This paper estimates a threshold monetary policy rule model for the USA, UK and Japan to investigate if monetary policy changes depend on business cycle conditions, i.e. recessions and expansions of the economy. Then, the paper evaluates the policy implications of this monetary policy rule. Using a long span of data, the paper provides clear-cut evidence that, while during expansions the monetary authorities of the above countries follow the Taylor rule, during recessions they tend to abandon this policy rule and follow a passive monetary policy focused on interest rate smoothing over time. As shown in the paper, this passive monetary policy can not dampen the volatility effects of negative demand or supply macroeconomic shocks on the economy.

1 Introduction

There is recently a growing research interest in investigating if monetary policy switches according to changes in business cycle conditions, namely the expansion and recession regimes of the economy (see, e.g. Rabanal (2004), Sims and Zha (2006), Davig and Leeper (2007), Davig and Doh (2009), inter alia). Answering the above question is of particular interest to both academics and market practitioners as it can reveal if, despite their official announcements and significant degree of independence over the post-Bretton Woods period (see, e.g. Assenmacher-Wesche (2006)), central banks (CBs) of developed countries follow a more discretionary policy under recessions or extreme economic events. This research is mainly focused on the US economy and the evidence provided is mixed. For instance, Rabanal (2004) finds that monetary policy authorities are concerned about real output stabilization during recessions. On the other hand, Davig and Doh (2009) more recently show that the response of monetary authorities to real output deviations is very weak during recessions.

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† The authors would like to thank the editor of this journal and two anonymous referees for very useful comments. We would like to also thank Harris Dellas, Simon Price and Vanghelis Vassilatos as well as the conference participants at the MMF10 conference held in Cyprus in year 2010 for useful comments on an earlier version of this paper. Any errors are ours.
To shed more light on the above question and examine evidence from other developed economies, in this paper we estimate a threshold monetary policy rule model for USA, UK and Japan, and evaluate the policy implications of this model based on a small-scale new Keynesian (NK) macroeconomic model. The above economies have been subjected to a large number of recessions over the last four decades. The threshold monetary policy rule model suggested in this paper constitutes a natural choice in investigating whether monetary policy changes with business cycle conditions. This happens because the model assumes that regime-switching in its policy parameters is endogenously triggered by real output gap deviations, which are bigger (or smaller) in magnitude than a critical value of this variable, which constitutes the threshold parameter of the model. These real output gap deviations are often used in practice to measure changes in business conditions (see, e.g. Stock and Watson (2003)). The theoretical underpinning of the above threshold switching monetary policy rule models can be found in Cukierman and Gerlach (2003), who consider a loss function of the CB switching between two economic regimes depending on whether real output gap deviations are bigger (or smaller) than zero.\(^1\) This function is considered to reflect changes in political pressures linked to costs of recessions (or higher unemployment), which tend to affect policy makers (see Blinder (1997)).\(^2\)

The results of the paper clearly indicate that, for all countries examined, the responses of monetary authorities to inflation rate and real output gap deviations vary considerably over the business cycle. During expansions, the CBs of the three countries are mainly concerned with inflation stabilization, and thus respond positively to both of the above sources of deviations. In contrast, during recessions the results of the paper provide clear-cut evidence that the CBs of all three countries examined abandon the Taylor rule (see Taylor (1993)) and instead follow a passive policy focused on smoothing short-term interest rates over time rather than on stabilizing real output. This passive stance of monetary authorities seems to happen not only during short-lived recessions due to financial crises (see, e.g. Davig and Leeper (2007)), but also during ordinary recessions lasting longer. Our threshold monetary policy rule model is found to capture the realized recessionary periods very efficiently. The above results are based on a value of the threshold parameter of our model above (or below) the level at which regime-switching occurs. This value is considered as unknown and, thus, is estimated by our data.

To study the policy implications of the above empirical findings, the paper carries out a simulation exercise based on a small-scale NK using our


\(^2\)Note that Dolado et al. (2005) attribute this behaviour of the CB monetary policy rule to the nonlinear structure of the economy and, in particular, to the convexity of the relationship between inflation and unemployment.
threshold monetary policy rule model to describe the behaviour of the monetary authorities. The results of this exercise clearly indicate that a passive monetary policy during recessions leads to substantial and prolonged variations in inflation rate as well as real output gap deviations from their target levels. The biggest of them are due to supply shocks. The expectation formation effects of a switch from the recession to expansion regime are not found to be enough to mitigate the above deviations. The paper shows that these deviations could be substantially dampened if monetary authorities responded more aggressively to inflation rate or output gap deviations from their target levels, as is predicted by the Taylor’s principle.

The paper is organized as follows. Section 2 presents our threshold monetary policy rule model and discusses its key features. Section 3 describes the data and estimates the model. Section 4 conducts the simulation exercise of the NK model based on the estimates of our threshold monetary policy rule parameters provided in Section 3. Section 5 concludes the paper.

2 A THRESHOLD MONETARY POLICY RULE MODEL

Assume that $i_t$ denotes the short-term (one-period) nominal interest rate, which is used as a monetary policy instrument by the CB at time $t$, $\pi_t$ is the inflation rate while $\pi^*$ is its target level, and $\tilde{y}_t$ is a measure of the real output gap, at time $t$. The latter is defined as the percentage change of real gross domestic product (GDP) relative to its potential level. Then, consider the following threshold monetary policy rule model of the CB, which allows for interest rate smoothing:

$$i_t = \begin{cases} 
(1-\rho)[a + \beta_1(\pi_{t-1} - \pi^*) + \gamma_1\tilde{y}_{t-1}] + \rho i_{t-1} + \varepsilon_{1,t}, & \text{if } \tilde{y}_{t-1} \leq \bar{q} \\
(1-\rho)[a + \beta_2(\pi_{t-1} - \pi^*) + \gamma_2\tilde{y}_{t-1}] + \rho i_{t-1} + \varepsilon_{2,t}, & \text{if } \tilde{y}_{t-1} > \bar{q} 
\end{cases}$$

where $\tilde{y}_{t-1}$ plays the role of the threshold variable of the model, $\bar{q}$ denotes the threshold parameter of the model, which is assumed to be unknown and $\varepsilon_{i,t}$, for $i = \{1,2\}$, are IID (independently and identically distributed) disturbance terms, with zero mean and variance $\sigma_i^2$. These error terms reflect monetary policy shocks. The attitude of the CB to smooth out interest rate $i_t$ over time is captured in the above model by the autoregressive coefficient $\rho$, which is assumed that takes a value in interval $[0,1)$.

Threshold model (1) implies that the monetary policy rule parameters, denoted by $\beta$ (betas) and $\gamma$ (gammas), where $i = \{1,2\}$, change abruptly

\[i_t = (1-\rho)i_{t-1}^* + \rho i_{t-1} + \varepsilon_{i,t}\]

This attitude can be attributed to various reasons, such as the fear of disrupting capital markets and financial instability in general (see, e.g., Martin and Milas (2004) and Driffl et al. (2006)). Moreover, the CB may regard interest rate smoothing as a learning device due to imperfect information.
between two regimes of the economy, denoted as ‘1’ and ‘2’. These regimes are identified by the following conditions: \( \tilde{y}_{t-1} \leq \bar{q} \) and \( \tilde{y}_{t-1} > \bar{q} \), respectively, and they reflect recessionary and expansionary conditions in the economy. As noted in the introduction, the use of real output gap variable, \( \tilde{y}_{t-1} \), in identifying the above two regimes is quite frequent in the literature. More specifically, model (1) implies that the CB sets up its target short-term interest rate, denoted as \( i^{*}_{t} \), according to the following backward-looking rule:

\[
i^{*}_{t} = a^{*} + \beta_{i}(\pi_{t-1} - \pi^{*}) + \gamma_{i}\tilde{y}_{t-1}, \quad \text{for } i = \{1, 2\}
\]

where \( a^{*} \) is the desired nominal interest rate when inflation rate and real output gap are set to their target long-run levels. This interest rate is defined as \( a^{*} = r^{*} + \pi^{*} \), where \( r^{*} \) denotes the long-run equilibrium real interest rate. Finally, note that model (1) can be reduced to the following standard (linear) Taylor rule:

\[
i_{t} = (1 - \rho)[a^{*} + \beta_{i}(\pi_{t-1} - \pi^{*}) + \gamma_{i}\tilde{y}_{t-1}] + \rho i_{t-1} + \epsilon_{t}
\]

or

\[
i_{t} = (1 - \rho)[a + \beta\pi_{t-1} + \gamma\tilde{y}_{t-1}] + \rho i_{t-1} + \epsilon_{t}
\]

where \( a = a^{*} - \beta\pi^{*} = r^{*} + (1 - \beta)\pi^{*} \), when policy rule parameters \( \beta \) and \( \gamma \) are considered constant across the two regimes. That is, the following joint hypothesis holds: \( \beta_{1} = \beta_{2} = \beta \) and \( \gamma_{1} = \gamma_{2} = \gamma \).

Threshold model (1) belongs to the wide class of regime-switching monetary policy rule models. Within this class, it shares some features with the Markov chain regime-switching (MRS) monetary policy rule models suggested in the literature by Dueker and Fischer (1996), Valente (2003), Assenmacher-Wesche (2006), Sims and Zha (2006), Davig and Leeper (2007), inter alia. Compared with the MRS models, model (1) has an attractive property. It directly links a regime shift in the monetary policy rule parameters to observable economic variables such as real output gap, which, as mentioned before, are often used by policy makers in predicting recessionary

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4 An alternative variable that is used for this purpose is unemployment rate. Ruge-Murcia (2004) have used this as a target variable of the monetary policy rule, instead of real output gap. However, the use of this variable in our analysis does not change its qualitative results. See an earlier version of this paper.

5 Note that, according to relationship (2), the CB sets up its target rate \( i^{*}_{t} \) in a backward-looking way. This can be justified on many fronts. First, backward-looking monetary policy rule models can be thought of as a reduced form of forward-looking models. These models do not suffer from estimation bias problems because of the endogenous nature of their explanatory variables, as it may happen with forward-looking monetary policy rule models. Second, as recently pointed out by Sims and Zha (2006), the choice of a backward-looking monetary policy rule can be also justified on many grounds on the basis of recent USA experience supporting that monetary authorities tend to react to past paths of inflation or other monetary aggregates, and not to forward expected ones. Furthermore, as also argued by Sims and Zha (2006), forward-looking monetary policy rule models are based on implausible identification assumptions, which may produce misleading results.
or expansionary conditions of the economy. The MRS monetary policy model links these policy parameter shifts to changes in business conditions indirectly through a state (unobserved) variable filtered from sample data. However, this variable may not only reflect changes in business cycle conditions. It may also capture some other economic events occurred during a sample period.

In contrast to smooth transition nonlinear regression models, used in investigating possible asymmetries in the CB’s preferences about inflation rate or real output gap deviations under specific monetary policy regimes characterizing certain economic periods, threshold model (1) is suitable for capturing abrupt and aggressive shifts in interest rate \( i_t \) policies occurring over long-term periods, such as those reflecting different business conditions. Evidence of such type of shifts in interest rate \( i_t \) is provided in many recent studies by splitting the sample to different subsamples, or by using dummy variables at prespecified dates. This approach, however, is not attractive for a number of reasons. First, it assumes that regime-switching happens at some known dates and, thus, it does not allow us to infer from the data when it exactly happens. Second, it assumes that a specific regime lasts forever. The last assumption does not consider the endogenous expectation formation effects of regime-switching in the conduct of monetary policy. As aptly noted in a number of recent papers (see, e.g. Davig and Leeper (2007) and Liu et al. (2009)), these effects can improve the efficiency of monetary policy and mitigate the effects of shocks on the economy.

3 Estimation of the Model

In this section, we estimate the threshold monetary policy rule model given by equation (1) based on data from the following three leading economies: USA, UK and Japan. The CBs of these three countries have obtained a significant degree of independence over the post-Bretton Woods era and have officially announced their will to fight against inflation since the end of the 1970s, after almost a decade of very high and volatile inflation rates (see, e.g. Tachibana (2004)). In particular, the Fed changed the course of its policy in October 1979, when its new chairman, Volker, signalled his intention to fight inflation. In June 1979, Margaret Thatcher came to power in the UK and inflation fighting became the main issue of the Bank of England. Finally, in Japan, price stabilization became the main policy objective after the first oil-price crisis in 1973 (see, e.g. Cargill et al. (1997)).
3.1 Data

Our dataset consists of quarterly, time series observations from 1960:I to 2010:II for USA, 1978:I to 2010:II for UK and 1971:I to 2010:II for Japan. These periods cover a long span of data and, thus, they capture a substantial number of changes in business conditions occurring in our sample, for all three countries. All economic series involved in our analysis are plotted in Fig. 1(a–c). These figures also include the dates of business cycle troughs (see vertical bars) of our sample, which are officially announced by their government institutions. As short-term nominal interest rates, in our analysis we consider the average Fed Funds rate for USA, the base rate of the Bank of England for UK and the ‘Call-Money’ rate for Japan. All these rates are calculated in the first month of each quarter. Inflation rates are calculated

![Fig. 1. Recession Periods](image-url)
based on the consumer price indices for all countries. Both inflation and interest rates are given at annual basis and as percentages. The real output gap is measured as the percentage change of real GDP relative to its potential level, i.e.

$$\hat{y}_t = \frac{\text{real GDP}_t - \text{real potential GDP}_t}{\text{real potential GDP}_t} \times 100$$

For the USA, it is constructed by the Congressional Budget Office, while for the other two countries it is provided by OECD. All the above data series for USA were downloaded from the Federal Reserve Bank of St. Louis, while for UK and Japan were taken from the OECD database.

Table 1 presents descriptive statistics, namely the mean and standard deviation, of all economic variables involved in threshold model (1) as well as for the real interest rates series, denoted as $r_t$. The latter is calculated as $r_t = \bar{\pi}_t - \bar{\pi}$, where $\bar{\pi}_t$ and $\bar{\pi}$ denote the four-quarter moving averages of current and past interest and inflation rates, respectively (see, e.g. Kim et al. (2005)). The results of Table 1 indicate that the average level of real output gap is negative and has substantial volatility (standard deviation), for all three countries. As was expected by the theory, the results of the table show that the countries that have higher in magnitude average levels of nominal (or real) interest rates have also higher average levels of inflation rates. Among the three countries considered, the UK has the highest average level of nominal interest rates and inflation rates followed by the USA and Japan.

### 3.2 Estimation Results

#### 3.2.1 Estimates of the Standard Taylor Rule

Before estimating our threshold switching monetary policy rule model given by equation (1), in this subsection we present estimates of the standard (linear) Taylor rule given by equation (2). A comparison between these two models’ estimates can reveal

---

**Table 1**

**Descriptive Statistics**

<table>
<thead>
<tr>
<th>Variables</th>
<th>USA</th>
<th>Std. Dev.</th>
<th>UK</th>
<th>Std. Dev.</th>
<th>Japan</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal interest rate</td>
<td>5.82</td>
<td>3.47</td>
<td>8.06</td>
<td>3.92</td>
<td>3.93</td>
<td>3.55</td>
</tr>
<tr>
<td>Real interest rate</td>
<td>1.75</td>
<td>2.08</td>
<td>3.70</td>
<td>2.38</td>
<td>0.95</td>
<td>2.83</td>
</tr>
<tr>
<td>Inflation</td>
<td>4.09</td>
<td>2.91</td>
<td>4.49</td>
<td>4.01</td>
<td>2.98</td>
<td>4.74</td>
</tr>
<tr>
<td>Output gap</td>
<td>-0.51</td>
<td>2.57</td>
<td>-0.25</td>
<td>2.49</td>
<td>-0.29</td>
<td>2.22</td>
</tr>
</tbody>
</table>

*Note: Std. Dev. stands for standard deviation.*
whether threshold model (1) constitutes a better specification of the data. Furthermore, it can indicate if wrong inference about the stance of monetary policy implied by linear model (2) can be attributed to ignoring regime-switching.

Estimates of model (2) are reported in Table 2. In particular, the table presents least squares estimates of the following parameters of this model: its intercept $a$, defined as $a = a^* - \beta \pi^*$, its policy rule parameters $\beta$ and $\gamma$, and autoregressive coefficient $\rho$. From these estimates of $\alpha$ and those of the long-run nominal interest rate $\pi^*$, reported in Table 1, we can retrieve sample estimates of the target levels of inflation rate $\pi^*$. These are used in the estimation of our threshold model (1) as values of inflation target $\pi^*$ (see, e.g. Siklos and Wohar (2005) or Clarida et al. (2000)). They are found to be as follows: 3.82 per cent for the USA, 4.58 per cent for the UK and 3.38 per cent for Japan. Note that these estimates of $\pi^*$ are very close to the sample estimates of the average inflation rates reported in Table 1.

In addition to the above, Table 2 reports values of a number of diagnostic statistics and information criteria, which can indicate if model (2) constitutes a satisfactory specification of our data compared with model (1). More specifically, they include Granger and Teräsvirta (1993) $F$-statistic (denoted $F_{GT}$) testing for nonlinearity in the residuals of linear model (2), Bai and Perron (2003) sequential statistic (denoted BP) testing for multiple structural breaks in parameters of model (2) and, finally, some metrics evaluating

<table>
<thead>
<tr>
<th></th>
<th>USA</th>
<th>UK</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>2.32**</td>
<td>3.91***</td>
<td>1.83***</td>
</tr>
<tr>
<td></td>
<td>(1.09)</td>
<td>(1.41)</td>
<td>(0.71)</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.85***</td>
<td>0.90***</td>
<td>0.91***</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.04)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.92***</td>
<td>0.91***</td>
<td>0.62***</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.22)</td>
<td>(0.18)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.76**</td>
<td>1.63***</td>
<td>1.05**</td>
</tr>
<tr>
<td></td>
<td>(0.35)</td>
<td>(0.56)</td>
<td>(0.49)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.88</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>$F_{GT}$</td>
<td>3.43</td>
<td>3.50</td>
<td>7.34</td>
</tr>
<tr>
<td>[p-value]</td>
<td>[0.02]</td>
<td>[0.02]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>BP (UD$_{max}$)</td>
<td>40.70***</td>
<td>31.47***</td>
<td>52.10***</td>
</tr>
<tr>
<td>SIC</td>
<td>3.27</td>
<td>2.63</td>
<td>2.07</td>
</tr>
<tr>
<td>MSE</td>
<td>1.39</td>
<td>0.70</td>
<td>0.41</td>
</tr>
<tr>
<td>Theil</td>
<td>0.17</td>
<td>0.09</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Notes: Standard errors are in parentheses. $a = a^* - \beta \pi^* = r^* + (1 - \beta) \pi^*$, $F_{GT}$ is Granger and Teräsvirta (1993) statistic testing for nonlinearity in the residuals of model (2). This is $F$-distributed with degrees of freedom given as (3, 194) for the USA, (3, 122) for the UK and (3, 150) for Japan. BP (UD$_{max}$) is Bai and Perron (2003) statistic testing against an unknown number of breaks. MSE stands for mean squared error and Theil for Theil’s inequality coefficient.

***, **, *Denote 1 per cent, 5 per cent, 10 per cent significance, respectively.
the goodness of fit of the model. The latter include Schwartz’s information criterion (denoted SIC), the mean squared error (MSE) and Theil’s inequality coefficient. Note that evidence of structural breaks in the structural parameters of linear model (2) can be taken as indication that threshold model (1) constitutes a better specification of the data, especially if these breaks are associated with changes in the business cycle conditions.

The results of Table 2 clearly indicate that the linear monetary policy rule model given by equation (2) does not constitute the correct specification of the data. The values of the nonlinearity and BP test statistics reported in the table clearly indicate that this model suffers from apparent nonlinearities, which can be attributed to shifts (structural breaks) in its parameters occurring in our sample. The structural breaks identified by the BP test are found to occur at the following dates: 1970:3 (68:2, 70:4), 1980:3 (80:2, 81:1) and 1989:2 (89:1, 91:3) for the USA, 1987:1 (86:4, 92:3) for the UK, and 1979:1 (77:3, 79:2), 1984:4 (84:3, 89:1) and 1991:2 (91:1, 92:1) for Japan, where confidence intervals of the dates of breaks are reported in parentheses. As can be confirmed from Fig. 1(a–c), these dates correspond to some of the most important business cycle troughs of the three countries examined.

Regarding the parameter estimates of linear model (2), the results of Table 2 reveal the following. First, the estimates of autoregressive coefficient \( \rho \) are very close to unity, which indicates a strong attitude of the CBs of all three countries to smooth changes in their policy interest rate \( i_t \), over time. Second, the estimates of policy rule parameter \( \beta \), reflecting the sensitivity of the CB to inflation rate deviations, is not found to be bigger than unity. This is in contrast to the strong anti-inflationary announcements made by the CBs of all three countries, especially after the eighties.\(^9\) On the other hand, the estimates of policy rule parameter \( \gamma \) indicate a strong stabilizing behaviour of the CBs towards real output deviations. The above estimation results, especially those related to \( \beta \), are surprising. They can be obviously attributed to the fact that the linear monetary policy rule model (2) does not account for regime type of shifts in its structural parameters, as those predicted by threshold model (1) and diagnosed by the BP and the nonlinearity test statistics reported in Table 2. Ignoring these shifts can obviously bias downwards the least squares estimates of beta and gamma coefficients.

3.2.2 Estimates of Threshold Model (1). The parameter estimates of our threshold monetary policy rule model (1), collected in vector \( \Theta = (\alpha, \rho, \beta_1, \gamma_1, \beta_2, \gamma_2, \sigma_1^2, \sigma_2^2) \), together with sample estimates of its threshold parameter \( q \) are reported in Table 3, for all three countries. In Fig. 1(a–c), we graphically present the sample values of threshold variable \( \tilde{y}_t \) for all

\(^9\)This is also in contrast to clear-cut evidence provided in the literature by many studies (see, e.g. Cukierman and Muscatelli (2008), Castelnuovo and Surico (2010), Tachibana (2004)) supporting that, during certain economic periods, e.g. Volker’s period for USA, 1992:4–2005:4 for UK, post 1980 for Japan, the attitude of the CBs was strongly anti-inflationary.
three countries against the sample estimate of $q$, given by solid horizontal lines. As mentioned before, these figures also present the dates of the business cycle troughs officially announced by government institutions of the three countries.

To estimate threshold parameter $\bar{q}$ and vector of parameters $\Theta$, we are based on Hansen’s (1997, 2000) maximum likelihood (ML) approach. This method enables us to consistently estimate $\bar{q}$ from our data based on a search method. In particular, it provides ML estimates of vector $\Theta$, which are conditional on the value of $\bar{q}$, which corresponds to the supremum of the ML values of model (1) across different values of threshold variable $\tilde{y}_t$ ordered from its 15th up to 85th percentile of its sample distribution. Together with the 95 per cent confidence intervals of $\bar{q}$, Table 3 also reports the percentiles of the sample distribution of $\tilde{y}_t$, which correspond to the sample estimate $\bar{q}$, found by the above searching method. These can indicate if regime-switching in monetary policy rule models’ parameters is mainly associated with extreme values of $\tilde{y}_t$, possibly reflecting extraordinary events in the economy as argued

![Table 3](image_url)

**Table 3**

Estimates of Threshold Model (1)

$$i_t = \begin{cases} (1-\rho)[a + \beta_1(\pi_{t-1} - \pi^*) + \gamma_1 \tilde{y}_{t-1}] + \rho \tilde{y}_{t-1} + \epsilon_{t-1}, & \text{if } \tilde{y}_{t-1} \leq \bar{q} \\ (1-\rho)[a + \beta_2(\pi_{t-1} - \pi^*) + \gamma_2 \tilde{y}_{t-1}] + \rho \tilde{y}_{t-1} + \epsilon_{2t}, & \text{if } \tilde{y}_{t-1} > \bar{q} \end{cases}$$

<table>
<thead>
<tr>
<th>Parameters</th>
<th>USA</th>
<th>UK</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>6.15***</td>
<td>6.81***</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>(0.35)</td>
<td>(0.81)</td>
<td>(1.70)</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.45</td>
<td>0.57*</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(0.33)</td>
<td>(0.32)</td>
<td>(0.27)</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>0.60*</td>
<td>0.70</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>(0.33)</td>
<td>(0.49)</td>
<td>(0.59)</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>1.35***</td>
<td>0.98***</td>
<td>1.17***</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.19)</td>
<td>(0.40)</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>0.52**</td>
<td>2.35***</td>
<td>2.71**</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.61)</td>
<td>(1.23)</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.81***</td>
<td>0.88***</td>
<td>0.94***</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>$\sigma_1^2$</td>
<td>3.12***</td>
<td>1.24***</td>
<td>0.14***</td>
</tr>
<tr>
<td></td>
<td>(0.55)</td>
<td>(0.28)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>$\sigma_2^2$</td>
<td>0.47***</td>
<td>0.41***</td>
<td>0.64***</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.06)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>$\bar{q}$</td>
<td>$-1.09$</td>
<td>$-1.12$</td>
<td>$-0.49$</td>
</tr>
<tr>
<td>95 per cent CI of $\bar{q}$</td>
<td>$[-2.82,2.18]$</td>
<td>$[-3.03,1.81]$</td>
<td>$[-2.32,2.03]$</td>
</tr>
<tr>
<td>LR test</td>
<td>92.15</td>
<td>25.55</td>
<td>50.52</td>
</tr>
<tr>
<td>[p-value LR]</td>
<td>[0.002]</td>
<td>[0.02]</td>
<td>[0.04]</td>
</tr>
<tr>
<td>p-value</td>
<td>0.90</td>
<td>2.60</td>
<td>1.81</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.48</td>
<td>0.34</td>
<td>0.50</td>
</tr>
<tr>
<td>SIC</td>
<td>2.87</td>
<td>2.51</td>
<td>1.81</td>
</tr>
<tr>
<td>MSE</td>
<td>1.34</td>
<td>0.67</td>
<td>0.386</td>
</tr>
<tr>
<td>Theil</td>
<td>0.17</td>
<td>0.091</td>
<td>0.118</td>
</tr>
</tbody>
</table>

**Note:** See Table 2.
by many authors in the literature (see, e.g. Greenspan (2005) and Friedman (2006)).

In addition to the above estimates of $\Theta$ and $\bar{q}$, the table also reports values of the diagnostic test statistics and information criteria reported in Table 2. Finally, the table reports values of likelihood ratio (LR) statistic testing the following null hypothesis:

$$H_0: \beta_1 = \beta_2 \text{ and } \gamma_1 = \gamma_2$$

against its alternative

$$H_a: \beta_1 \neq \beta_2 \text{ or } \gamma_1 \neq \gamma_2$$

Testing the above null hypothesis against its alternative is critical in inferring if policy rule parameters beta and gamma change across the two regimes of the economy, as is assumed by our threshold model (1). If the null hypothesis is rejected, this will constitute further evidence against the standard Taylor rule, given by the linear equation (2).

The results of Table 3 lead to a number of conclusions, which have important policy implications. First, they clearly indicate that threshold monetary policy rule model (1) constitutes a better specification of the data than the standard Taylor rule. This is true for all three countries considered. The superiority of model (1) is supported by all diagnostic statistics and information criteria reported in the table. The values of $F_{GT}$ statistic do not reveal any apparent nonlinearity of model (1), while those of SIC, MSE and Theil’s metrics indicate that this model fits better into the data than model (2). In addition to this, the reported values of the LR test statistic clearly reject the null hypothesis $H_0: \beta_1 = \beta_2$ and $\gamma_1 = \gamma_2$ against its alternative $H_a: \beta_1 \neq \beta_2$ or $\gamma_1 \neq \gamma_2$, which means that there is a regime type of shift in the monetary policy rule parameters beta and gamma, as is predicted by model (1).

The second conclusion that can be drawn from the results of Table 3 is that the estimates of policy parameters beta and gamma differ substantially between the two business cycle regimes considered. These estimates reveal that, during expansions, the CBs of all three countries react very strongly to inflation rate or real output gap deviations from their target levels. This happens for values of real output gap $\bar{y}_t$ bigger than the following estimates:

10This statistic is defined as follows:

$$\text{LR} = -2(l_{\text{restricted}} - l_{\text{unrestricted}})$$

where $l_{\text{restricted}}$ and $l_{\text{unrestricted}}$ are respectively the ML values of model (1) under the null hypothesis (referred to as restricted) and the alternative hypothesis (referred to as unrestricted). As the threshold parameter $\bar{q}$ is not identified under the null hypothesis, the above statistic has a non-conventional distribution. This distribution is the supremum of a $\chi^2$ distribution (see Hansen (1996)). Thus, to obtain the significance level of this LR statistic we will rely on a simulation method, which replicates its sample distribution. This is done based on a nonparametric bootstrap simulation procedure relying on 1000 iterations (see Hansen (1996)). This procedure is also used to construct the 95 per cent confidence intervals of the sample estimate of the threshold parameter $\bar{q}$, reported in Table 3.
of threshold parameter $\bar{q}$: $-1.09$ for the USA, $-1.12$ for the UK and $-0.49$ for Japan. Note that these values of $\bar{q}$ are well below the value of zero assumed in theoretical threshold monetary policy rule models or in applied work (see, e.g. Bec et al. (2002), Cukierman and Gerlach (2003) and Davig and Leeper (2008)). They correspond to the following percentiles of the sample distribution of $\bar{y}_t$: 0.33, 0.31 and 0.50.

The reported in Table 3 estimates of policy rule parameters $\beta$ and $\gamma_2$ in the expansion regime indicate that the Fed is more sensitive to positive deviations of inflation rate from its target level compared with those of real output gap. The opposite happens for the CBs of UK and Japan, where the estimates of $\gamma_2$ are found to be bigger in magnitude than those of $\beta$. In contrast to the expansion, in the recession regime the results of the table reveal that the reactions of the CBs of all three countries to inflation rate or real output deviations are not significant at 5 per cent level. These results support the view that the CBs of the above three countries abandon the Taylor rule when the economy is in recession, which means that they do not follow a countercyclical monetary policy. Instead, their policy becomes passive and is characterized by an attitude of smoothing interest rates. Note also that, for the USA and the UK, this regime is characterized by quite high levels of volatility.

The percentiles of $\bar{y}_t$ corresponding to the estimates of $\bar{q}$, reported in Table 3, reveal that the above passive attitude characterizing the CBs’ policy behaviour of all three countries examined does not only happen during short-lived recessions triggered by financial crises like those of the stock market crash of year 1987, the currency and stock market crises of years 1997–98 and 2003, respectively, as was believed in the literature (see, e.g. Davig and Leeper (2007, 2008)). But, it also occurs during recession periods lasting longer, including the recent one started in year 2008 by the collapse of Lehman brothers. As Fig. 1(a–c) indicate, our threshold model (1) can capture the above all recession periods very efficiently.

### 4 Monetary Policy Reaction under Different Business Conditions

The finding of the previous section that monetary policy becomes passive (inactive) in the recession regime raises a number of important questions about

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11 Similar evidence is provided by Cukierman and Muscatelli (2008). This can be attributed to the strong attitude of the UK and Japanese monetary authorities to dampen the effects of positive demand shocks on the economy and, hence, on inflation rate.

12 We found that these results are robust to the exclusion of the recent recession period 2008–2010 from our sample. For this period, we found that correlation between changes in the CB interest rate $i$, and real output gap deviations $\bar{y}$, either at their leads or lags was weak or negative for the USA. As Fig. 1(a–c) indicates, this may be attributed to the fact that, for period 2008–2010, cuts in interest rates did not follow closely all negative real output deviations. Note that, as Fig. 1(a–c) shows, interest rate $i$, becomes flat after its initial period substantial falls, for all three countries. The latter can be obviously attributed to the smoothing interest rate attitude of the CB.
the efficiency of monetary policy to dampen the effects of supply or demand shocks on the economy under this regime. To answer these questions, in this section we calculate impulse response functions (IRFs) of output, inflation and the short-term interest rates to exogenous demand or supply shocks based on a small-scale NK model assuming that the monetary policy rule is given by threshold model (1). The supply shock can be thought of as a cost-push structural shock, while the demand shock as one to the IS curve.

More specifically, the NK model that we consider in our analysis is given as follows:13,14

\[ \tilde{\pi}_t = bE_t(\tilde{\pi}_{t+1}) + \kappa \tilde{y}_t + z_{S,t} \] (3.a)

\[ \tilde{y}_t = E_t(\tilde{y}_{t+1}) - \frac{1}{\delta}[\tilde{y}_t - E_t(\tilde{\pi}_{t+1})] + z_{D,t} \] (3.b)

and

\[ \tilde{i}_t = (1-\rho)[(\beta_1 \tilde{\pi}_{t-1} + \gamma_1 \tilde{y}_{t-1})I(\tilde{y}_{t-1} \leq \bar{q}) + (\beta_2 \tilde{\pi}_{t-1} + \gamma_2 \tilde{y}_{t-1})I(\tilde{y}_{t-1} > \bar{q})] + \rho \tilde{i}_{t-1} \] (3.c)

where \( b \) is a discount factor, \( \delta \) is the relative risk aversion coefficient and \( \kappa = \delta \left[ \frac{(1-\omega \cdot b)(1-\omega)}{\omega} \right] \) is a function of how frequently price adjustments occur (see Calvo (1983)), where \( \omega \) captures the degree of price stickiness in the economy. In equations (3.a) and (3.b), the two variables \( Z_{S,t} \) and \( Z_{D,t} \) represent two exogenous and regime-independent aggregate supply and demand processes following the autoregressive models of lag order one:

\[ z_{S,t} = \rho_S z_{S,t-1} + \varepsilon_{S,t} \]

\[ z_{D,t} = \rho_D z_{D,t-1} + \varepsilon_{D,t} \]

where \( |\rho_S| < 1 \) and \( |\rho_D| < 1 \), while \( \varepsilon_{S,t} \) and \( \varepsilon_{D,t} \) constitute two IID zero-mean structural error terms, which have \( E(\varepsilon_{S,t} \varepsilon_{D,s}) = 0 \), for all \( t \) and \( s \). These two error terms represent the two exogenous supply and demand structural shocks, respectively.

In the NK model defined by equations (3.a)-(3.c), equation (3.a) describes the change in the aggregate price level (or inflation deviation \( \tilde{\pi}_t \)) from its target rate as a function of its expected future level and the current deviation of real output from its steady state. This relationship can be derived from the aggregation of optimal price-setting decisions by monopolistically competitive firms in an environment in which each firm adjusts its price with a constant probability at any period (see, e.g. Calvo (1983)). Equation (3.b) combines a standard Euler equation for consumption with a market clearing condition equating aggregate consumption and output.

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14This model is linearized around a steady state inflation rate and output of zero to keep the analysis simple.
This is the so-called IS equation, which determines the current level of aggregate output (or output deviation $\tilde{y}_t$), as a function of the \textit{ex-ante} real rate and expected future output. Finally, equation (3.c) constitutes the CB’s monetary policy rule, given by our threshold model (1) estimated in our previous section.

Model (3.a)–(3.c) can be written into the following structural equation form:

$$Bx_t = AE_t(x_{t+1}) + D(\tilde{y}_{t-1} \leq \tilde{q})x_{t-1} + z_t$$  \hspace{1cm} (4.a)

$$Bx_t = AE_t(x_{t+1}) + D(\tilde{y}_{t-1} > \tilde{q})x_{t-1} + z_t$$  \hspace{1cm} (4.b)

with

$$z_t = Rz_{t-1} + \varepsilon_t$$

where $x_t = [\tilde{\pi}_t, \tilde{y}_t, i_t]'$ is the vector of endogenous variables, $z_t = [Z_{S,t}, Z_{D,t}, 0]'$ is a vector that contains the two exogenous processes $Z_{S,t}$ and $Z_{D,t}$, $\varepsilon_t = [\varepsilon_{S,t}, \varepsilon_{D,t}, 0]'$ is a vector that contains the two structural shocks $\varepsilon_{S,t}$ and $\varepsilon_{D,t}$, and

$$B = \begin{bmatrix} 1 & -\kappa & 0 \\ 0 & 1 & \frac{1}{\delta} \\ 0 & 0 & 1 \end{bmatrix}, \quad A = \begin{bmatrix} b & 0 & 0 \\ 1 & 0 & \frac{1}{\delta} \\ 0 & 0 & 0 \end{bmatrix}, \quad D(\tilde{y}_{t-1} \leq \tilde{q}) = \begin{bmatrix} (1-\rho)\beta_1 & (1-\rho)\gamma_1 & \rho \\ 0 & 0 & 0 \end{bmatrix}$$

$$D(\tilde{y}_{t-1} > \tilde{q}) = \begin{bmatrix} 0 & 0 & 0 \\ (1-\rho)\beta_2 & (1-\rho)\gamma_2 & \rho \\ 0 & 0 & 0 \end{bmatrix} \quad \text{and} \quad R = \begin{bmatrix} \rho_S & 0 & 0 \\ 0 & \rho_D & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

The above model implies the following matrix of transition probabilities between the two monetary policy regimes from time $t-1$ to $t$:

$$P = \begin{bmatrix} p_{11} & p_{12} = 1-p_{11} \\ p_{21} = 1-p_{22} & p_{22} \end{bmatrix}$$

where

$$p_{11} = \Pr(\beta_t = \beta_1 \land \gamma_t = \gamma_1 | \beta_{t-1} = \beta_1 \land \gamma_{t-1} = \gamma_1)$$

and

$$p_{22} = \Pr(\beta_t = \beta_2 \land \gamma_t = \gamma_2 | \beta_{t-1} = \beta_2 \land \gamma_{t-1} = \gamma_2)$$

Solving out the system of equations (4.a) and (4.b) for vector $x_t$ gives the following Threshold Regime-Switching Rational Expectations (TRSRE) model:

$$x_t = B^{-1}AE_t(x_{t+1}) + B^{-1}D(\tilde{y}_{t-1} \leq \tilde{q})x_{t-1} + B^{-1}z_t$$  \hspace{1cm} (5.a)

and
The above model has an analogous representation to the MRS rational expectation model studied, among others, by Cho and Moreno (2011) and Cho (2009). Thus, its general rational expectation equilibrium (REE) solution can be written in the following minimum state variable form:

\[ x_t = \mathbf{B}^{-1} \mathbf{A} E_t(x_{t-1}) + \mathbf{B}^{-1} \mathbf{D} (\tilde{y}_{t-1} > \tilde{q}) x_{t-1} + \mathbf{B}^{-1} \mathbf{z}_t \] (5.b)

The REE solution implies that the vector of endogenous variables \( x_t \) depends on the monetary policy regime of the economy at time \( t \), as well as its lag values \( x_{t-1} \) and vector \( \mathbf{z}_t \).

The REE solution given by equations (6.a) and (6.b) can be used to obtain IRFs of the endogenous variables of the NK model, namely \( \pi_{tk}, \tilde{y}_{tk} \) and \( \hat{t}_{tk} \) at time \( t + k \), to structural shocks \( \varepsilon_{S,t} \) and \( \varepsilon_{D,t} \), for \( k = 1, 2, 3 \ldots \) quarters ahead. To this end, we need to calculate matrices \( \mathbf{\Omega}() \) and \( \mathbf{\Gamma}() \). This can be done numerically based on the forward algorithm suggested by Cho (2009). In so doing, we need to assign values of the vector of structural parameters of the NK model (3.a)–(3.b) entered in matrices \( \mathbf{B}, \mathbf{A}, \mathbf{D}(\cdot) \) and \( \mathbf{R} \), which determine matrices \( \mathbf{\Omega}() \) and \( \mathbf{\Gamma}() \). Actually, two sets of parameters are required. The first is invariant to the specific monetary policy regime and it involves the subjective discount factor \( b \), the relative risk aversion parameter \( \delta \), the degree of stickiness \( \omega \) and the autoregressive coefficients \( \rho_S \) and \( \rho_D \). Following Davig and Leeper (2007), Clarida et al. (2000), Liu et al. (2009), the above parameters are set equal to the following values: \( b = 0.99, \delta = 1.0, \omega = 0.67, \kappa = 0.17, \rho_S = 0.85 \) and \( \rho_D = 0.85 \). Note that the above all values of the autoregressive coefficients \( \rho_S \) and \( \rho_D \) guarantee that the forward convergence condition of the TRSRE model (5.a)–(5.b) holds for a broad set of values of the remaining parameter of the model.

The second set of parameter values required to determine the REE solution given by equations (6.a) and (6.b) is monetary policy regime dependent. These parameters are set equal to their sample estimates reported in Table 3. Finally, the transition probabilities \( p_{11} \) and \( p_{22} \) are calculated ex post based on the number of times that the monetary policy rule corresponds to regimes ‘1’ and ‘2’, respectively, over our whole sample. These are found to be \( (p_{11} = 0.83, p_{22} = 0.91) \) for the USA, \( (p_{11} = 0.92, p_{22} = 0.96) \) for the UK and \( (p_{11} = 0.87, p_{22} = 0.87) \) for Japan. These estimates of \( p_{11} \) and \( p_{22} \) imply that regime-switching is not so frequent, especially for the UK. Thus, the CBs of all three countries will tend to stay in one regime. This happens for long periods of time, as can be confirmed by Fig. 1(a–c).
4.1 Determinacy Regions of the REE Solution

The estimates of threshold model (1) provided in the previous section do not imply determinacy (uniqueness) of the REE solution of TRSRE model (5.a)–(5.c), given by equations (6.a) and (6.b), for all three countries. Note that this happens despite the fact that this solution is found to be mean square stable and forward convergent. Mean square stability means that the REE solution is bounded in a small neighbourhood with probability, which tends to one, while forward convergence implies that this solution rules out rational bubbles in equilibrium.

The lack of determinacy of the REE solution (6.a)–(6.b) can be attributed to the fact that threshold monetary policy rule model (1) is sufficiently passive in the recession regime, compared with the expansion (see, e.g. Davig and Leeper (2007)). It is also related to the small values of the transition probabilities between the two regimes, noted above. To see for which values of policy parameters beta and gamma determinacy of the above REE solution is achieved, in Fig. 2 we graphically present surfaces of the determinacy/indeterminacy regions of this solution with respect to values of policy parameters $\beta_i$ or $\gamma_i$, while holding fixed the values of remaining parameters of the NK model. The surfaces presented in this figure clearly indicate that determinacy of the REE solution (6.a)–(6.b) requires higher values of policy rule parameters $\beta_i$ and $\gamma_i$ in regime ‘1’, especially of $\beta_i$ capturing the responses of short-term interest rate $i_t$ to inflation rate deviations from its target level.

4.2 IRFs under Different Monetary Policy Rule Regimes

To study the effects of supply or demand shocks on the economy when monetary policy is passive, in Figs 3(a,b)–5(a,b) we graphically present the IRFs of $\tilde{r}_{t+k}$, $\tilde{y}_{t+k}$ and $\tilde{i}_{t+k}$ implied by the TRSRE model (5.a)–(5.b), for all the three countries. These IRFs are calculated following 1 per cent standard deviation negative supply and demand shocks $\varepsilon_{S,t}$ and $\varepsilon_{D,t}$, respectively. They

15 Necessary conditions for determinacy of the REE solution (6.a)–(6.b) are mean square stability and forward convergence (which rules out rational bubbles), as well as the following condition to hold: $r_d(\Sigma) < 1$, where $r_d(\cdot)$ denotes the maximum eigenvalue of matrix $\Sigma$ defined in the Appendix. Mean square stability requires the following condition $r_d(\Sigma_W) < 1$, where matrix $\Sigma_W$ is defined in the Appendix. The values of the above maximum eigenvalues that we have found in our empirical analysis are as follows: $r_d(\Sigma_W) = 0.20 < 1$ and $r_d(\Sigma_F) = 1.01 > 1$ for USA, $r_d(\Sigma_W) = 0.28 < 1$ and $r_d(\Sigma_F) = 1.05 > 1$ for UK and $r_d(\Sigma_W) = 0.48 < 1$ and $r_d(\Sigma_F) = 1.12 > 1$ for Japan. These eigenvalues show that the REE is indeterminate for all countries. However, the conditions of mean square stability and forward convergence hold for all three countries.

16 Note that the effects of positive shocks were also examined, but these do not change the main conclusions of our analysis. These produce IRFs that are symmetric to those given in Figs 3(a)–5(a).
assume that, at current time \( t \), the economy lies in one of the two different regimes \( i \), where \( i = \{1,2\} \). But, they allow for regime-switching in the future due to the endogenous nature of regime-switching assumed by threshold model (1). This enables us to account for the dynamic expectation formation effects of regime-switching on the efficiency of the monetary policy, as noted in Section 2.

The figures labelled with A present IRFs, which correspond to the point estimates of policy rule parameters beta and gamma of model (1) provided by our empirical analysis of Section 3. Note that, for the recession regime (regime ‘1’), these parameters are set to values very close to zero (i.e. \( \beta_1 = \gamma_1 = 0.05 \)), as
they are not found to be different than zero in this regime.\footnote{Note that we do not assume that the values of $\beta_1$ and $\gamma_1$ are exactly zero in order to avoid numerical convergence problems of the algorithm calculating the REE solution (6.a)–(6.b), occurring when $\beta_1 = \gamma_1 = 0$ (see Cho (2009)).} In addition to the above, the figures also present IRFs, which assume different degrees of passiveness (or activeness) of policy rule parameters beta and gamma in regime ‘1’. These are given in Figs 3–5 labelled with B. The values of parameters $\beta_1$ and $\gamma_1$ chosen for these IRFs satisfy the determinacy conditions of the REE solution given by equations (6.a) and (6.b), implied by the surfaces of Fig. 2. Note that some of these values of $\beta_1$ and $\gamma_1$ are chosen to be very close to their point estimates corresponding to the expansion regime, reported in Table 3. This is done in order to see if there are possible gains arisen (in terms of output and inflation rates volatility), when adopting an active monetary policy rule under the recession regime.

Inspection of the IRFs of Figs 3(a,b)–5(a,b) leads to a number of conclusions with important policy implications. First, they show that supply and demand shocks lead to direct and sizable cuts in the short interest rate $i_t$ and the other two macroeconomic variables of the NK model, namely $\pi_t$ and $y_t$. These interest rates cuts are bigger in magnitude for the supply shocks and much smaller under the recession regime. The latter can be obviously attributed to the passive policy followed by monetary authorities under this regime. As was expected, the reaction of interest rate $i_t$ to the above shocks is described by a hump shaped function independently on whether the economy is on the expansion or recession regime.

The above reductions in interest rate $i_t$ lead to almost monotonic increases in the future output gap and inflation rate, for all three countries. What differs across them is the magnitude of these responses to the different sources of shocks in each economic regime. In particular, under the expansion regime, demand shocks cause smaller in magnitude variations in inflation rate and output gap deviations for the UK and Japan (see Figs 3(a)–5(a)), compared with those for the USA. This can be obviously attributed to the fact that the values of gamma policy parameters (see estimates of $\gamma_2$ in Table 3) are much bigger than unity for these two countries, while for the USA are smaller. The above pattern of responses is not observed for supply shocks. In this case, variation of inflation rate and output gap deviations from their target levels under the expansion regime are analogous, for all three countries. This happens because there are not big differences in the way that the three countries respond to inflation deviations from their target level under the expansion regime, as the estimates of $\beta_2$, reported in Table 3, indicate.

In contrast to the expansion regime, under the recession the supply and demand shocks cause bigger in magnitude and more persistent variations in inflation rate and output gap deviations from their target levels, for all three countries. This is obviously due to the inaction of monetary policy under this
Fig. 3. (a) IRFs for USA. (b) IRFs for the USA under the Recession Regime

Note for (a): Regime ‘1’ stands for the recession regime ($\beta_1 = 0.05$, $\gamma_1 = 0.05$), while regime ‘2’ for the expansion (point estimates).

Note for (b): Reg1.1 stands for $\beta_1 = 0.05$ and $\gamma_1 = 0.05$, Reg1.2 for $\beta_1 = 0$ and $\gamma_1 = 1.80$, Reg1.3 for $\beta_1 = 1.10$ and $\gamma_1 = 0$ and Reg1.4 for $\beta_1 = 1.10$ and $\gamma_1 = 0.80$. 

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Fig. 4. (a) IRFs for UK. (b) IRFs for the UK under the Recession Regime

Note for (a): Regime ‘1’ stands for the recession regime ($\beta_1 = 0.05$, $\gamma_1 = 0.05$), while regime ‘2’ for the expansion (point estimates).

Note for (b): Reg1.1 stands for $\beta_1 = 0.05$ and $\gamma_1 = 0.05$, Reg1.2 for $\beta_1 = 0.6$ and $\gamma_1 = 3.0$, Reg1.3 for $\beta_1 = 1.20$ and $\gamma_1 = 0$ and Reg1.4 for $\beta_1 = 1.20$ and $\gamma_1 = 0.80$. 

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Fig. 5. (a) IRFs for Japan. (b) IRFs for Japan under the Recession Regime

*Note for (a):* Regime ‘1’ stands for the recession regime ($\beta_1 = 0.05$, $\gamma_1 = 0.05$), while regime ‘2’ for the expansion (point estimates).

*Note for (b):* Reg1.1 stands for $\beta_1 = 0.05$ and $\gamma_1 = 0.05$, Reg1.2 for $\beta_1 = 0.5$ and $\gamma_1 = 3.0$, Reg1.3 for $\beta_1 = 1.40$ and $\gamma_1 = 0$ and Reg1.4 for $\beta_1 = 1.40$ and $\gamma_1 = 0.80$. 

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regime. Figures 3(b)–5(b), presenting IRFs with different degree of activeness under the recession regime, clearly indicate that the above variations could have been substantially reduced, if monetary authorities had followed an active policy with respect to inflation rate or output gap deviations. In particular, the graphs of these figures reveal that inflation rate and/or output gap deviations from their target levels could have reached their corresponding levels of volatility under the expansion regime, if policy rule parameters $\beta_1$ and $\gamma_1$ had taken values like $\beta_1 > 1.0$ (or $\beta_1 > 1.0$ and $\gamma_1 > 0.0$) for supply shocks and $\gamma_1 > 1.0$ (or $\beta_1 > 0.0$ and $\gamma_1 > 1.0$) for demand shocks. That is, monetary authorities were taken strong action against negative inflation or real output gap deviations from their target levels.

5 Conclusions

This paper has employed a threshold switching monetary policy rule model with the aim of examining whether monetary policy rules change according to different business cycle conditions, i.e. recession and expansion. To capture these conditions, our model uses the real output gap as threshold variable. To evaluate the policy implications of this model, the paper carries out a simulation exercise based on a small-scale NK model enriched by our threshold monetary policy rule to describe the behaviour of monetary authorities.

Based on data from the USA, UK and Japan, the paper provides strong evidence that, during recessions, monetary authorities (CBs) abandon the Taylor rule and follow a passive, no-state contingent policy focusing on smoothing interest rates over time. This happens not only under short-lived recessions triggered by financial crises as was believed in the literature, but also under ordinary recessions lasting longer. Our simulation study shows that this passive behaviour of CBs leads to substantial and prolonged variations in inflation rate and real output gap deviations from their target levels. The biggest one of them can be attributed to supply shocks. The paper shows that these deviations could be substantially dampened if monetary authorities responded more aggressively to inflation or output gap deviations.

Appendix

In this appendix, we present more analytically the REE solution of the TRSRE model (5.a)–(5.b), given by equations (6.a) and (6.b). In particular, we give the definitions of matrices $\Omega(\cdot)$ and $\Gamma(\cdot)$ involved in this solution, as well as those of matrices $\Sigma_\Omega$ and $\Sigma_F$ whose maximum values determine the mean square stability and determinacy conditions. The above solution can be obtained following the same steps as Cho (2009), for the MRS model.

The REE solution (6.a)–(6.b) can be obtained by solving forward the system of equations (5.a) and (5.b) and imposing the forward condition ruling out rational bubbles in equilibrium. This will yield
\[ \mathbf{x}_t = \mathbf{\Omega} (\tilde{y}_{t-1} \leq \tilde{q}) \mathbf{x}_{t-1} + \mathbf{\Gamma} (\tilde{y}_{t-1} \leq \tilde{q}) \mathbf{z}_t \]

and
\[ \mathbf{x}_t = \mathbf{\Omega} (\tilde{y}_{t-1} > \tilde{q}) \mathbf{x}_{t-1} + \mathbf{\Gamma} (\tilde{y}_{t-1} > \tilde{q}) \mathbf{z}_t \]

where
\[ \mathbf{\Omega} (\tilde{y}_{t-1} \leq \tilde{q}) = \lim_{k \to \infty} \mathbf{\Omega}_k (\tilde{y}_{t-1} \leq \tilde{q}) \quad \text{and} \quad \mathbf{\Omega} (\tilde{y}_{t-1} > \tilde{q}) = \lim_{k \to \infty} \mathbf{\Omega}_k (\tilde{y}_{t-1} > \tilde{q}) \]
\[ \mathbf{\Gamma} (\tilde{y}_{t-1} \leq \tilde{q}) = \lim_{k \to \infty} \mathbf{\Gamma}_k (\tilde{y}_{t-1} \leq \tilde{q}) \quad \text{and} \quad \mathbf{\Gamma} (\tilde{y}_{t-1} > \tilde{q}) = \lim_{k \to \infty} \mathbf{\Gamma}_k (\tilde{y}_{t-1} > \tilde{q}) \]

and
\[ \mathbf{\Omega}_k (\tilde{y}_{t-1} \leq \tilde{q}) = \mathbf{\Phi}_k (\tilde{y}_{t-1} \leq \tilde{q})^{-1} \mathbf{B}^{-1} \mathbf{D} (\tilde{y}_{t-1} \leq \tilde{q}) \]
\[ \mathbf{\Omega}_k (\tilde{y}_{t-1} > \tilde{q}) = \mathbf{\Phi}_k (\tilde{y}_{t-1} > \tilde{q})^{-1} \mathbf{B}^{-1} \mathbf{D} (\tilde{y}_{t-1} > \tilde{q}) \]
\[ \mathbf{\Gamma}_k (\tilde{y}_{t-1} \leq \tilde{q}) = \mathbf{\Phi}_k (\tilde{y}_{t-1} \leq \tilde{q})^{-1} \mathbf{B}^{-1} (\tilde{y}_{t-1} \leq \tilde{q}) \mathbf{E}_k [\mathbf{F}_k (\tilde{y}_{t-1} \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} \leq \tilde{q}) \mathbf{\Gamma}_k (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q})] \]
\[ \mathbf{\Gamma}_k (\tilde{y}_{t-1} > \tilde{q}) = \mathbf{\Phi}_k (\tilde{y}_{t-1} > \tilde{q})^{-1} \mathbf{B}^{-1} (\tilde{y}_{t-1} > \tilde{q}) \mathbf{E}_k [\mathbf{F}_k (\tilde{y}_{t-1} > \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} > \tilde{q}) \mathbf{\Gamma}_k (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q})] \]

with
\[ \mathbf{\Phi}_k (\tilde{y}_{t-1} \leq \tilde{q}) = (\mathbf{I} - \mathbf{E} [\mathbf{B}^{-1} \mathbf{A} (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} \leq \tilde{q}) \mathbf{\Omega}_k (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q})]) \]
\[ \mathbf{F}_k (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} \leq \tilde{q}) = \mathbf{\Phi}_k (\tilde{y}_{t-1} \leq \tilde{q})^{-1} \mathbf{B}^{-1} \mathbf{A} (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} \leq \tilde{q}) \]
\[ \mathbf{\Phi}_k (\tilde{y}_{t-1} > \tilde{q}) = (\mathbf{I} - \mathbf{E} [\mathbf{B}^{-1} \mathbf{A} (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} > \tilde{q}) \mathbf{\Omega}_k (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q})]) \]
\[ \mathbf{F}_k (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} > \tilde{q}) = \mathbf{\Phi}_k (\tilde{y}_{t-1} > \tilde{q})^{-1} \mathbf{B}^{-1} \mathbf{A} (\tilde{y}_t \leq \tilde{q}, \tilde{y}_t > \tilde{q} | \tilde{y}_{t-1} > \tilde{q}) \]

Matrices \( \Sigma_\mathbf{\Omega} \) and \( \Sigma_\mathbf{F} \) are defined as follows
\[ \Sigma_\mathbf{\Omega} = [p_\mathbf{y} \mathbf{\Omega} (\tilde{y}_{t-1} \leq \tilde{q}, \tilde{y}_{t-1} > \tilde{q}) \otimes \mathbf{\Omega} (\tilde{y}_{t-1} \leq \tilde{q}, \tilde{y}_{t-1} > \tilde{q})] \]
\[ \Sigma_\mathbf{F} = [p_\mathbf{y} \mathbf{F} (\tilde{y}_{t-1} \leq \tilde{q}, \tilde{y}_{t-1} > \tilde{q}) \otimes \mathbf{F} (\tilde{y}_{t-1} \leq \tilde{q}, \tilde{y}_{t-1} > \tilde{q})] \]

References


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