to the New Keynesian IS curve, the second equation to the New Keynesian Phillips curve, and the third equation is the CB's monetary policy reaction. Each equation has an error term that follows an AR(1) process. The monetary policy rule has switching parameters that change depending on the value of the threshold variable: $\gamma_s = \gamma_1 I_1(q_t \leq \tau) + \gamma_2 I_2(q_t > \tau)$, where $I_{1,2}(\cdot)$ are indicator functions that take a value of one if

[20] See Sterken (2006) or Gerdesmeier and Roffia (2004).

the condition in parentheses is true and zero otherwise. This model has a discrete nonlinearity; then, numerical methods are applied to solve it. We follow closely Davig and Leeper (2006b), who discretize the state space and solve the model using a monotone map algorithm. Exogenous shocks are discretized using a gaussian quadrature, as in Tauchen and Hussey (1991).[21]

For simplicity, simulations are carried out supposing only one shock different from zero (u_t^π) and $E_t\hat{\pi}_{t+1} = \hat{\pi}_t$. Those assumptions reduce considerably computer time consumption and do not modify conclusions. The set of parameters used in the Phillips and the IS curves are $\beta = 0.99$, $\kappa = 0.1$, $\sigma = 1$, $\rho_u = 0.9$, $\sigma_{u^\pi} = \sigma_{u^x} = 0.0050$.

Figure 1 depicts the optimal response of inflation to a supply shock (u_t^π) when the central bank reaction to inflation deviations is larger (smaller) if the output gap is above (below) zero ($\beta_2^\pi > \beta_1^\pi$).[22] As expected, the larger the shock, the larger the response —in the same direction— of the inflation rate, being this response even larger when the economic performance is poor ($x_{t-1} \leq 0$). Note that in both cases the optimal response of inflation is above the optimal response under the linear case (with β^π equal to $0.5\beta_1^\pi + 0.5\beta_2^\pi$). This kind of reaction induces a positive inflation bias in the long run.

Figure 2 depicts the optimal response of inflation to a supply shock when the central bank reaction to the output gap is larger (smaller) if the output gap is below (above) zero ($\beta_1^x > \beta_2^x$).[23] As in the previous case, the response of the inflation rate to a supply shock —in the same direction— is larger when the output gap is negative in period $t-1$. The rise in the interest rate to deal with the supply shock produces a negative reaction in the output gap, which leads to authorities to offset in part the strengthen of the monetary policy. When the output gap is less than zero, the offset is larger in comparison with the reaction under a period of expansion. Then, when $\beta_1^x > \beta_2^x$ the central bank reacts weaker to confront a positive supply shock if the economy is under a poor economic performance. This central bank behavior also induces a positive inflation bias in the long run.[24]

Figure 3 shows the inflation response to a supply shock when the smoothness parameter is larger (smaller) if the output gap is below (above) zero ($\rho_1 > \rho_2$). This means that the central bank reacts faster moving the monetary policy rate when the economy is in an expansion period than in a recession one. This kind of monetary policy reaction, other things equal, produces a negative inflation bias in comparison with the linear response. Since the monetary autority reacts slowly when inflation pressures are low (the first regime), the inflation level is lower in average.

[21] See the Appendix for details.

[22] For the Taylor rule it was assumed $\beta_1^\pi = 1$; $\beta_2^\pi = 3$; $\beta^x = 0.6$; and $\rho = 0$.

[23] For the Taylor rule it was assumed $\beta^\pi = 2$; $\beta_1^x = 0.9$; $\beta_2^x = 0.3$; and $\rho = 0$.

[24] We obtained the same conclusions doing similar exercises but in response to a demand shock (u_t^x).

Suppose that the CBC's monetary policy rule is as Equation 1 in Table 2.[25] Note that this Taylor rule involves a joint asymmetric behavior of the three situations that we described above independently. For such a monetary policy rule the inflation response to a supply shock is asymmetric and negative biased (Figure 4). This means that the negative bias originated by different regimes in the smoothness parameter dominates the positive bias originated by different regimes in both the output gap and the inflation–deviation response parameters. Also, we use the NKM with this switching monetary rule to simulate a long serie for inflation deviations. The results show that the artificial serie presents some asymmetry and more probability to be below zero, as its PDF shows (Figure 5).[26] This is interesting since the mean average of the actual inflation deviation during the sample period is less than zero, so the estimated CBC's monetary policy rule may explain in part the observed evolution of inflation under the inflation-targeting period.[27]

5 Conclusions

Estimating a threshold model for the CBC's policy rule, we have found empirical support to an asymmetric behavior of the CBC depending on actual economic conditions like the output gap level, the inflation deviation from the inflation, and economic growth. However, the CBC's response to both the output gap and inflation deviations are different statistically only in the case when the output gap is considered as the threshold variable, being stronger under recessions with respect to the output gap, and stronger in expansions with respect to inflation deviations. Finding this kind of CB behavior may have important effects on the achievement of the inflation target, as our simulations show. In particular, we find that the asymmetry in the CBC's policy rule may explain part of the observed negative bias in the achievement of the inflation target during the inflation-targeting period.

Many questions emerge from the paper. A monetary policy reaction like the Taylor rule can ommit crucial infomation that policymakers take into account in their decisions. Then asymmetries in our estimated monetary policy rule can capture the effect of ommited variables, specially if they produce nonlinear effects in the economy. Also, the paper does not explain

[25] We start considering an ex–post rule for this exercise. Inflation bias in the sense of Cukierman (2000) and others is related to an asymmetric response to output gap deviations, then we consider first the case with output gap as threshold variable and 0% as threshold level (we cannot reject this value). Simulations with other specifications will be considered in a future version of the paper.

[26] We simulate a long inflation serie with the model (150,000 observations). The probability to report a negative deviation was 53% and both the mean and the median are less than zero.

[27] If we consider twelve–month price variation, the mean average of inflation deviations is -0.1, whereas if we consider the annualized monthly core inflation (as we use in estimations) the corresponding mean average is equal to -0.8.

what drives the asymmetric behavior of the monetary policy rule. We have implicitly assumed that the central bank has asymmetric preferences regarding output gap and inflation deviations, but we could have asymmetric responses due to nonlinearities in the economic structure, like the Phillips curve, for example. These and other issues can be part of a future reseach agenda.

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Appendix

A Solution of the standard NKM under an asymmetric monetary policy rule

The standard New–Keynesian model is conformed by three equations: an IS curve, a forward–looking Phillips curve, and a monetary policy rule:

$$
\begin{aligned}
x_t &= E_t x_{t+1} - \sigma^{-1}(\hat{\imath}_t - E_t \hat{\pi}_{t+1}) + u_t^x \\
\hat{\pi}_t &= \beta E_t \hat{\pi}_{t+1} + \kappa x_t + u_t^\pi \\
\hat{\imath}_t &= \rho_s \hat{\imath}_{t-1} + (1-\rho_s)[\beta_s^\pi E_t \hat{\pi}_{t+1} + \beta_s^x x_t] + u_t^i
\end{aligned}
$$

Each equation has an error term that follows an AR(1) process. The monetary policy reaction has switching parameters that change depending on the value of the threshold variable. $\gamma_s = \gamma_1 I_1(q_t \leq \tau) + \gamma_2 I_2(q_t > \tau)$, where $I_{1,2}(\cdot)$ are indicator functions that take a value of one if the condition in parentheses prevails and zero otherwise.

Our aim is to find a policy function that yields an optimal response of control variables given a set of values for state variables. The switching monetary policy reaction introduces a discrete nonlinearity to the system; then, standard methods to solve rational expectations models cannot be used in this case. In order to solve the model, we discretize the state space and use a monotone map algorithm, as in Davig and Leeper (2006b). The algorithm is as follows:

First, given a set of values for state variables $(u_t^\pi, u_t^x, u_t^i, \hat{\imath}_{t-1}, q_t)$, we can define the actual regime for monetary policy (we observe q_t). Suppose now that we have an initial policy function for each control variable: $\hat{\imath}_t = pf^i(u_t^\pi, u_t^x, u_t^i, \hat{\imath}_{t-1}, q_t)$, $x_t = pf^x(u_t^\pi, u_t^x, u_t^i, \hat{\imath}_{t-1}, q_t)$, and $\hat{\pi}_t = pf^i(u_t^\pi, u_t^x, u_t^i, \hat{\imath}_{t-1}, q_t)$.[28] Replacing initial policy functions in the one–period–ahead expected control variables we have:

$$
\begin{aligned}
x_t &= E_t[pf^x(u_{t+1}^\pi, \hat{\imath}_t, x_t)] - \sigma^{-1}(\hat{\imath}_t - E_t[pf^\pi(u_{t+1}^\pi, \hat{\imath}_t, x_t)]) \\
\hat{\pi}_t &= \beta E_t[pf^\pi(u_{t+1}^\pi, \hat{\imath}_t, x_t)] + \kappa x_t + u_t^\pi \\
\hat{\imath}_t &= \rho_s \hat{\imath}_{t-1} + (1-\rho_s)\{\beta_s^\pi E_t[pf^\pi(u_{t+1}^\pi, \hat{\imath}_t, x_t)] + \beta_s^x x_t\},
\end{aligned}
$$

[28] The solution for the model with one regime could be a good choice.

where, to simplify the discussion, we ommit the monetary shock and the demand shock. Also, we have supposed that the threshold variable is the lagged output gap.

Second, we must aproximate the expectation expressions. Note that we have to make inferences only about u^{π}_{t+1}, since we know $\hat{\imath}_t$ and x_t in period t. Using the gaussian quadrature (Tauchen and Hussey, 1991), the exogenous autoregresive shock (u^{π}_{t+1}) is approximated by a markov chain. Then, expectations on inflation and output gap are as follows:

$$
\begin{aligned}
E_t\hat{\pi}_{t+1} &\approx \sum_{j=1}^{qp} pf^{\pi}[u^{\pi}(S_{t+1}=j), \hat{\imath}_t, x_t] * P(S_{t+1}=j/S_t=k) \\
E_t x_{t+1} &\approx \sum_{j=1}^{qp} pf^{x}[u^{\pi}(S_{t+1}=j), \hat{\imath}_t, x_t] * P(S_{t+1}=j/S_t=k)
\end{aligned}
$$

where we assume qp possible states for u^{π} ($S_t = j$, with $j = 1, ..., qp$) and $P(S_{t+1} = j/S_t = k)$ is associated to a transition matrix P which (k,j) element represents the probability of $S_{t+1} = j$ given that $S_t = k$. Since we observe u^{π}_t, we know the state S in period t. Then, replacing the expected values for the inflation deviation and the output gap in period *t+1*, we have a linear system with three equations for three unknowns (controls).

Third, we solve the system for the whole set of state variables. This process generates new policy functions for control variables that replace the initial ones. We iterate until new policy functions do not differ from the previous ones.

B Data

- Real interest rate gap ($\hat{r}$): Absolute deviation of real monetary policy rate (r) from real neutral interest rate ($\bar{r}$). r and $\bar{r}$ are constructed as described in the main text. Source: Central Bank of Chile and Fuentes and Gredig (2007).

- Inflation deviation from target ($\hat{\pi}$): Absolute deviation of the annualized month–to–month inflation rate (using CPIX1 as price index) from the official inflation target. Source: Central Bank of Chile.

- Output gap ($\hat{x}$): % deviation of GDP from its long–run tendency. Monthly GDP is proxied by IMACEC serie and GDP trend is obtained as in Fuentes et al. (2007). Source: Central bank of Chile and Fuentes et al. (2007).

- Real exchange rate gap ($r\hat{e}r$): % deviation of the real exchange rate from its HP trend.

Source: Central Bank of Chile and own estimates.

- Oil price gap ($\hat{oil}$): % deviation of the WTI oil price from its HP trend. Source: Bloomberg.
- Inflation forecast ($\hat{\pi}^e$): One–year–ahead expected inflation according to a linear interpolation between actual and next year's december forecasts. Source: Consensus forecast.

C Tables

Eq.	β^{π}	β^{x}	β^{rer}	ρ^{r}	R^2	J	P value	No. Obs
(1)	1.072***	0.485***		0.869***	0.83	21.6	0.71	195
	(0.076)	(0.101)		(0.023)				
(2)	1.062***	0.497***	0.021	0.870***	0.83	21.6	0.66	195
	(0.076)	(0.103)	(0.032)	(0.024)				

Two-step GMM estimations. Standard errors robust to serial correlation (up to 6 lags) in parentheses. Newey-West covariance matrix. J denotes the Hansen's overidentifying test. *** (**, *) denotes 1% (5%, 10%) significance.
Source: Author's estimations.

Table 1: Standard monetary policy reaction

Eq.	$I_1(\hat{x} \leq 0); I_2(\hat{x} > 0)$	$I_1(\hat{\pi} \leq 0); I_2(\hat{\pi} > 0)$	$I_1(\hat{y} \leq 5.5); I_1(\hat{y} > 5.5)$
β_1^π	0.883***	0.882***	1.003***
	(0.122)	(0.203)	(0.041)
β_1^x	0.818***	0.859**	0.533***
	(0.184)	(0.428)	(0.089)
ρ_1^r	0.919***	0.971***	0.826***
	(0.017)	(0.014)	(0.021)
β_2^π	1.170***	1.097***	1.563***
	(0.046)	(0.019)	(0.255)
β_2^x	0.399***	0.541***	1.438**
	(0.044)	(0.053)	(0.612)
ρ_2^r	0.840***	0.765***	0.965***
	(0.028)	(0.019)	(0.013)
Linearity test	10.19**	100.5***	40.01***
$H_0 : \beta_1^\pi = \beta_2^\pi$	4.87**	1.11	4.68**
$H_0 : \beta_1^x = \beta_2^x$	4.89**	0.55	2.14
$H_0 : \rho_1^r = \rho_2^r$	5.87**	76.83**	30.32***
$J_{1;2}$ (p-value)	0.91; 0.91	0.83; 0.95	0.96; 0.96
No. obs.$_{1;2}$	102; 93	134; 61	100; 95

Two-step GMM estimations. Standard errors robust to serial correlation (up to 6 lags) in parentheses. Newey-West covariance matrix. J denotes the Hansen's overidentifying test. *** (**, *) denotes 1% (5%, 10%) significance. $_{1,2}$ denotes the first and second regime, respectively. Source: Author's estimations.

Table 2: Asymmetric monetary policy reaction with known threshold value

Eq.	$I_1(\hat{x} \leq \tau_x^*)$; $I_2(\hat{x} > \tau_x^*)$	$I_1(\hat{\pi} \leq \tau_\pi^*)$; $I_2(\hat{\pi} > \tau_\pi^*)$	$I_1(\hat{y} \leq \tau_y^*)$; $I_1(\hat{y} > \tau_y^*)$
β_1^π	0.910***	0.920***	1.005***
	(0.095)	(0.219)	(0.039)
β_1^x	0.750***	0.862*	0.369***
	(0.170)	(0.450)	(0.052)
ρ_1^r	0.923***	0.971***	0.734***
	(0.015)	(0.014)	(0.032)
β_2^π	1.214***	1.068***	1.163**
	(0.027)	(0.013)	(0.527)
β_2^x	0.409***	0.591***	0.847
	(0.021)	(0.057)	(2.59)
ρ_2^r	0.821***	0.760***	0.985***
	(0.025)	(0.021)	(0.043)
τ^*	1.1%	0.36%	4.6%
	[-1.43%, 1.15%]	[-1.93%, 0.43%]	[4.49%, 5.24%]
SupW (statistic)	41.67*	67.37***	85.57***
SupW (p-value)	0.100	0.010	0.003
$H_0 : \beta_1^\pi = \beta_2^\pi$	9.46***	0.46	0.09
$H_0 : \beta_1^x = \beta_2^x$	3.95**	0.36	0.03
$H_0 : \rho_1^r = \rho_2^r$	12.47***	69.31***	22.08***
$J_{1;2}$ (p-value)	0.79; 0.99	0.86; 0.98	0.24; 0.74
No. obs.$_{1;2}$	144; 51	142; 53	79; 116

Two-step GMM estimations. Standard errors robust to serial correlation (up to 6 lags) in parentheses. Newey-West covariance matrix. J denotes the Hansen's overidentifying test. *** (**, *) denotes 1% (5%, 10%) significance. $_{1,2}$ denotes the first and second regime, respectively. Confidence intervals for thresholds at 10% level. Source: Author's estimations.

Table 3: Asymmetric monetary policy reaction with unknown threshold value

Eq.	$I_1(\hat{x} \leq 0)$; $I_2(\hat{x} > 0)$	$I_1(\hat{\pi} \leq 0)$; $I_2(\hat{\pi} > 0)$	$I_1(\hat{y} \leq 5.5)$; $I_1(\hat{y} > 5.5)$
β_1^π	1.435***	1.285*	2.625***
	(0.204)	(0.788)	(0.386)
β_1^x	0.977***	0.892***	0.906***
	(0.121)	(0.259)	(0.062)
ρ_1^r	0.877***	0.965***	0.846***
	(0.020)	(0.013)	(0.015)
β_2^π	1.853***	1.450***	1.752*
	(0.204)	(0.120)	(1.020)
β_2^x	0.391***	0.959***	0.965
	(0.105)	(0.077)	(1.562)
ρ_2^r	0.902***	0.838***	0.965***
	(0.010)	(0.011)	(0.035)
Linearity test	32.7***	93.06***	20.60***
$H_0 : \beta_1^\pi = \beta_2^\pi$	2.09	0.04	0.64
$H_0 : \beta_1^x = \beta_2^x$	13.53***	0.06	0.00
$H_0 : \rho_1^r = \rho_2^r$	1.29	57.14***	10.02***
$J_{1;2}$ (p-value)	0.93; 0.98	0.87; 0.98	0.92;
No. obs.$_{1;2}$	117; 49	117; 49	94; 72

Two-step GMM estimations. Standard errors robust to serial correlation (up to 6 lags) in parentheses. Newey-West covariance matrix. J denotes the Hansen's overidentifying test. *** (**, *) denotes 1% (5%, 10%) significance. $_{1,2}$ denotes the first and second regime, respectively. Source: Author's estimations.

Table 4: Asymmetric monetary policy reaction with known threshold value: real-time estimation

Eq.	$I_1(\hat{x} \leq \tau_x^*)$; $I_2(\hat{x} > \tau_x^*)$	$I_1(\hat{\pi} \leq \tau_\pi^*)$; $I_2(\hat{\pi} > \tau_\pi^*)$	$I_1(\hat{y} \leq \tau_y^*)$; $I_1(\hat{y} > \tau_y^*)$
β_1^π	1.807***	1.442	2.034***
	(0.324)	(0.932)	(0.242)
β_1^x	0.927***	1.038***	0.820***
	(0.103)	(0.369)	(0.050)
ρ_1^r	0.872	0.970***	0.798**
	(0.019)	(0.131)	(0.020)
β_2^π	2.40***	1.362***	1.490
	(0.234)	(0.055)	(1.545)
β_2^x	0.208***	0.975***	0.204
	(0.024)	(0.065)	(1.094)
ρ_2^r	0.864***	0.835***	0.976***
	(0.010)	(0.011)	(0.053)
τ^*	0.9%	0.2%	5.2%
	[-1.42%, %0.95]	[-1.62%, 0.21%]	[4.48%, 5.24%]
SupW (statistic)	25.45	110.8***	97.05***
SupW (p-value)	0.275	0.004	0.008
$H_0 : \beta_1^\pi = \beta_2^\pi$	2.25	0.01	0.121
$H_0 : \beta_1^x = \beta_2^x$	46.50***	0.03	0.316
$H_0 : \rho_1^r = \rho_2^r$	0.21	61.30***	9.87***
$J_{1;2}$ (p-value)	0.89; 0.98	0.91; 0.99	0.95; 0.65
No. obs.$_{1;2}$	142; 24	122; 44	88; 78

Two-step GMM estimations. Standard errors robust to serial correlation (up to 6 lags) in parentheses. Newey-West covariance matrix. J denotes the Hansen's overidentifying test. *** (**, *) denotes 1% (5%, 10%) significance. $_{1,2}$ denotes the first and second regime, respectively. Source: Author's estimations.

Table 5: Asymmetric monetary policy reaction with unknown threshold value: real-time estimation

D Figures

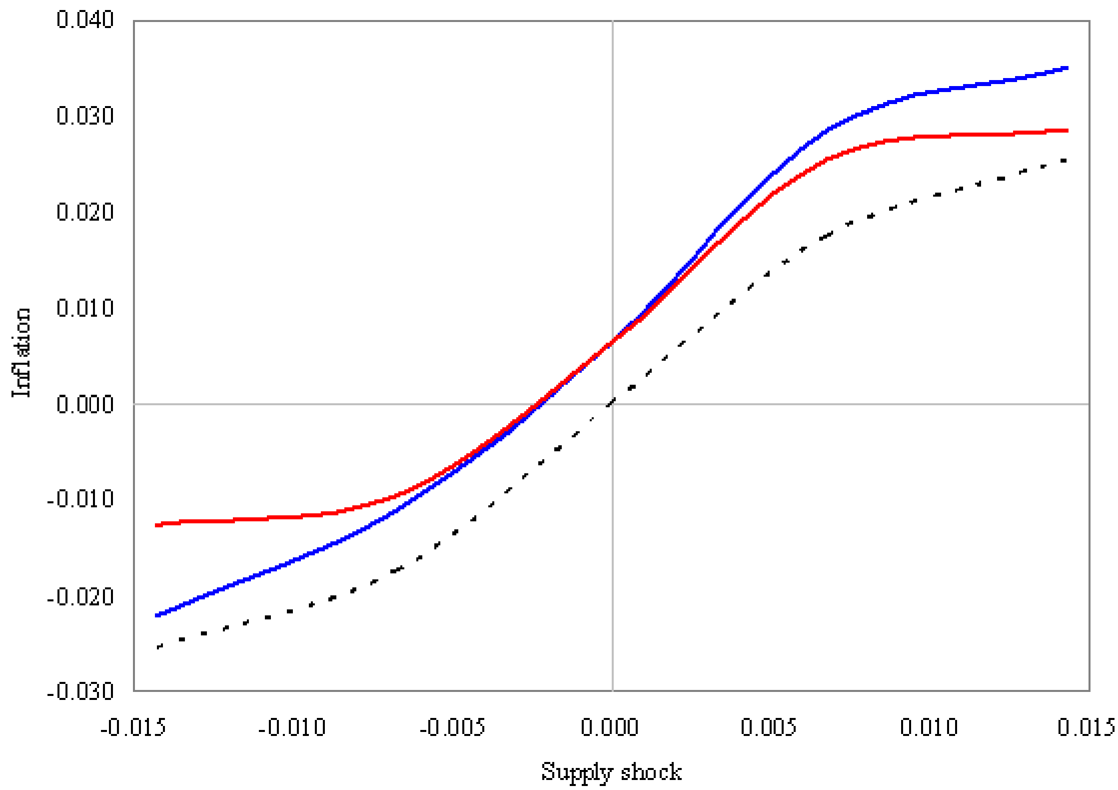

Figure 1: Optimal inflation response to a supply shock when $\beta_1^\pi < \beta_2^\pi$. Blue line: first regime ($x_{t-1} \leq 0$); red line: second regime ($x_{t-1} > 0$).

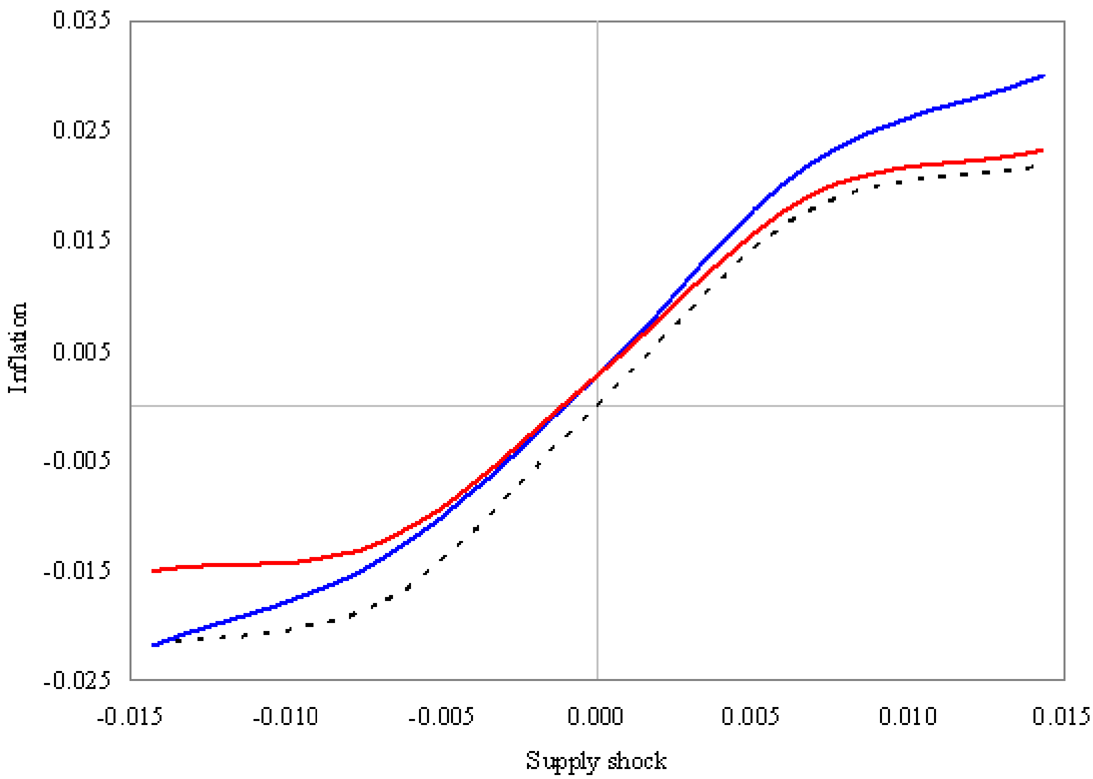

Figure 2: Optimal inflation response to a supply shock when $\beta_1^x > \beta_2^x$. Blue line: first regime ($x_{t-1} \leq 0$); red line: second regime ($x_{t-1} > 0$).

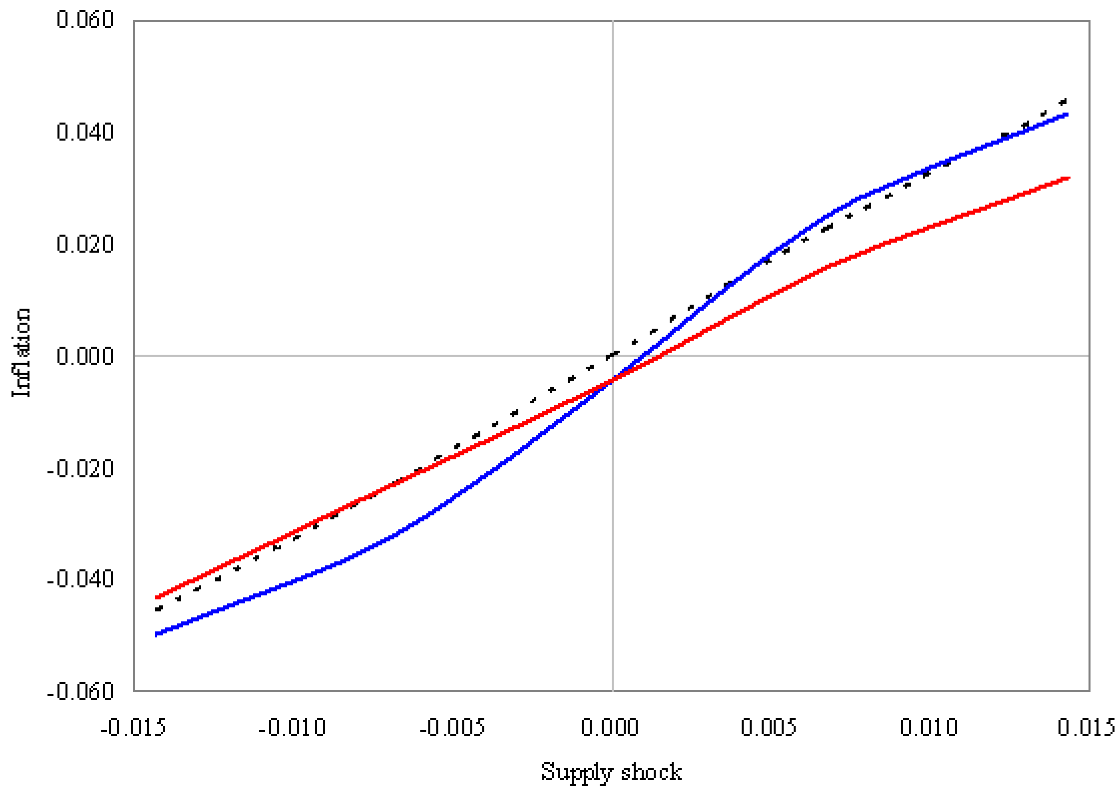

Figure 3: Optimal inflation response to a supply shock when $\rho_1 > \rho_2$. Blue line: first regime($x_{t-1} \leq 0$); red line: second regime ($x_{t-1} > 0$).

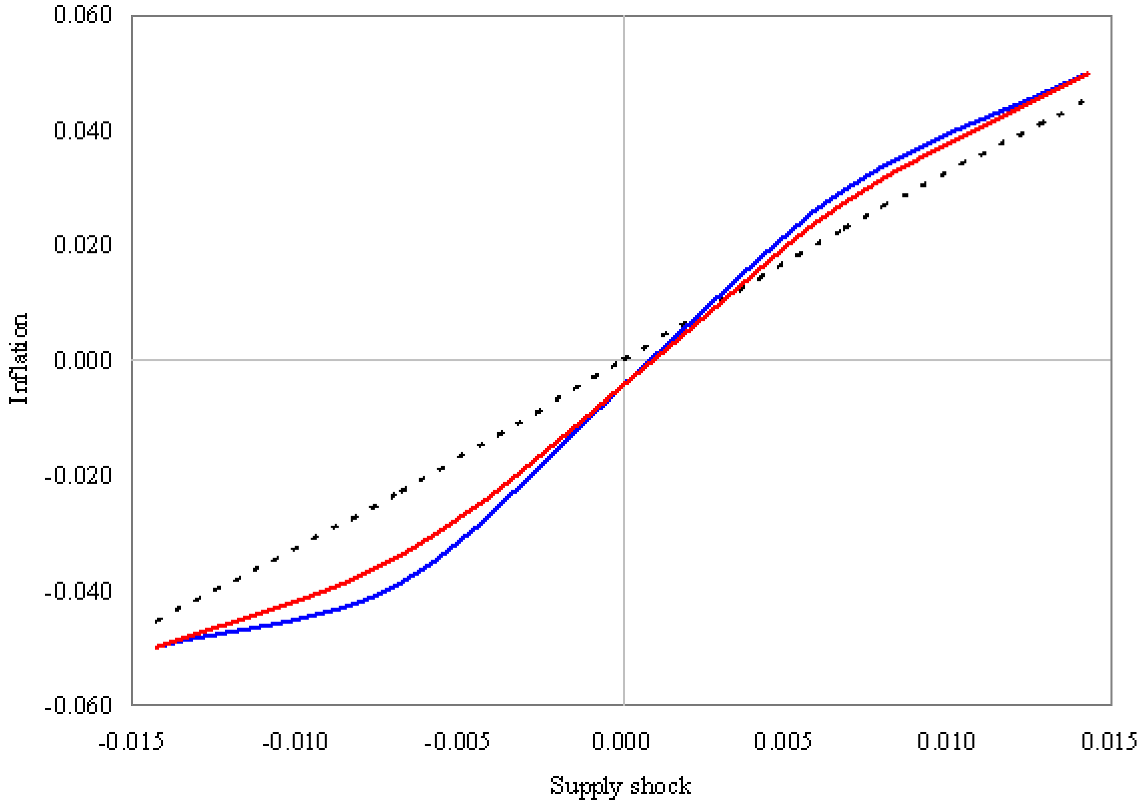

Figure 4: Optimal inflation response to a supply shock when the monetary policy rule is as Equation 1 from Table 2. Blue line: first regime ($x_{t-1} \leq 0$); red line: second regime ($x_{t-1} > 0$).

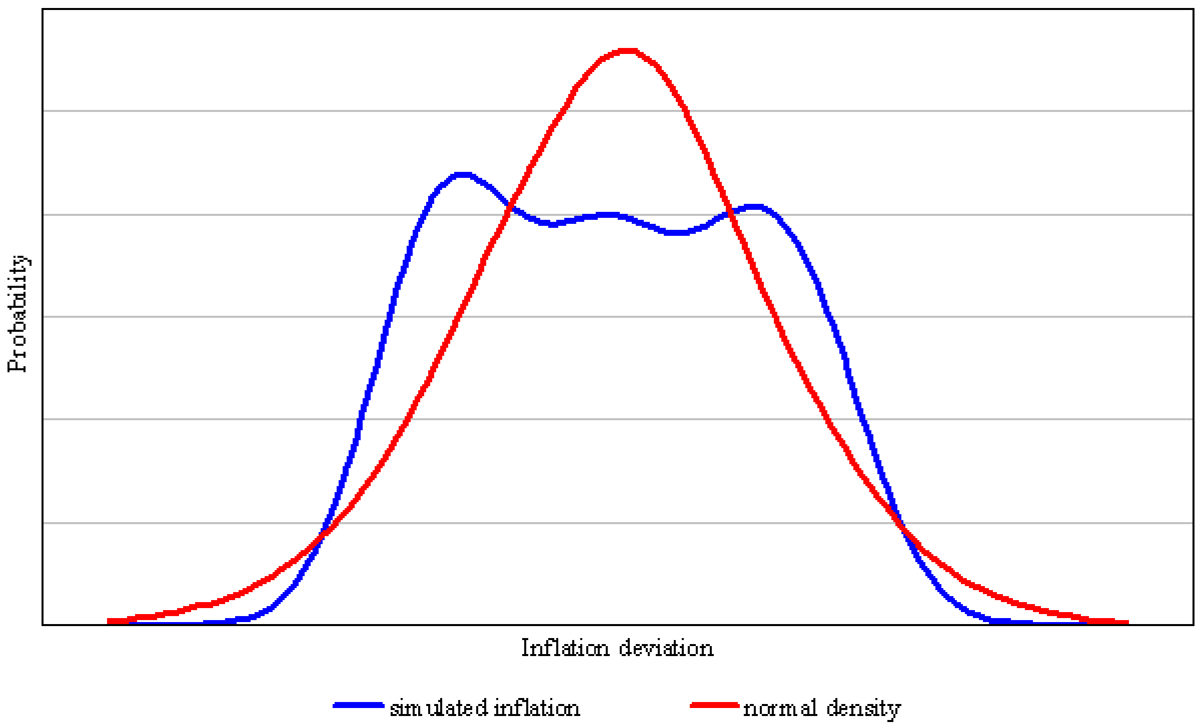

Figure 5: Simulated inflation from the standard NKM with a monetary rule as in Equation 1 Table 2.

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