Essays in Asymmetric Monetary Policy Preferences

by

Congyi Hu

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Abstract

This thesis investigates the open economy policy rule under the assumption of asymmetries in monetary policy preference, and how such asymmetric monetary policy preference can contribute to the exchange rate forecasting literature.

The first chapter estimates an open economy monetary policy rule for the Bank of England and assesses its policy preference in the era of inflation targeting. The reduced-form estimates of the central bank policy function suggest that the preferences for the Bank of England can be characterised as asymmetries during the inflation targeting period, with the interest rate responses to the downside of the economy being larger than the response to the upside of the economy of the same magnitude. However, these results are not robust when we include the unconventional monetary policy period.

The second chapter extends the standard Taylor rule fundamentals of the exchange rate by incorporating the asymmetric monetary preferences. We present an exchange rate forecasting model (augmented Taylor rule fundamentals) under a credible inflation-targeting regime, in which the exchange rate could have asymmetric responses to the level of inflation and output gap. Our empirical results indicate the importance of asymmetric exchange rate response for modelling the exchange rate movement. In particular, the augmented Taylor rule fundamentals can provide more robust short-term exchange rate predictability than the standard Taylor rule fundamental during the conventional monetary policy period.

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General Introduction

It is well known that the combination of a quadratic loss function and a linear economic structure leads to a linear interest rate reaction function or Taylor rule, in which the policy instrument interest rate is a linear function of the inflation and output gap deviations from their respective targets. Although the empirical evidence illustrates that Taylor rule is able to capture the dynamic of short-term interest rate in the past two decades, researchers have challenged this conventional setup. In particular, they have argued that the loss function for the central bank is not quadratic, and therefore the Taylor rule derived from such function may not have a simple linear form.

This argument is based on two grounds. First, on the policy side, Blinder (1997, p. 6), the ex-vice-chairman of the Federal Reserve, argued that ***"academic macroeconomists tend to use quadratic loss functions for reason of mathematical convenience, thinking much about their substantive implications. The assumption is not innocuous...I believe that both practical central bankers and academics would benefit from more serious thinking about the functional form of the loss function".*** In addition, Blinder (1998, pp. 19-20) also stated that ***"Central banks 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".*** This statement suggests that the Fed may have asymmetric monetary preference under political pressure. Furthermore, there are numerous studies show that empirical evidence is generally in favour of the existence of asymmetric monetary preferences. The quadratic specification and the subsequent linear interest reaction only implies that the central bank assigns equal weight to the positive and negative deviation of inflation and output from the target values, and it cannot capture asymmetric monetary policy responses. Based on the evidence of asymmetry, the Taylor rule or interest rate reaction function is not necessarily linear, but instead is best described by a nonlinear form.

Past literature who investigates the nonlinear interest rate reaction function mainly focused on a closed economy. In order to address this issue, this thesis investigates the asymmetric monetary policy preferences in an open economy context. For the first chapter, the research question is whether UK monetary policymakers have asymmetric policy intervention within an open economy framework. Our theoretical framework follows the Arghyrou and Pourpourides (2016) model, they show an optimal open economy monetary policy rule in which asymmetric monetary policy preferences not only cause the asymmetric policy responses but also lead to asymmetric exchange rate response under credible inflation targeting regime. We estimate such policy rule by using the GMM technique for the UK quarterly data in the era of inflation targeting. The empirical findings can be summarised as follows. First, we find that the Bank of England (BoE) weights the downside of the economy more than the upside during the inflation targeting period. That is to say, the Bank of England respond more aggressively when output and inflation fall below their target value. This is the first empirical evidence shows that the BoE has negative output gap asymmetry as the previous empirical literature who focused on closed economy model suggest that the Bank of England respond more aggressively when output and inflation exceed their target value. Therefore, it is important to consider the open economy factors when conducting the monetary policy analysis, especially for a small open economy like the

UK[1]. To the best of my knowledge, Caglayan *et al.* 2016 is the only study that examines the asymmetric monetary preference under the open economy, and their empirical analysis is based on the UK and Canada data. However, their theoretical framework is not sufficient to capture the open economy effects for the UK. Due to its theoretical limitation, we investigate the asymmetric monetary preferences based on a new theoretical model, which is more consistent with the UK monetary policy practices. We will discuss more details in the section 1.2.1

In addition, existing studies have found strong evidence of exchange rate predictability with Taylor rule fundamentals. Taylor rule fundamentals of exchange rate based on a linear Taylor rule for monetary policy. If we assume that two economies both set interest rates according to the linear Taylor rule and the bilateral exchange rate will reflect their relative interest rate, then their bilateral exchange rate can be determined as a linear function of their output gap and their inflation level. In the second chapter, we challenge this set up from the following perspectives. First, the existing empirical literature has shown that countries under credible inflation targeting monetary policy experience asymmetric exchange rate response under inflation surprises. In particular, the depreciations following negative inflation surprises (actual inflation is lower than its expected value) are larger than the appreciation following positive inflation surprises (actual inflation is greater than its expected value). Second, as we mentioned before, the empirical evidence suggests that Taylor rule are not necessarily linear, and therefore a linear Taylor rule based exchange rate model may not adequate to capture the complexities of the exchange rate movement. We suspect that the

[1] The character of smalls refers to the fact that, the UK is price taker as its policy cannot alter the key macroeconomic variables like the interest rate or the world price. In macroeconomic literature, there is a consensus that the UK is a small open economy.

asymmetry in exchange rate response is due to the asymmetry in the central bank's preference. We first derive an augmented Taylor rule fundamentals from a nonlinear interest rate reaction function, in which the exchange rates are allowed to have asymmetric responses. Hence, the research question for the second chapter is whether the augmented Taylor rule fundamentals can provide stronger evidence of short-term exchange rate predictability than the Taylor rule fundamentals for countries with credible inflation targeting monetary policy. Our empirical results suggest that the augmented Taylor rule fundamentals can outperform the Taylor rule fundamentals during the conventional monetary policy period (the inflation targeting period but prior to the recent financial crisis).

However, once we include the unconventional monetary policy period and the pre-inflation targeting period, the evidence of exchange rate predictability for augmented Taylor rule fundamentals is much weak. The reasons for such weak exchange rate predictability can be summarised as follows. Firstly, the augmented Taylor rule fundamentals assume that the central bank use interest rate as its main policy instrument, however, the major central banks have changed its policy instruments from interest rate to other variables during the unconventional monetary policy period. Therefore, the augmented Taylor rule is not sufficient to capture the policy shift for the unconventional monetary policy period. Secondly, based on the theoretical framework and past empirical evidence, the asymmetric exchange rate behaviour mainly applies to a country that operates credible inflation targeting regime. However, the monetary policy cannot be regarded as credible inflation targeting regime before the inflation targeting period. Hence, due to the inconsistencies between the model assumption and the monetary policy regime, it should be no surprise for the relatively weaker exchange rate predictability for the unconventional monetary policy period and the pre-inflation targeting period.

Chapter 1

Asymmetric Central Bank Preferences in Small Open Economies with Inflation-targeting Regimes: Evidence from the UK

1.1 Introduction

1.1.1 Background

It is commonly known that the monetary policy plays an essential role in the operation of the economy. Past literature has reached a consensus for evaluating the monetary policy in the early 2000s. In particular, they assumed that the central bank minimises a quadratic loss function subject to a linear structure of the economy, and use such framework to derive an optimal policy rule for the monetary authority. This type of policy rule shows that the short-term interest rate is a linear function of inflation and output in which the monetary authority assigns equal weight to the positive and negative deviation of inflation and output from the target levels.

However, some researchers have demonstrated that the use of quadratic loss function and the linear interest rate reaction are questionable. On the theoretical side, Gali *et al.* (2002) argue that the cost of output fluctuations are asymmetric for the US, and therefore policymakers may assign different weights between positive and negative deviations from the output and inflation targets. In addition, Persson and Tabellini (1999) and Cukierman and Gerlach (2003) show that the career concerned policymakers may have larger aversion to output contraction than to output expansion as they are more likely to be reappointed with such asymmetric objective. On the empirical side, a number of papers have derived and estimated a nonlinear policy rule under the assumption that policymakers have asymmetric preference. Generally speaking, the empirical evidence supports the notion of the nonlinear policy rule and the existence of asymmetric objective for the monetary authority (see Dolado *et al*. 2005, Surico 2007a, 2007b). However, the existing literature mainly examines the assumption of asymmetric preferences within a closed economy, only a few studies have explored such assumption under an open economy framework.

1.1.2 Motivation

In this study, we investigate the assumption of asymmetric monetary preference for the BoE within an open economy new-Keynesian framework. In doing so, we follow the theoretical framework derived by Arghyrou and Pourpourides (2016), (hereafter, A&P). In contrast with the existing literature, the optimal policy rule provided by A&P taking into account the effects of asymmetric monetary policy preference on exchange rate behaviour, in which the asymmetric monetary preferences will not only lead to asymmetric interest rate responses, but more importantly, also cause asymmetric exchange rate responses. We argue that A&P's theoretical framework is suitable for the UK data for the following reasons. Firstly, the important presumption of A&P's model is the asymmetric interest rate responses and the potential asymmetric exchange rate response only occurs if the central bank operates a credible inflation targeting monetary policy, which is in line with the BoE policy framework as the BoE has adopted a formal inflation targeting regime in October of 1992 and achieved credibility in anchoring inflation expectation after the adoption of the inflation targeting regime. Secondly, the past empirical literature has illustrated that the asymmetric exchange rate responses are significant for the British Pound during the inflation targeting period (Clarida and Waldman, 2008). As a result, an open economy policy rule that embodies the potential asymmetric exchange rate responses is crucial for investigating the BoE's monetary preference during the inflation targeting era.

1.1.3 Main Findings

We estimate the open economy monetary policy rule by using the generalised method of moments (GMM) for the UK during the inflation targeting period, 1992Q4-2015Q4. In order to deal with the policy shift during the financial crisis, we split the sample into two types of sub-sample periods, before and after the unconventional monetary period. The main empirical findings for this chapter can be summarised as follows: for the case of the UK, the researchers mainly found that the BoE react more aggressively when the inflation is greater than its target value but not the opposite after the introduction of the inflation targeting regime. This seems plausible during periods of inflation stabilisation where the BoE is trying to build up credibility and anchor the inflation expectation. However, by considering the effects of asymmetric monetary policy preference on exchange rate behaviour, our empirical results suggest that the BoE are more averse to negative than to positive output gaps of the equal size during the inflation targeting period but prior to the financial crisis, and has larger aversion to negative inflation gap than to positive inflation gap before to the introduction of QE, which to my best knowledge is the first in the literature for investigating the BoE's monetary policy preferences.

The rest of the paper is organized as follows: Section 1.2 discusses the past literature of the asymmetric monetary preferences. Section 1.3 presents the detail theoretical framework of A&P's model. Section 1.4 shows the data, estimation strategy and the empirical results. Section 1.5 provides the robustness checks for the empirical findings, and the conclusion is represented in section 1.6.

1.2 Literature review

A nonlinear policy rule can be regarded as the most common way to identify the asymmetric monetary preference. The nonlinear policy function arises because the loss function for policymakers is not quadratic, or the structure of the economy is not linear. By challenging the quadratic loss function or the linear economic structure, past literature has provided international evidence that supports the notion of nonlinear policy function. Examples include Nobay and Peel (2003), Ruge-Murica (2003), Cukierman and Muscatelli (2008), among others. Cukierman and Gerlach (2003) adopt a nonlinear inflation reaction function and demonstrate that the hypothesis of asymmetric objective holds for some OECD economies. Dolado *et al*. (2004) derive a monetary policy rule based on two types of non-linearity. Firstly, the central bank's preferences are asymmetric. Secondly, the aggregate supply relation is non-linear. By estimating the monetary policy rule, they find that the US monetary policy can be characterised as non-linear after 1983 but not before 1979. In addition, there is no evidence in favour of the non-linear aggregate supply relation.

Another approach to assessing the nonlinear policy rule is using threshold regression, in which the policy reaction function follows different regimes characterised by an inflation or output threshold. Therefore, the central bank may have different monetary preference depending on the state of the economy. Taylor and Davradkis (2006) is the first study to use this approach to investigate the non-linear Taylor rule, followed by Komlan (2013), Sznajdersk (2014), among others. The evidence found by these studies confirm non-linear interest rate setting behaviour for the UK, Canada, the ECB and some emerging economies.

One of the popular theoretical models to explaining the central bank's asymmetric preference is provided by Surico (2007a). He adopts a linear exponential (Linex) loss function but maintains a linear economic structure, and derive an optimal policy rule in which the monetary authority is allowed to assign different weights to positive and negative deviations of inflation and output from the target values. He estimates the reduced form of the policy rule for the Fed, and found that the monetary policy preference for the Fed has been asymmetric with respect to both inflation and output gaps. Similar evidence is found for the European Central Bank (ECB), in which output contractions trigger larger policy responses than output expansions of the same size (Surico, 2007b). In addition, he extends his model by introducing the monetary aggregate into the policy function, however, the empirical evidence suggests the stabilisation of the money growth rate is not an independent goal of the ECB monetary policy.

1.2.1 The past empirical evidence for the BoE

As the asymmetry arises because the actual inflation deviates from its target value, such framework may more suitable for a country with formal inflation targeting regime. In particular, the UK has received some attention with previous research. Srinvasan *et al*. (2006) further developed Surico's framework with two main modifications. Firstly, they introduced a zone-quadratic preference specification for the UK economy. They argue that the BoE controls inflation within a target range rather than aiming for a target point. The advantage of specifying a range that it can provide flexibility to the policymakers and signal the public that control of inflation is imperfect. Secondly, they use the ex-post monthly forecast of inflation to estimate the policy reaction function. The coefficient on both squared output gap and the squared inflation gap are positive and significant. That is, there is a deflationary bias for the UK, which is consistent with the previous empirical evidence for the UK (Mishkin and Posen, 1997, Ruge-Murica, 2004). In addition, the BoE was attempting to keep inflation forecast within a range only for the period between 1992 and 1995.

Likewise, Boinet and Martin (2008) also test the assumption that the BoE targets the range of inflation rate rather a specific rate. In particular, they derive an optimal monetary policy rule that allows for both zone-like and asymmetric behaviour. They classified four cases for comparison: liner, asymmetric, zone symmetric and zone asymmetric. The evidence in favour of a zone-like response to inflation, with a linear interest response to the output gap. However, there is no evidence in favour of asymmetric policy responses. In addition, Taylor and Davradakis (2006) firstly propose a threshold model to examine potential nonlinearity in the Taylor rule for the BoE during the inflation targeting period. The interest rate setting behaviour can be well captured by a Taylor rule if the expected inflation is significantly greater than its target rate. On the other hand, the interest rate becomes unrelated to the expected inflation rate if it less than the target rate. Therefore, the difference in the interest adjustment leads to asymmetry for interest rate setting.

Cukierman and Muscatelli (2008) use smooth transition regressions to test the nonlinear Taylor rule for UK data over two sub-sample periods, 1979Q3-1990Q3 and 1992Q4-2005Q4. The two sub-periods arise because the BoE has adopted the inflation targeting regime in October of 1992. Compared with the studies I have mentioned above, the also include the pre-inflation targeting period. The empirical results suggest that the BoE has weighted more on recession before the inflation targeting period, however, during the inflation targeting period, such preference has been switched in which the BoE has larger policy response to positive inflation gap.

It should be noted that past literature mainly focuses on the closed economy model. To the best of my knowledge, Caglayan *et al.* (2016) is the only study that investigates an optimal open economy policy function with the assumption of asymmetric preference. They derive and examine the optimal open economy policy rule for both BoE and the Bank of Canada (BoC), and the reported results suggest that the BoE has positive inflation and positive output gap asymmetries under an open economy environment. In addition, the real exchange rate enters the monetary policy rule as the real exchange rate has strong negative impacts on the interest rate. According to their model assumption, the depreciation of the real exchange rate will result into a reduction in domestic output, putting a downward pressure on the domestic interest rate, and therefore the negative impact of real exchange rate on interest rate is consistent with their theoretical framework.

It is clear that Caglayan *et al.* (2016) has investigated the open economy policy rule under the assumption of asymmetric monetary policy preference. However, we argue that our theoretical framework and the empirical analysis are more consistent with the dynamics of the UK economy. The main differences can be summarised as follows. Firstly, although we introduce the exchange rate term in the policy rule, we do not explicitly show that the exchange rate has a direct impact on the interest rate. In contrast, we explicitly show that the asymmetric response of interest rate to the deviation of the output gap and inflation gap, and such asymmetric responses will potentially lead to the asymmetric exchange rate responses through the uncovered interest rate parity (UIRP) condition.

Secondly, they include the pre-inflation targeting period for the estimation (back to 1983Q1), and without any concerns of the policy shift. If the estimation covers the period before the inflation targeting regime, the empirical evidence should distinguish the structure change of the monetary policy around 1992Q4 when the BoE monetary policy shifted to a framework of inflation targeting. Furthermore, it is clear that the UK experienced relatively higher inflation between 1983Q1 and 1992Q4, the average inflation in this period was two times higher than the post-inflation targeting period.[2] If the BoE considers the inflation stabilisation as its objective, then such higher inflation is not plausible. Therefore, the potential structure change of the monetary policy around 1992Q4 should be considered.

Finally, they propose an open economy Phillips curve by including changes in the real exchange rate, which is inconsistent with the UK data. There is empirical evidence suggests that a tight relationship between real exchange rate and inflation is not supported by the UK data. Kara and Nelson (2003) estimate open economy Phillips curve for the UK, the coefficient on the change of real exchange rate is wrongly signed

[2] The average CPI inflation for UK is 4.9% between 1983Q1 and 1992Q3 and down to average 2% after the 1992Q4.

regardless of the estimation period. They conclude that ***“the elasticity of inflation with respect to exchange rate depreciation does not take its expected positive value”.*** While, our theoretical framework excludes the exchange rate effects on inflation in the aggregate supply relation, and therefore is more consistent with the UK data, at least empirically.

1.3 Model Settings

Despite the fact that Surico’s model has been widely cited, the subsequent literature mainly evaluates the optimal policy rule in the context of a closed economy framework. This is due to the fact that many researchers argued that the exchange rate or other foreign factors are implicitly incorporated in domestic variables such as prices, and therefore their effect can be excluded for the monetary policy analysis (see Taylor 2001, McCallum and Nelson, 2000). However, A&P has further modified Surico model and make it possible to explore the central bank policy rule in an open economy environment. In this section, we outline the theoretical model as described in A&P.

1.3.1 The motivation for A&P (2016)

A&P’s model was motivated by two stylized facts from the past empirical studies. First, under a credible inflation targeting regime, the exchange rate effects of inflation announcements go against the traditional Purchasing Power Parity (PPP) hypothesis. The unexpected positive inflation surprises (the actual inflation rate higher than its expected value) would lead to an appreciation of the domestic currency. On the other hand, when the positive inflation surprise (the actual inflation rate is lower than its expected value) occurs, the domestic exchange rate is often to depreciate. The second stylized fact is that the relationship described above is not linear but subject to sign effects. In detail, the depreciation following a negative inflation surprise is large in absolute size and stronger statistical significance than the appreciation following positive inflation surprise. It also should be noted that both stylized facts are stronger statistical significance for inflation targeting country than non-inflation targeting country (Clarida and Waldman, 2008).

Based on these two stylized facts and given the fact that such evidence is more significant for inflation targeting countries. A&P argue that the asymmetric exchange rate responses to inflation rate are due to the central bank's asymmetry monetary policy preferences. In detail, if central banks have larger aversion to inflation rate under its target level (and/or actual output gap under its potential level) than to inflation rate greater than its target level (and/or actual output gap beyond its potential level). Then, under credible inflation targeting regime, they will reduce the interest rate more aggressively when nominal interest rate must be reduced to meet the inflation target than to increase the interest rate when interest rates need to be increased to meet the same target. Consequently, changes in nominal interest rates result in changes in ex-ante real interest rates, then cause stronger depreciation under negative inflation surprises rather and weaker appreciation under positive inflation surprises. Finally, they present an open economy model, which provide a theoretical explanation for asymmetries in exchange rate responses based on asymmetric monetary policy preferences.

1.3.2 The policy preference and a non-linear policy rule

The structure of the economy is represented by a purely forward-looking new Keynesian, sticky prices framework, presented in Clarida *et al.* (1999), where the output gap and the inflation rate are respectively expressed in terms of an IS equation and a Phillips curve:

$$y_t = -\phi[i_t - \pi_{t+1}^e] + \theta S_t + y_{t+1}^e + \varepsilon_t, \ \phi, \theta > 0 \qquad (1.1)$$

$$\pi_t = \lambda y_t + \beta \pi_{t+1}^e + \eta_t, \ \lambda, \beta > 0 \qquad (1.2)$$ [3]

We denote the output gap by $y_t = Y_t - \overline{Y_t}$, Y_t and $\overline{Y_t}$ are the logs of real gross domestic product (GDP) and potential real GDP. π_t is the inflation rate, and is defined as the percent change in the aggregate price level between periods $t-1$ and t. S_t is the nominal exchange rate, the increase of S_t denotes a deprecation of the domestic currency. The coefficients ϕ, θ, λ and β are greater than zero. The superscript e represent the expectation of the variable while ε_t and η_t are innovations to the output gap and the inflation rate. The equation (1.1) is a standard forward-looking optimising IS equation, which can be derived as a log-linear approximation to the Euler condition. However, for analytical purpose, it is an augmented version by adding the nominal exchange rate. It basically brings the notion of consumption smoothing into an aggregate demand formulation by making the output gap a positive function of its future value and the nominal exchange rate, and a negative function of the real rate of interest. On the other hand, equation (1.2) is the Phillips equation that can be derived from the Calvo (1983) model with the staggered price adjustment in which firms set prices as a constant mark-up over the marginal cost. It shows that each firm adjusts its price with a constant probability in any given period, and independently from the time elapsed from the last adjustment.

[3] It should be noted that if β = 1, the system described by (1.1) and (1.2) has no stable solution. It can only jump to a new equilibrium. The system only gives a stable path if β is less than unity.

It should be noted that the specifications of equation (1.1) and (1.2) demonstrate that the aggregate demand and supply relations are purely forward-looking and without any backwards-looking element. Past literature has identified that the forward-looking elements have been dominated for the UK economy while the backwards-looking elements are either insignificant or only account for a small proportion of inflation and output gap dynamics (see, Leith and Malley, 2007 and Batini *et al*. 2005). Hence, we suspect that the forward-looking specification is more consistent with the UK economy. In addition, A&P assumes UIRP holds for the economy.

$$(1 + i_t) = \frac{s_{t+1}^e}{s_t}(1 + i_t^f) \qquad (1.3)$$

Where i_t^f is the foreign interest rate. Following Surico (2007a), the monetary policymakers choose the nominal interest rate in each period to minimise the loss function, L

$$L = \frac{e^{\alpha(\pi_t - \pi^*)} - \alpha(\pi_t - \pi^*) - 1}{\alpha^2} + \delta\left(\frac{e^{\gamma y_t} - \gamma y_t - 1}{\gamma^2}\right) + \frac{\mu}{2}(i_t - i^*)^2 \qquad (1.4)$$

Where π^* and i^* are the inflation target rate and the interest rate target. The parameters δ and μ denotes the central bank's aversion towards output fluctuations around potential and towards interest rate fluctuations around i^*. The parameters α and γ capture any asymmetry in the objective function of the monetary policymakers. The negative value of γ implies that, everything else equals, monetary policymakers assign higher weights to output contraction than to an output expansion when setting the interest rate. A similar interpretation holds for α, the negative value of α implies that low inflation relative to the target is more costly than high inflation. It should be also noted that the linex loss function nest the quadratic loss function when both α and γ tend to zero[4].

[4] This can be obtained by simplifying the exponential term as a second order Taylor approximation.

The monetary policymaker minimises L in (1.4) subject to (1.1), (1.2) and (1.3) and the first-order condition reads:[5]

$$\left[\phi + \theta\left(\frac{s_t}{1+i_t}\right)\right] Z_t = \mu(i_t - i^*) \quad (1.8)$$

Where $Z_t = \lambda \frac{e^{\alpha(\pi_t - \pi^*)} - 1}{\alpha} + \delta \frac{e^{\gamma y_t} - 1}{\gamma}$. The first order condition depicts an optimal but potentially nonlinear response of the monetary authority to the development in the economy. The parameter α and γ are crucial for the evaluation of the monetary policy preference. When α and γ tend to zero, the assumption of asymmetric monetary preference will be collapsed, which suggest a linear policy rule with symmetric monetary prefence. Hence, testing whether the parameters α and γ are significantly different from zero are equivalent to testing the hypothesis of asymmetric monetary preferences. If both alpha and gamma are significantly different from zero, we can confirm the central bank has the asymmetric response of interest rate to the deviations of inflation rate the and output gap from their target value. In contrast, if both alpha and gamma have to be equal to zero, then it implies the symmetric central bank preference.

1.4 Empirical Analysis

1.4.1 Data

This section shows the data descriptions, estimates, and the relevant test of the nonlinear policy reaction function. According to A&P's framework, the asymmetric monetary preference should only achieve in a country with a credible inflation targeting regime in which the expectations of inflation are well anchored to the credible inflation target. Over the last 20 years or so, the BoE's has been recognized as the most

[5] See Appendix 1 for the detailed derivation of the first order condition

successful example for adopting the inflation targeting regime because of the significant reduction in the level and variability of the inflation (Haldane, 2000, Gürkaynak, 2010). Hence, we choose to examine the asymmetric monetary preference in the optimal non-linear policy rule of the BoE. This analysis is based on the quarterly data of the UK during the inflation targeting period, between 1992Q4 and 2015Q4. An important concern with our sample period is it also includes the period of the financial crisis, Great Recession, and slow recovery for the UK economy. It is clear that the theoretical frameworks suggested by Surico and A&P postulate that the monetary policy reaction function takes the form of an optimal interest rate rule. This renders our analysis more suitable for the period of conventional monetary policy rather than the period of unconventional monetary policy, where the main monetary policy instrument is the changes in the level of money supply rather than changes in interest rate, due to the zero lower bound limit. Consequently, we infer that any policy shift for monetary policy may reduce the explanatory power of the model. For this reason, we use different sub-periods to deal with the potential structural change of the monetary policy during the inflation targeting period. We will illustrate more details in the next part.

For our empirical analysis, the policy interest rate is represented by the three-month Treasury bill, which is obtained from the website of the BoE. Inflation is measured as the annual change in the retail price index (RPI). In addition, we also report the policy reaction function estimates using the change in the consumer price index (CPI). Both inflation measures are obtained from the Office for National Statistics (ONS) website. The nominal exchange rate is represented by the nominal effective exchange rate from

BIS (Bank for International Settlements)[6], the increase of the exchange rate means a depreciation of the GBP (Pound Sterling).

Furthermore, we use the Hodrick-Prescott cyclical component (HP filter) of the logarithm of real GDP to constructing the output gap. However, it is known that filtered values at the end of the sample are very different from those in the middle, and also characterized by spurious dynamics (see Hamilton, 1994). As a result, we follow Baxter and King's (1995) approach, by dropping observations at the beginning and at the end of the sample. In practice, we construct the output gap series based on the UK real GDP, 1980Q1-2018Q1, and drop the observations before 1992Q4 and after 2015Q4. Therefore, our output gap series can avoid the end of sample problem of filter values.

1.4.2 Estimation strategy

Our main objective is to estimate the nonlinear policy reaction function to evaluating whether the monetary preference parameters α and γ are significant differently from zero. In order to achieve this, we linearise the exponential term in the first order condition by using a second order Taylor series approximations (see Dijk *et al*, 2002, for a survey). Then, the first order condition is reparametrized as follows:[7]

$$i_t = i^* + d_1' \left[\phi(\pi_t - \pi^*) + \theta \frac{s_t}{(1+i_t)}(\pi_t - \pi^*)\right] + d_2' \left[\phi(\pi_t - \pi^*)^2 + \theta \frac{s_t}{(1+i_t)}(\pi_t - \pi^*)^2\right] + d_3' \left[\phi y_t + \theta \frac{s_t}{(1+i_t)} y_t\right] + d_4' \left[\phi {y_t}^2 + \theta \frac{s_t}{(1+i_t)} {y_t}^2\right] + v_t \quad (2.0)$$

[6] The nominal effective exchange rate is based on the bilateral trade with the UK. Euro, Dollar and Yen assign the majority of the weights in calculating sterling nominal effective exchange rate indices. For details, see http://www.bis.org/statistics/eer.html.

[7] See Appendix 2 for the Taylor series approximation of the first order condition.

Equation (2.0) is the policy reaction function for the BoE, where $d_1' = \frac{\lambda}{\mu}, d_3' = \frac{\delta}{\mu}$ $d_2' = \alpha d_1'/2$ and $d_4' = \gamma d_3'/2$. The parameters d_1' and d_3' are the convolutional parameters corresponding to the structure of the economy. Following the specification in the previous section, d_1' and d_3' should be greater than zero as λ, μ and δ are all great than zero based on A&P's framework. It is clear that the parameters (d_1', d_2', d_3' *and* d_4') from equation (2.0) can only be interpreted as convolutions of the coefficients corresponding to policy preference and the structure of the economy, and we are not able to recover all the structural parameters from equation (2.0) However, we can recover the asymmetric preference α and γ as $\alpha = 2d_2'/d_1'$, $\gamma = 2d_4'/d_3'$. In detail, the joint restriction of $d_2' = d_4' = 0$ with $d_1', d_3' \neq 0$ indicates $\alpha = \gamma = 0$. Therefore, we can test the null hypothesis $d_2' = d_4' = 0$ to identify the central bank's asymmetric preferences since the above null hypothesis is equivalent to the original null hypothesis $\alpha = \gamma = 0$. We test such null hypothesis using the standard Wald test. If the null of symmetric preference can be rejected, then we conduct the policy function estimation to quantify the degree of nonlinearity.

Our empirical analysis consists of two-stage estimations. In order to estimate the coefficients of d_1', d_2', d_3' *and* d_4', the value of ϕ and θ are crucial. As there is no strong information for ϕ and θ, we let the data speak about the value of ϕ and θ rather than assume them. We perform single IS equation estimation based on UK data to obtaining the value ϕ and θ. By treating these two coefficients as constant in the policy reaction, we can replace ϕ and θ in the policy reaction function with the estimated values from IS estimation results. Finally, we are able to recover α and γ by estimating the policy reaction function.

1.4.3 The open economy IS equation estimates

The specific form of the IS equation is based on A&P's model (equation 1.1), which is augmented with the nominal exchange rate. According to the previous literature, the general specification to capture the open economy effects is adding the real exchange rate (see, Svensson, 2000). However, in order to derive the first order condition as showed in A&P, the use of nominal exchange rate is crucial. As our theoretical framework is based on A&P's model, we also use equation 1.1 for our IS equation estimation.

There are several reasons for supporting this open economy specification. Due to the relative price stickiness in the short run, we can rewrite the real exchange rate by assuming $p^* = p$, then we can get q $\approx s$. Furthermore, the real exchange rate generally shares a high correlation with the nominal exchange rate. In addition, McCallum and Nelson's (2000) demonstrate a depreciation of domestic currency tends to increase the output gap for two reasons (For both nominal term and real term). Firstly, higher output gap due to higher export demand from the deprecation. Secondly, a depreciation increase the costing of producing domestic goods and therefore decrease potential output. By adding these two effects together, it is clear that the nominal exchange rate should has a positive relationship with the output gap.

Prior to the estimation, we assume that the structure of the economy follows the hypothesis of rational expectation. Under rational expectation, the expected term can be replaced by the realised value, and therefore $\pi_{t+1}^e = \pi_{t+1}$ and $y_{t+1}^e = y_{t+1}$. In addition, we also introduce a dummy variable to control the extreme periods, and the IS equation can be further modified as follows:

$$y_t = -\phi[i_t - \pi_{t+1}] - \phi'[i_t - \pi_{t+1}] * d + \theta S_t + \theta' S_t * d + \omega y_{t+1} + \omega' y_{t+1} * d + \varepsilon_t \quad (2.1)$$

Where d is a dummy variable. We set d equals to 1 for 1992Q4-1993Q4 and 2007Q4-2008Q3, and 0 elsewhere. The setting of the dummy variable can capture an important aspect of the change of economic condition during the sample period. Although the UK has withdrawn the pound sterling from the European Exchange Rate Mechanism (ERM) and introduced the inflation targeting after the ERM crisis (1991-1992). There was still remarkable uncertainty about the implication of the new monetary policy regime and the inflationary consequence of the sterling devaluation. During the period between 1992Q4 and 1993Q4, there was a falling of interest rate, exchange rate, and associated with the negative output gap. Furthermore, the Global Financial Crisis started in July 2007, and the first reduction of the UK interest rate take place in December 2007. And, the BoE has introduced the Quantitative Ease (QE) in October 2008. Consequently, we argue that the period for 1992Q4-1993Q4 and 2007Q4-2008Q3 are the exceptional phases for the UK economy as this period was associated with monetary policy change and potential uncertainty.

We now report the estimates of the IS equation. Based on our setting of the dummy, we regard the period between 1994Q1 and 2007Q2 as a normal economic period. This sub-period is in the inflation targeting period, but after the ERM crisis and before the recent financial crisis, and therefore it excludes the extreme periods for our sample series. As we include the dummy variable to control the extreme periods, we can extend the normal economic period, which covers the period between 1992Q4 and 2008Q3 for the IS equation estimation. In addition, we also perform estimation for the period 1992Q4-2007Q3 as this period is in the inflation targeting period but prior to the financial crisis, which could be regarded as a potential normal economic period. Consequently, we report the IS estimation results for 1992Q4-2008Q3, 1992Q4-2007Q3. However, we also include the IS estimation result for the period 1994Q1-2007Q2 as this is the most representative period of conventional monetary policy within the data sample**.** Therefore, the estimates for 1992Q4-2008Q3 and 1992Q4-2007Q3 must be consistent with the estimates for 1994Q1-2007Q2, otherwise we cannot clarify the use of the dummy for period 1992Q4-2007Q3 and 1992Q4-2008Q3.

By controlling the extreme period for 1992Q4-2008Q3 and 1992Q4-2007Q3, the estimated coefficient for those three sub-periods should be consistent as all of them meet the requirement of the normal economic condition. It should be noted that the period between 1994Q1 and 2007Q2 excludes the extreme periods, and therefore we do not use the dummy variable for this period. Furthermore, it is known that the monetary policy can be regarded as unconventional after the introduction of QE in October 2008, and the economic condition turned out to be abnormal. However, for purpose of comparison, and with the potential instability check, we also perform the estimation for the full inflation targeting period. We estimate the open economy IS equation for the UK using GMM technique. Three lags of output gap, RPI inflation, interest rate and exchange rate are used as instruments. The alternative inflation measure CPI is also used as BoE has switched its inflation targeting measure from RPI to CPI in October 2003. In addition, in order to capture the open economy influences, we include foreign interest rate as instruments.

Table 1.1 reports the results of IS equation estimation. As we can see from the table, the coefficient on the ex-ante interest rate and the nominal exchange rate for the UK are highly significant across all four periods, and the signs are consistent with the model prediction (ϕ, θ and $\omega > 0$). The estimated coefficients for 1992Q4-2008Q3, 1992Q4-2007Q3 and 1994Q1-2007Q2 do not differ widely. In particular, the value of ϕ are consistent for these periods. The full sample estimates are also close to the normal period, and therefore our open economy IS equation holds for the UK economy during the inflation targeting period.

Table 1.1: GMM estimates of the open economy IS equation (nominal exchange rate)[8]

	1992Q4-2007Q3	1992Q4-2008Q3	1992Q4-2015Q4	1994Q1-2007Q2
ϕ	0.09***	0.07***	0.06***	0.07***
	(0.020)	(0.020)	(0.001)	(0.017)
θ	0.10***	0.07**	0.09***	0.05***
	(0.026)	(0.035)	(0.027)	(0.017)
ω	0.83***	0.76***	0.81***	0.79***
	(0.018)	(0.030)	(0.028)	(0.015)

Notes: Instruments are the constant and three lags of the following variables (starting from date $t-1$): output gap, CPI inflation, RPI inflation, interest rate, foreign Interest rate[9], nominal exchange rate. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at the 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix[10].

As we mentioned in the previous section, the past literature uses the real exchange rate to capture the open economy influences. Hence, we also perform the estimation by using the real exchange rate for the robustness check. According to the table 1.2, the estimation results are extremely close to the estimates for the nominal exchange rate, and therefore we argue that the empirical evidence supports our specification for using nominal exchange rate instead of the real exchange rate. In addition, for the full sample estimates, the results are not consistent with the previous case. Although the interest elasticity remains significant, the coefficient of exchange rate on output gap becomes insignificant. This situation may reflect the fact that our open economy IS equation may

[8] For full sample estimates, the dummy d equals to 1 for 1992Q4-1993Q4 and 2007Q4 onwards, and 0 elsewhere.

[9] The foreign interest rate is the weighted average nominal interest rate of Euro area (0.62), US (0.23) and Japan (0.15).

[10] We use Newey–West correction of the variance–covariance matrix when estimate the open economy IS equation, and therefore the standard errors are reported by using Newey-west correction.

have the problem of instability if we extend the sample to the unconventional monetary policy period.

Table 1.2: GMM estimates of the open economy IS equation (real exchange rate)

	1992Q4-2007Q3	1992Q4-2008Q3	1992Q4-2015Q4	1994Q1-2007Q2
ϕ	0.10***	0.08***	0.04***	0.08***
	(0.022)	(0.014)	(0.001)	(0.015)
θ	0.09***	0.08***	0.04	0.05***
	(0.023)	(0.023)	(0.030)	(0.015)
ω	0.83***	0.76***	0.82***	0.79***
	(0.017)	0.024)	(0.027)	(0.014)

Notes: Instruments are constant and three lags of the following variables (starting from date $t-1$): output gap, CPI inflation, RPI inflation, interest rate, foreign Interest rate, real exchange rate. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at the 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

1.4.4 Policy function estimates

Based on the open economy IS equation estimation, it is clear that the estimates are consistent among three sub-sample periods, and follow the theoretical assumption of the A&P's model. We now turn to the policy function estimation. UK has initially used RPI inflation for setting the inflation target,[11] but switched to CPI in 2003. We have previously argued that the policy function mainly applies to the conventional monetary policy period. It is clear that RPI covers most of the conventional monetary policy period as the target measure of inflation for our sample, and therefore we choose RPI as our baseline case. Then, the inflation gap is equal to the difference between the annual change of RPI and the BoE's inflation target rate, 2.5%. As a way to provide a robustness check, we also report results using CPI as the measure of inflation. However, when the BoE switched its inflation measure to CPI in October 2003, the target rate

[11] The BoE actually use RPIX (RPI excluding mortgage interest payments) as the measure of inflation targeting. However, due to the lack of variability (see Martin and Milas, 2004), we therefore choose RPI as a proxy of RPIX, which is consistent with the previous empirical studies for UK data. Indeed, Clarida *et al*. (2000) show that estimating interest rate reaction function over a small sample with little variability in inflation would result highly misleading results.

was also changed to 2%. Consequently, the inflation gap for the CPI case is equal to the difference between the annual change of CPI and 2%. It should be noted that we assumed that the change of inflation target measure did not demonstrate a change in the policy regime. The coefficients of ϕ and θ are assumed as constant in the policy function. In order to keep the notion with the IS estimates, we use the same sub-periods as the IS equation estimation. We regard the period 1992Q4-2008Q3 and 1992Q4-2007Q3 as the period for conventional monetary policy while period 1992Q4-2015Q4 is the period includes unconventional monetary policy period. The reference values of ϕ and θ in policy function for different sub-periods estimates are reported in Table 1.3.

Table 1.3: The reference values of ϕ and θ for the policy function estimates.

	1992Q4-2007Q3	1992Q4-2008Q3	1992Q4-2015Q4
ϕ	0.09	0.07	0.06
θ	0.10	0.07	0.09

In addition, the asymmetric preference parameters α and γ are computed by $\alpha = 2d_2'/d_1'$, $\gamma = 2d_4'/d_3'$ and the standard errors are obtained using the delta method (Oehler, 1992)[12]. We estimate the equation using the GMM with an optimal weighting matrix that accounts for possible heteroscedasticity and auto-correlation for the error term. In addition, the reliability of estimation depends crucially on the validity of the instruments, and therefore we evaluate the instruments by using the Sargan-Hansen J test for over-identifying restriction. The rejection of the null hypothesis demonstrates that the estimates are not consistent as instruments are orthogonal to the error terms, which implies that the set of instruments are not valid for the estimation.

[12] The delta method approximates the standard errors of transformation of the coefficients using a first-order Taylor approximation.

It should be noted that the estimation of the policy function is without the dummy. This is due to the fact that the purpose of using dummy is to control the extreme period of the UK economy. However, the extreme period is not the same as the unconventional monetary policy period. In the previous section, we have illustrated the interest reaction function mainly applies to the conventional monetary period. The use of dummy is crucial for the IS equation to justify the normal economic period, otherwise, it will lead to insignificant estimates of ϕ and θ. On the other hand, the interest reaction function estimates are relative stable, the use of the dummy will not change the significance for each sub-sample estimates.

Table 1.4 reports the GMM estimates of the policy reaction function coefficient and the asymmetric preference parameters for the period between 1992Q4-2008Q3. Firstly, we can confirm that the BoE follows a nonlinear interest response to both inflation and output gap. Indeed, the coefficients which govern the nonlinearity in policy rule (d_2 and d_4) are significantly different from zero, which implies that the hypothesis of linear interest rate response to the inflation rate and output gap can be rejected. Secondly, the negative sign of the recovered coefficients (α and γ) illustrate that the BoE has larger aversion to negative rather than positive output gap value (and inflation rate below the target level). In addition, such findings are robust for both inflation rate measures.

Table 1.4: Reduced form Estimates of the policy function for 1992Q4-2008Q3

	CPI	RPI
d_0	5.37***	5.29***
	(0.10)	(0.08)
d_1	2.50***	1.82***
	(0.71)	(0.40)
d_2	-1.69***	-1.48***
	(0.32)	(0.28)
d_3	3.49***	3.61***
	(0.71)	(0.69)
d_4	-1.20***	-1.04***

	(0.22)	(0.18)
α	-1.34***	-1.64***
	(0.12)	(0.21)
γ	-0.68***	-0.58***
	(0.03)	(0.03)
ϕ	0.07	0.07
θ	0.07	0.07
π^*	2%	2.5%
W(2) p-value	0.00	0.00
J(31) p-value	0.11	0.18

Note: Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W (n) is the Wald test of joint null hypothesis of $d_2' = d_4' = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

Compared with Table 1.4, Table 1.5 reports the sub-sample period's results for the alternative conventional monetary policy period. Again, we can confirm the nonlinear interest response for the BoE, however, compared with the previous case, such nonlinear interest rate response only respect to the output gap. The γ takes the expected sign and consistent with the pervious case, which indicates that the BoE has higher tolerances of output beyond its equilibrium level than below the equilibrium level. On the other hand, the positive and insignificant sign of α are found for both inflation measures, and therefore the asymmetric preference for inflation fluctuations did not exist for this period. But, there is one thing to note that the asymmetric response to output gap also has important implication to the inflation deviations. It is known that, the weak output are generally associated with the risk of future deflation or lower inflation. Consequently, the stronger reaction to the negative output could also due to the risk of future deflation, and potentially suggest that the BoE has less tolerance to inflation under its target rate than beyond its target rate.

Table 1.5: Reduced form Estimates of the policy function for 1992Q4-2007Q3

	CPI	RPI
d_0	5.41***	5.21***
	(0.12)	(0.07)
d_1	2.98***	2.24***
	(0.47)	(0.37)
d_2	0.90	0.60
	(0.95)	(0.56)
d_3	2.67***	3.72***
	(051)	(0.54)
d_4	-1.84***	-2.80***
	(0.55)	(0.74)
α	0.60	0.52
	(0.30)	(0.22)
γ	-1.36***	-1.50***
	(0.18)	(0.16)
ϕ	0.09	0.09
θ	0.10	0.10
π^*	2%	2.5%
W(2) p-value	0.00	0.00
J(31) p-value	0.16	0.20

Note:Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W(n) is the Wald test of joint null hypothesis of $d'_2 = d'_4 = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent.. The script *** and ** denote the rejection of the null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

As we can see from the Table 1.6, once we included the unconventional monetary policy period, the nonlinearity of policy responses to both the output gap and inflation are confirmed in the case of the CPI measure. In particular, the recovered coefficients (α and γ) are negative and statistically different from zero. The results indicate that the BoE assigns more weight for inflation below its target level and output below its equilibrium level for the entire inflation targeting period.

In contrast, the coefficients α and γ are never statistically different from zero under the RPI inflation measurement. For RPI case, it is not completely how these results should be evaluated. In particular, based on the results of the Wald test, we can reject the hypothesis of a linear interest rate response to inflation and output gap. However, the recovered asymmetric coefficients α and γ are not significant different from zero, which are not consistent with the results of the Wald test. In addition, the significant negative value of d_1 violates the model assumption as the value of d_1 should be greater than zero based on the model assumption. Furthermore, the over-identify restrictions for the validate instruments can be rejected for both measures of inflation at 5% significance levels. Overall, such contradictory results suggest that there are only limited evidence for the asymmetric monetary preference once we include the unconventional monetary policy period.

We suspect there are two main reasons behind such counterintuitive findings. Firstly, during the unconventional monetary policy period, the structure of the economy may have changed, in which the aggregate supply and aggrade demand relations may differ from our theoretical framework. Therefore, the first stage IS equation estimates are not sufficient to capture the changes of the structural economy. Secondly, our policy function assumes that the central banks use the interest rate as their policy instrument. However, during the unconventional monetary policy period, it is clear that the policy instrument has changed from interest rate to money supply or other variables. Hence, the results are indicative of the effect of the zero lower bound on the estimation of the policy reaction function.

Table 1.6: Reduced form Estimates of the policy function for 1992Q4-2015Q4

	CPI	RPI
d_0	4.85***	4.38***
	(0.11)	(0.10)
d_1	0.79**	-0.69**
	(0.32)	(0.24)
d_2	-1.85***	-0.41***
	(0.18)	(0.12)
d_3	1.76***	2.08***
	(0.20)	(0.36)
d_4	-0.21***	0.12

	(0.079)	(0.12)
α	-4.68***	1.20
	(0.87)	(0.37)
γ	-0.24**	0.12
	(0.05)	(0.06)
ϕ	0.06	0.06
θ	0.09	0.09
π^*	2%	2.5%
W(2) p-value	0.00	0.00
J(31) p-value	0.02	0.04

Note:Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W (n) is the Wald test of joint null hypothesis of $d_2' = d_4' = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

1.5 Robustness Check

1.5.1 Sensitivity checks for the policy function estimates

Compared with the previous literature for studying the central bank asymmetric preference, their estimation strategy of policy function does not restrict the value of ϕ and θ from the structure of the economy. They treat the coefficients from policy function as convolutions of the structural parameters of the model. However, in our empirical analysis, we rely on the results of IS estimation from the previous section to recover the asymmetric preference parameters. Therefore, our empirical analysis are more consistent with the UK data. However, it should be noted the standard deviations of the estimates of the policy function might be subject to generated regressors bias due to the fact that the 2nd stage estimation (policy function estimations) does not take into account the uncertainty from the 1st stage estimation (IS equation estimation). In order to deal with this problem, we check the sensitivity of the results using the estimates for the IS equation from the previous literature.

There are two purposes for this section. Firstly, whether our estimates of open economy IS equation are in line with the existing literature. Secondly, whether the central bank asymmetric preference still exists under the different IS specifications. The UK empirical evidence of single IS equation estimation is limited compared with the US evidence. Generally speaking, the estimated values of ϕ are positive but below 1 for the US, the range of empirical estimate are around 0.2 for most of the literature who used IV (instrumental variable) approach. But, for the UK's case, the empirical evidence suggests a slightly higher value due to the openness of the UK economy. Here, we will discuss some empirical evidence of IS equations estimates for the UK, and cite theirs IS coefficients to re-estimate the policy function.

Nelson and Nikolov (2004) estimate the following IS equation based on UK quarterly data from 1957Q1-2000Q4:

$$y_t = -\phi[i_t - \pi^e_{t+1}] + \beta(g_t - g^e_{t+1}) + y^e_{t+1} + \varepsilon_t$$

Where β denotes the steady-state of government purchase in GDP and g_t is log real government purchase. They use the IV method to estimate the above equation, and the reported coefficient on ex-ante real interest rate (ϕ) is 0.086.

The forward-looking IS equation has been compared empirically to the backwards-looking version. Estrella and Fuhre (2003) have shown that the latter one can better describe US data. In addition, they mentioned that the forward-looking version suffered from the issue of stability, and conclude that backwards-looking formulation is somewhat more stable than forward-looking formulation. However, by estimating the IS equation for UK data, Kara and Nelson (2004) draw a different conclusion. Their estimation results suggest that forward-looking IS equation for the UK are considerably more stable and interpretable than its backwards-looking counterparts. In order to test whether the forward-looking specification is stable and consistent with the theoretical prediction. They estimated two sample periods, 1957Q1-2002Q4 (ϕ =0.0844) and 1979Q-2002Q4 (ϕ =0.1319), and both of samples can provide significant and correctly signed coefficient on the ex-ante real rate. However, for the backward looking version, the coefficient on expected real interest rate are incorrectly signed and insignificant. They also conduct the robustness check for IS equation without the government-expenditure term, and the estimated coefficient is 0.0789, which is similar with the estimates that include the government spending.

Furthermore, the existing literature has mainly focused on a closed economy IS equation because the absence of the exchange rate, however, as shown in Neiss and Nelson (2003), the impacts of the exchange rate on aggregate demand can be regarded as are being incorporated with the real interest elasticity. Consequently, they argued that the real interest elasticity should be higher if the IS equation contains open economy influences, and therefore they set 0.15 for the model calibration exercise. Kara and Nelson (2003) also use the same value for calibration. Furthermore, in the Bank of England's Quarterly Economic Model (BEQM, 2005), they set a relative low value of 0.05. Table 1.7 provides a brief summary of IS equation coefficients from existing literature, and it is clear that the results of our estimates are located in the same range as the previous studies.

Tale 1.7: The summary of IS equation coefficients from existing literature[13]

Author	Real Interest elasticity	Method	Data Sample
Nelson and Nikolov (2004)	0.086	Instrument Variables	1957Q1-2000Q4
Kara and Nelson (2004)	0.0789	Instrument Variables	1957Q1-2002Q4
Neiss and Nelson (2003), Kara and Nelson (2003)	0.15	Pre-set value for calibration	N.A
Bank of England's Quarterly Economic Model (2005)	0.05	Pre-set value for calibration	N.A
Table 1.3 Estimates	0.07-0.09	Instrument Variables	1992Q4-2008Q3, 1992Q4-20007Q3

The general specification of the open economy IS curve includes the real exchange rate, however adding real exchange rate often leads to insignificant or incorrectly signed coefficient.[14] The results are more reasonable when longer lags are included.[15] The potential reason for weak empirical evidence is the real exchange rate tends to be stable for long periods, and only move dramatically after the change in the macroeconomic framework. For instance, after the Global financial crisis, the British pound has depreciated around 25 percent in later 2008. Furthermore, the British pound has depreciated around 15 percent after the exit from ERM in 1992. However, the open economy IS equation is not able to disentangle from the negative effects associated with the Global financial crisis and the exit from ERM. This is also the reason why we introduce dummy to capture the extreme period in the previous section for open economy IS equation estimates. According to our results, the estimated value of θ is

[13] We have used the annualised interest and inflation rate for estimation, and therefore the real interest elasticity should be $\phi * 4$ if the quarterly interest and inflation rate were used. In order to keep the same notion with the policy function estimation, we assume all the real interest elasticity was computed based on the annualised interest and inflation rate.

[14] Nelson and Nikolov (2004) has reported that the estimated coefficient on real exchange rate is only 0.0015 and insignificant for UK data.

[15] OBR (Office for Budget Responsibility) main macroeconomics model (Murray, 2012).

rather close to ϕ, and therefore we set θ equals to ϕ as the first scenario. For the rest of two, we attach relative smaller value, which are just a half and one thirds of the real interest elasticity. The relative small value of θ also arise because the effects of the exchange rate and foreign output on aggregate demand can be generally regarded as being incorporated in price based on past literature. The $\theta(1)$ represent the case where the θ equals to the value of ϕ. In addition, $\theta(2)$ and $\theta(3)$ depict that the θ is half and one thirds to the value of ϕ. Overall, we have four cases for robustness checks based on the real interest elasticity from Table 1.7, and each case attach with three different pre-set values of θ.

Table 1. 8: The alternative value of ϕ and θ for policy function estimation

	Case 1	Case 2	Case 3	Case 4
Reference	Bank of England's Quarterly Economic Model (2005)	Kara and Nelson (2004)	Nelson and Nikolov (2004)	Neiss and Nelson (2003),
ϕ	0.050	0.079	0.086	0.150
$\theta(1)$	0.050	0.079	0.086	0.150
$\theta(2)$	0.025	0.039	0.043	0.075
$\theta(3)$	0.016	0.026	0.028	0.050

Due to the policy function setting, the same scenarios would generate the same asymmetric preference parameters across different cases. For example, as long as we set θ is equal to ϕ, the value of α and γ would be the same regardless of the value of real interest elasticity. Here, we only report the results where the values for ϕ and θ are equivalent. We also estimate the policy function using two extreme cases where θ is ten times higher than the value of ϕ and ten times lower than the value of ϕ, the results are still consistent with our previous findings[16] In addition, as we only obtain reasonable results for 1992Q4-2015Q4 under CPI inflation measure, the robustness check for

[16] Due to the extreme cases are not plausible for the UK economy, we do not report the results.

1992Q4-2105Q4 is based on CPI. For the rest of two sub-sample periods, we use RPI for the robustness check.

Overall, our sensitivity check confirms our initial findings in the previous section in which the monetary preferences of the BoE have been highly asymmetric during the inflation targeting period. For all three sub-samples period estimates, the results are extremely close to its original setting in the previous section. In particular, when setting the interest rate, the BoE assign higher weights to the output contraction than the output expansion. Again, the period between 1992Q4 and 2008Q3 provides the most consistent result with the A&P's model where the BoE has larger policy responses to negative deviations of inflation and output gap from the target value. For the period between 1992Q4 and 2007Q3, there is only robust evidence for asymmetric preference to the output gap. If we include the unconventional monetary policy period, we can only confirm the asymmetric preference by using CPI data, but it suffered from the issue of weak instruments and the asymmetric preferences are not robust for the RPI case. As a result, we confirm the full sample period provides the least powerful evidence for A&P's model.

Table 1.9: Reduced form Estimates of the policy function for 1992Q4-2008Q3, alternative value of ϕ and θ

	Case 1	Case 2	Case 3	Case 4
d_0	5.29***	5.29***	5.29***	5.29***
	(0.09)	(0.09)	(0.09)	(0.09)
d_1	1.46***	1.59***	0.84***	2.52***
	(0.33)	(0.36)	(0.19)	(0.56)
d_2	-1.20***	-1.31***	-0.69***	-2.07***
	(0.23)	(0.25)	(0.13)	(0.40)
d_3	2.94***	3.20***	1.68***	5.06***
	(0.56)	(0.61)	(0.32)	(0.97)
d_4	-0.85***	-0.92***	-0.48***	-1.47***
	(0.15)	(0.16)	(0.09)	(0.26)
α	-1.64***	-1.64***	-1.64***	-1.64***
	(0.21)	(0.21)	(0.21)	(0.21)
γ	-0.58***	-0.58***	-0.58***	-0.58***
	(0.03)	(0.03)	(0.03)	(0.03)

ϕ	0.086	0.079	0.15	0.05
θ	0.086	0.079	0.15	0.05
W(2) p-value	0.00	0.00	0.00	0.00
J(31) p-value	0.16	0.16	0.16	0.16

Note: Case 1 indicates ϕ=0.086 and $\theta = 0.086$. Case 2 indicates ϕ=0.079 and $\theta = 0.079$. Case 3 indicates ϕ=0.15 and $\theta = 0.15$. Case 4 indicates ϕ=0.05 and $\theta = 0.05$.Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W (n) is the Wald test of joint null hypothesis of $d'_2 = d'_4 = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

Table 1.10: Reduced form Estimates of the policy function for 1992Q4-2007Q3, alternative value of ϕ and θ

	Case 1	Case 2	Case 3	Case 4
d_0	5.21***	5.21***	5.21***	5.21***
	(0.07)	(0.07)	(0.07)	(0.07)
d_1	2.51***	2.74***	1.44***	4.32***
	(0.42)	(0.45)	(0.24)	(0.72)
d_2	0.67	0.73	0.38	1.15
	(0.63)	(0.68)	(0.36)	(1.08)
d_3	4.14***	4.51***	2.37***	7.13***
	(0.60)	(0.66)	(0.35)	(1.04)
d_4	-3.12***	-3.39***	-1.79***	-5.36***
	(0.83)	(0.91)	(0.48)	(1.43)
α	0.54	0.54	0.54	0.54
	(0.22)	(0.22)	(0.22)	(0.22)
γ	-1.50***	-1.50***	-1.50***	-1.50***
	(0.16)	(0.16)	(0.16)	(0.16)
ϕ	0.086	0.079	0.15	0.05
θ	0.086	0.079	0.15	0.05
W(2) p-value	0.00	0.00	0.00	0.00
J(31) p-value	0.19	0.20	0.20	0.20

Note: Case 1 indicates ϕ=0.086 and $\theta = 0.086$. Case 2 indicates ϕ=0.079 and $\theta = 0.079$.Case 3 indicates ϕ=0.15 and $\theta = 0.15$. Case 4 indicates ϕ=0.05 and $\theta = 0.05$. Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W (n) is the Wald test of joint null hypothesis of $d'_2 = d'_4 = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

Table 1.11: Reduced form Estimates of the policy function for 1992Q4-2015Q4, alternative value of ϕ and θ

	Case 1	Case 2	Case 3	Case 4
d_0	4.87***	4.87***	4.87***	4.87***
	(0.11)	(0.11)	(0.11)	(0.11)
d_1	0.77**	0.84**	0.44**	1.33**
	(0.32)	(0.35)	(0.18)	(0.54)
d_2	-1.83***	-1.99***	-1.05***	-3.14***
	(0.18)	(0.1)	(0.10)	(0.30)
d_3	1.69***	1.84***	0.97***	2.91***
	(0.18)	(0.20)	(0.10)	(0.32)
d_4	-0.25***	-0.27***	-0.12***	-0.43***
	(0.07)	(0.08)	(0.04)	(0.12)
α	-4.70***	-4.70***	-4.70***	-4.70***
	(0.88)	(0.88)	(0.88)	(0.88)
γ	-0.30***	-0.30***	-0.30***	-0.30***
	(0.05)	(0.03)	(0.05)	(0.05)
ϕ	0.086	0.079	0.15	0.05
θ	0.086	0.079	0.15	0.05
W(2) p-value	0.00	0.00	0.00	0.00
J(31) p-value	0.01	0.01	0.01	0.01

Note: Case 1 indicates ϕ=0.086 and $\theta = 0.086$. Case 2 indicates ϕ=0.079 and $\theta = 0.079$. Case 3 indicates ϕ=0.15 and $\theta = 0.15$. Case 4 indicates ϕ=0.05 and $\theta = 0.05$. Instruments are the constant and five lags of the following variables (starting from date $t - 1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W (n) is the Wald test of joint null hypothesis of $d'_2 = d'_4 = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

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1.5.2 Target rate or Target band?

It should be noted that our previous empirical analysis assumes that the BoE targets the inflation rate to a specific rate (either 2% or 2.5%). However, the actual policy framework is more complicated than our settings. In detail, the BoE had a target range of 1-4% prior to 1995. Then, they reinterpreted the inflation target to a numerical value of 2.5% in 1995. Since 1997, the BoE introduced a tolerance range with 1%, which imply that the BoE allows inflation rate could either go 1 percent beyond or below than its target rate. Consequently, there are possibilities that the BoE could target the inflation either to its lower band or upper band instead of its official target rate.

On the basis of the above, we perform another robustness test. In detail, we re-estimate the policy function by using the same empirical strategy and the pre-set values of θ and ϕ (see Table 1.1) as the baseline case in section 1.4.4. The only difference is we change the π^* from its official inflation targeting rate to its lower band and upper band rate. The lower band and upper band for CPI are 1% and 3%, and are 1.5% and 3.5% for RPI. The setting implies that the BoE has 1% tolerance level to its inflation target rate.

In terms of the period between 1992Q4-2008Q3, the results for the lower band are consistent with our baseline analysis. The BoE has nonlinear interest response to both inflation and output gap, and such nonlinear interest response can be quantified as the BoE assign higher weights to inflation below its target level and output gap below its equilibrium level. On the other hand, the upper band target rate provides less powerful evidence as we can only obtain a nonlinear interest response to the output gap.

Table 1. 12: Reduced form Estimates of the policy function for 1992Q4-2008Q3, alternative inflation targeting rate

	CPI		RPI	
	Lower band	Upper band	Lower band	Upper band
d_0	5.03***	5.73***	4.82***	5.53***
	(0.13)	(0.14)	(0.08)	(0.12)
d_1	1.48	-0.13	3.62***	0.67
	(1.29)	(0.42)	(0.85)	(1.06)
d_2	-0.70**	-1.80***	-1.19***	-0.98**
	(0.33)	(0.28)	(0.35)	(0.41)
d_3	4.02***	3.05***	4.45***	2.73***
	(0.61)	(0.79)	(0.55)	(0.91)
d_4	-1.18***	-1.15***	-1.26***	-1.05***
	(0.20)	(0.24)	(0.17)	(0.24)
α	-0.94**	28.04	-0.66***	-2.90
	(0.21)	(46.04)	(0.04)	(2.86)
γ	-0.58***	-0.74***	-0.56***	-0.76***
	(0.02)	(0.04)	(0.02)	(0.07)
ϕ	0.07	0.07	0.07	0.07

θ	0.07	0.07	0.07	0.07
π^*	1%	3%	1.5%	3.5%
W(2) p-value	0.00	0.00	0.00	0.00
J(31) p-value	0.09	0.11	0.17	0.09

Note:Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W(n) is the Wald test of joint null hypothesis of $d_2' = d_4' = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

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For the period between 1992Q4 and 2007Q3, the lower band confirms the nonlinear interest response to the output gap but not to the inflation rate, which is consistent with our initial empirical findings. The BoE still has large aversions to the output gap below its equilibrium level under the lower band target. However, the results do not follow the assumption of A&P's model. Indeed, the coefficient of d_1 is positive based on the structure of the economy, but we obtain negative value for both inflation measures. In terms of the upper band, the results remains problematic for our analysis. It is clear that we can obtain the asymmetric preference for both inflation rate and output gap. However, it should be noted that the negative output gap always associate with the risk of deflation or low inflation. Hence, the sign for parameters of asymmetric monetary policy preference should be the same. In other words, once we obtain na egative value of γ, then the sign of α should also be negative as it implies that the BoE weights the downside of the economy more than the upside. Here, we obtain the opposite sign for α and γ in the case of the upper band, and therefore the implication of the results are not clear.

Table 1. 13: Reduced form Estimates of the policy function for 1992Q4-2007Q3, alternative inflation targeting rate

	CPI		RPI	
	Lower band	Upper band	Lower band	Upper band
d_0	5.29***	7.18***	4.96***	6.09***
	(0.08)	(0.20)	(0.10)	(0.12)
d_1	-4.17***	12.52***	-0.14	5.24***
	(1.32)	(1.87)	(1.03)	(1.20)
d_2	3.38***	3.97***	1.04*	1.22**
	(0.78)	(0.76)	(0.60)	(0.50)
d_3	2.46***	1.31**	4.08***	3.25***
	(0.58)	(0.57)	(0.50)	(0.62)
d_4	-1.41**	-1.44***	-3.13***	-3.20***
	(0.55)	(0.50)	(0.77)	(0.62)
α	-1.62***	0.62***	-14.50	0.46***
	(0.09)	(0.01)	(48.19)	(0.04)
γ	-1.14***	-2.20***	-1.54***	-1.96***
	(0.18)	(0.38)	(0.16)	(0.16)
ϕ	0.09	0.09	0.09	0.09
θ	0.10	0.10	0.10	0.10
π^*	1%	3%	1.5%	3.5%
W(2) p-value	0.00	0.00	0.00	0.00
J(31) p-value	0.15	0.20	0.19	0.28

Note:Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W(n) is the Wald test of joint null hypothesis of $d'_2 = d'_4 = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

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If we include the unconventional monetary policy period for the policy function estimation, the results again provide the least evidence for the nonlinear interest response. In addition, the results do not provide a better interpretation of the policy reaction function compared with our baseline case. For the lower band, although there are nonlinear interest responses to inflation for CPI and output gap for RPI, we are only able to quantify the nonlinearities for CPI as the coefficients govern the asymmetric preference are both insignificant for RPI. For the upper band, we obtain the significant and negative values of d_1, which again violate the model assumption.

Table 1. 14: Reduced form Estimates of the policy function for 1992Q4-2015Q4, alternative inflation targeting rate

	CPI		RPI	
	Lower band	Upper band	Lower band	Upper band
d_0	4.52***	4.73***	4.72***	4.21***
	(0.13)	(0.13)	(0.11)	(0.13)
d_1	1.32	-2.07***	-0.95***	-1.13***
	(1.07)	(0.46)	(0.22)	(0.30)
d_2	-1.02***	-1.79***	-0.14**	-0.57***
	(0.36)	(0.21)	(0.06)	(0.21)
d_3	1.93***	2.18***	2.29***	1.90***
	(0.30)	(0.30)	(0.37)	(0.53)
d_4	-0.09	-0.12	-0.11	0.27
	(0.10)	(0.11)	(0.15)	(0.18)
α	-1.54**	1.72***	0.28	1.02***
	(0.36)	(0.15)	(0.10)	(0.19)
γ	-0.10	-0.10	-0.10	0.28
	(0.06)	(0.05)	(0.07)	(0.11)
ϕ	0.06	0.06	0.06	0.06
θ	0.09	0.09	0.09	0.09
π^*	1%	3%	1.5%	3.5%
W(2) p-value	0.02	0.00	0.01	0.02
J(31) p-value	0.02	0.01	0.05	0.02

Note:Instruments are the constant and five lags of the following variables (starting from date $t-1$): output gap, squared output gap, CPI inflation, RPI inflation, interest rate, foreign interest rate, nominal exchange rate. W(n) is the Wald test of joint null hypothesis of $d_2' = d_4' = 0$. J(m) is the statistics of Sargan-Hansen J test for m over-identify restriction, a rejection of null hypothesis indicates the estimates are not consistent. The script *** and ** denote the rejection of null hypothesis of coefficient is zero at 1% and 5% significance levels. Values in parentheses are strand errors using the Newey-West correction for the covariance matrix.

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Overall, using the lower band and upper band of the inflation target rate do not provide better results for the central bank's asymmetric preference. In particular, the results of the lower band for 1992Q-2007Q4 and the upper band for 1992Q4-2015Q4 are not intuitive as those results violate the model's assumption. Hence, we conclude that in practice the BoE follows its official inflation target rate.

1.6 Conclusion

This paper has investigated a nonlinear optimal monetary policy model for the BoE within the context of an open economy framework. By doing so, we follow the theoretical framework suggest by A&P. In contrast with the existing literature, A&P's model considers the exchange rate effects of the monetary policy preferences, and more importantly, the model explains the reported asymmetric exchange rate responses based on the asymmetric monetary policy preference. This feature is crucial for the UK economy as the movement of the British pound can be characterised as asymmetric from the previous empirical studies.

We estimate the policy reaction function for the BoE using the GMM method. As there is no strong information about the structural parameters in the policy function, we firstily perform an open economy IS estimation to obtain the structural parameters. Then, replacing the structural parameters in the policy function by using the estimated value from IS estimates to conducting the second stage estimation (policy function estimation). The data is on quarterly basis and span the period from 1992Q4 to 2015Q4. Due to the structural change of the monetary policy in the financial crisis, we estimate the policy function for three sub-sample periods, 1992Q4-2007Q3, 1992Q4-2008Q3 and 1992Q4-2015Q4. The first two periods are the conventional monetary policy period while the last period covers the unconventional monetary policy period. For the conventional monetary policy period, the empirical evidence suggests that the negative output gap trigger larger policy responses than positive output gap of the same size for the BoE. In addition, we also found the BoE is more averse to the negative inflation gap rather than the positive inflation gap, but only occurs for 1992Q4-2008Q3 not for 1992Q4-2007Q3. It is known that the negative output is always accompanied with the risk of future deflation or low inflation, the larger aversion to negative output may reflect the BoE also assign more weight on the negative inflation gap. Thus, our results for 1992Q4-2007Q3 also reflect the fact that the BoE may have larger aversions to the negative inflation gap than positive inflation gap. Overall, we conclude that the BoE has larger policy responses to the downside of the economy than the upside of the economy during the conventional monetary policy period. Once we include the unconventional monetary period for our policy function estimates, the evidence of asymmetric monetary policy preferences is not robust as there is an inconsistency between CPI and RPI inflation measures and the hypothesis of invalid instruments cannot be rejected.

In addition, although the BoE targets the inflation to a specific numerical value, we consider the possibility that the BoE could target the inflation rate to its upper band level or lower band level. This arises because the BoE has introduced a tolerance range for its numerical target rate. By re-estimating the policy reaction function using the lower band and upper band of inflation, the results are less powerful and seem inconsistent with the model's assumption. Consequently, we argue that the target rate of 2.5% (or 2% for CPI) is more plausible to investigate the BoE's monetary policy within the context of an open economy framework.

Furthermore, I suggest two points for the further research. First, it should be noted that the standard deviations of the policy function estimates might be subject to generated regressors bias due to the fact that the policy function estimates do not take into account the uncertainty from the IS equation estimates. In order to address this issue, we conduct sensitivity checks for the policy function estimates using the estimates for the IS equation from the previous literature. But, there is a more robust approach to address this issue. In detail, we can conduct a bootstrap exercise for the two regressions and compute confidence intervals for the estimates to address the possible issue of generated regression bias. Thus, we can better control the uncertainty of the IS estimation, and strength the findings from the policy function estimates. Secondly, the A&P model applies to a small open economy that operates credible inflation targeting monetary policy. There is no reason to investigate the model only for the BoE, and therefore we suggest that A&P's model could expand to a set of countries who have similar monetary policy framework with the BoE.

Chapter 2

Out-of-sample Exchange Rate Predictability with Asymmetric Monetary Preferences

2.1 Introduction

It is well known that there is a missing link between the exchange rate and economic or financial fundamentals. Past literature has found that the exchange rate is extremely difficult to predict using macroeconomic fundamentals. In particular, there is no strong empirical evidence that macroeconomic fundamentals can provide better forecasting performance than a naive random walk. Obstfeld and Rogoff (2000) describe this phenomenon as "exchange rate disconnect puzzle."

The exchange rate disconnect puzzle has received numerous attention from previous literature, and many of them have reported positive results for economic exchange rate models. However, these findings are still questionable. For example, Sarno and Taylor (2000) state that "***Overall, the conclusion emerges that, although the theory of exchange rate determination has produced a number of plausible models, empirical work on exchange rates still has not produced models that are sufficiently satisfactory to be considered reliable and robust***."

Since the late 2000s, the literature has reported some positive results by implementing new macroeconomic fundamentals or more powerful test statistics. Recently, the literature has reached a consensus that the empirical evidence is not favourable to traditional economic model such as Purchasing Power Parity (PPP), Uncovered Interest Rate Parity (UIRP) and monetary models. But, there is a consensus that Taylor rule fundamentals has more out-of-sample predictability than the traditional economic models, and can outperform a naive random walk (Rossi 2014).

Taylor rule is a monetary policy rule initiated by Taylor (1993). It shows that the central bank sets interest rate in response to change in inflation and the output gap. If two economies follow Taylor rule and subtracting a Taylor rule for the foreign country from a Taylor for the domestic country, we can obtain an equation of the interest rate differential. As UIRP shows that their bilateral exchange rate is determined by their interest rate differential, then, we can replace the interest rate differential in the UIRP by their inflation levels and output gaps. Thus, a Taylor rule exchange rate equation is derived.

The present study challenges the Taylor rule fundamentals from the following perspectives. The main implication of Taylor rule fundamentals is it shows that the increase (decrease) in domestic inflation generate forecasts of exchange rate appreciation (depreciation), which is consistent with the past empirical evidence that bad news of inflation is good news for the exchange rate. However, past empirical evidence also suggests the relationship described above is not linear but subject to sign effects. The depreciation following bad news of inflation are larger than the appreciation following the good inflation news, and therefore this phenomenon can be described as asymmetric exchange rate responses under inflation announcements.

It is clear that the Taylor rule only assumes that interest rate is a linear function of the output gap and inflation, and therefore the Taylor rule based fundamentals cannot capture the asymmetric exchange rate responses. In order to capture the asymmetric exchange rate behaviour in responses to the deviations of output gap and inflation, we first extend the conventional Taylor rule exchange rate model. Compared with the standard Taylor rule exchange rate model, we present an augmented Taylor rule fundamentals based on a nonlinear monetary policy rule, in which exchange rate is not only a function of inflation and output gaps but also a function of their squared value. This specification allows us to determine the exchange rate using the assumption of asymmetric exchange rate responses. Secondly, given the fact that the empirical evidence of asymmetric exchange rate responses is more significant for inflation targeting countries, we investigate the out-of-sample exchange rate predictability of the augmented Taylor rule fundamentals for six inflation targeting countries exchange rate (Australia, Canada, Norway, New Zealand, Sweden and the UK) relative to the United States dollar. In order to test the out-of-sample exchange rate predictability, we estimate the augmented Taylor rule fundamental by OLS in rolling regression and use the CW statistic (Clark and West, 2006)[17] to examine the exchange rate predictability. In addition, as a way to provide a robustness check, we also report the DMW statistic (see Diebold and Mariano, 1995, and West 1996) and the ratio of the root mean squared forecasted error (RMSFE) of the augmented Taylor rule fundamentals to that of the random walk model.

We consider four sub-periods for our estimates, the full available sample, the whole inflation targeting period, the conventional monetary policy period (after the introduction of inflation targeting regime but prior to the zero lower bound period), and the unconventional monetary policy period (the period of zero lower bound). The

[17] The CW statistic is explained further in the chapter, please see section 2.4.2.

reason for using sub-periods is the monetary policy may experience several policy shifts during the last three decades, therefore, the explanatory power of the augmented Taylor rule may differ for each sub-period. For instance, the empirical evidence suggests that the asymmetric exchange rate responses are more significant after the introduction of the inflation targeting regime, however, with the introduction of QE and interest rate enters the zero lower bound, such asymmetric exchange rate responses may be questionable during and after the recent financial crisis. Hence, it is important to check whether the exchange rate predictability can survive after the financial crisis or before the adoption of inflation targeting regime. For comparison purposes, we also evaluate the out-of-sample exchange rate predictability for Taylor rule fundamentals and interest rate fundamentals.

Our empirical results illustrate the role of asymmetric exchange rate responses are essential for determining the exchange rate movement. By using the CW statistic to evaluate the out-of-sample performances, the augmented Taylor rule fundamentals can provide stronger evidence of exchange rate predictability than the Taylor rule fundamentals during the conventional monetary policy period. However, the exchange rate predictability for augmented Taylor rule fundamentals falls apart when we include the pre-inflation targeting period or the unconventional monetary policy period. On the other hand, Taylor rule fundamentals can maintain its predictability when we included both periods. In addition, the evidence of exchange rate predictability is much lower for the interest rate fundamentals

The rest of the chapter is organized as follows: Section 2.2 discusses the past literature for Taylor rule fundamentals. Section 2.3 presents the theoretical framework for standard Taylor rule fundamentals and augmented Taylor rule fundamentals. Section 2.4 shows the data and methodology while section 2.5 shows the estimation strategy and the empirical results, and the conclusion is represented in section 2.6.

2.2 Literature review

In the last ten years, existing studies have illustrated that the Taylor rule fundamentals is able to provide better exchange rate predictability than the random walk model, and it has become the dominant model for exchange rate forecasting literature. Molodtsova and Papell (2009) show that Taylor rule fundamentals can provide strong short-run evidence of exchange rate predictability. They evaluate the exchange rate predictability using the CW statistic for 12 OECD countries relative to the United States over the post-Bretton Woods period. At the one-month horizon, they found that there are 11 out of 12 currencies have evidence of exchange rate predictability at 5 percent significance levels. On the other hand, the evidence of exchange rate predictability for PPP, interest rate fundamentals and monetary model is much weak compared with the Taylor rule fundamentals.

However, there is a data issue for evaluating the out-of-sample exchange rate predictability using economic fundamentals. This issue arises because the data of main macroeconomic variables (such as GDP) are continuously revised by statistical agencies. Therefore, empirical analysis based on revised data often generates different conclusion for those based on real-time data (Croushore and Stark, 2003). In order to address this issue, Molodtsova *et al.* (2008) use real-time data to estimate Taylor rule fundamentals for the US and Germany from 1979. Their empirical results suggest that the out-of-sample exchange rate predictability for Taylor rule fundamentals is robust for using real-time data, and the evidence with real-time data are even stronger than the evidence with revised data. In addition, Molodtsova *et al.* (2011) show similar evidence for evaluating Taylor rule fundamentals exchange rate predictability of dollar/euro exchange rate by using the real-time data.

Another issue with Taylor rule fundamentals is whether the Taylor rule variables are still relevant after the recent financial crisis. It is clear that the Taylor rule assumes the short-term interest rate as the main policy instrument. However, this assumption may collapse after the recent financial crisis. As the interest rates in major advanced economies have been at the zero lower bound along with the introduction of QE, it is more reasonable to assume the change in the level of money supply as the main monetary policy instrument rather than changes in the interest rate. Consequently, an important question to explore is whether the exchange rate predictability of Taylor rule fundamental can still hold when the date extended to the post-unconventional monetary policy period (Chinn 2008). Ince *et al.* (2016) extend the data of Molodtsova and Papell (2009) to December 2014, and find the out-of-sample exchange rate predictability of Taylor rule fundamentals does not collapse even if the periods of the financial crisis and zero lower bound are included in the sample. Furthermore, in order to analyse the out-of-sample exchange rate predictability during the financial crisis, Molodtsova and Papell (2013) modified the Taylor rule fundamentals by including the financial stress variable in the Taylor rule. For their empirical analysis, although the out-of-sample exchange rate predictability for Taylor rule fundamentals does not fall apart during the financial crisis, the modified Taylor rule fundamentals that incorporate financial condition variables outperform the original Taylor rule fundamentals.

It should be noted that the positive empirical evidence of Taylor rule fundamentals depends on the choice of evaluation methods. In particular, the reported evidence of exchange rate predictability for Taylor rule fundamentals is only significant for CW statistic, although with the exceptions. Rogoff and Stavrakeva (2008) have pointed out that the successful results by using CW statistic do not necessarily mean that the Taylor rule fundamentals has forecasting ability. The forecasting ability only occurs when the mean squared forecasted error (MSFE) for the alternative model (Taylor rule fundamentals) is significantly less than the MSFE for the null model. However, the predictability occurs when the coefficients on the alternative model are significantly different from zero in a regression, and therefore, is not equivalent to forecasting content. Therefore, Molodtsova (2009) stated that the positive results based on CW statistic only imply exchange rate predictability rather than forecast ability. Overall, the evidence of exchange rate predictability does not mean that the model would be useful for exchange rate market.

2.3 Taylor rule fundamental

2.3.1 Standard Taylor rule fundamentals

The idea of Taylor fundamental model of exchange rates is linking the exchange rate with a set of fundamentals based on a Taylor rule for monetary policy. Here, we will discuss and adopt the approach from 7, (hereafter, M&P).

Taylor (1993) proposed the idea that the central bank sets the interest rate as a function of how inflation deviates from its target level and also as a function of how actual output differs from its potential level, and therefore Taylor rule can be specified as:

$$i_t^* = \pi_t + \omega(\pi_t - \pi_t^*) + \beta y_t + r^* \quad (1.1)$$

Where i_t^* is the target nominal interest rate, π_t is the inflation rate, π_t^* is the target inflation rate, y_t is the output gap (deviation of actual real GDP from its potential level) and r^* is the equilibrium real interest rate. Taylor rule demonstrates that the central bank will increase the target for the nominal interest rate if inflation above its target level (and/or actual output above its potential level). By combing the parameters r^* and $\omega\pi_t^*$ into one constant term μ, we can have the following equation:

$$i_t^* = \mu + \alpha\pi_t + \beta y_t \quad (1.2)$$

Where $\mu = r^* - \omega\pi_t^*$. M&P adjusted the equation (1.2) by taking into account two facts from the past literature. According to the open economy setting suggested by Svensson (2000), central banks try to maintain the exchange rates at its purchasing power parity level. As the result, they add the real exchange rate to equation (1.2). In addition, they include a lagged dependent variable to capture interest rate smoothing, which reflects the fact that the interest rate changes are gradually as central banks do not want to overachieve their target (see Clarida, Gali and Gertler, 1998). Accordingly, we obtain the following equation:

$$i_t = (1-\rho) * (\mu + \alpha\pi_t + \beta y_t + \gamma q_t) + \rho i_{t-1} + \epsilon_t \quad (1.3)$$

Where q_t denotes the real exchange rate and ϵ_t is the monetary policy shock. Equation (1.3) is the adjusted Taylor rule for all countries except for the United States. As γ is equals to zero for the United States, the Taylor rule for the US as follows:

$$i_t = (1-\rho) * (\mu + \alpha\pi_t + \beta y_t) + \rho i_{t-1} + \epsilon_t \quad (1.4)$$

By subtracting the adjusted Taylor rule for the foreign country from that for the US and redefine the coefficients, we can obtain the following equation:

$$i_t - i_t^f = \varphi_0 + \varphi_1\pi_t - \varphi_2\pi_t^f + \varphi_3 y_t - \varphi_4 y_t^f - \varphi_5 q_t + \varphi_6 i_{t-1} - \varphi_7 i_{t-1}^f + u_t \ (1.5)$$

Where f denotes the foreign variables and φ_0 is a constant.

According to uncovered interest parity (UIRP) condition:

$$(1 + i_t) = \frac{s_{t+1}^e}{s_t}(1 + i_t^f) \ (1.6)$$

Where s_t is the nominal exchange rate between the dollar and foreign currency and i_t^f is the foreign interest rate. The increase of s_t means the deprecation of dollar. The superscript e represent the expectation of the variable. By taking log for the both sides:

$$i_t - i_t^f = \Delta_{s_{t+1}}^e \ (1.7)$$

Then, we can derive an exchange rate forecasting equation by substituting the interest rate differential out using equation (1.5),

$$\Delta s_{t+1} = \varphi_0 + \varphi_1\pi_t - \varphi_2\pi_t^f + \varphi_3 y_t - \varphi_4 y_t^f - \varphi_5 q_t^f + \varphi_6 i_{t-1} - \varphi_7 i_{t-1}^f + \varepsilon_t \ (1.8)$$

Under UIRP condition and rational expectations, any event that causes the Fed to raise the Fed funds rate will produce immediate appreciation of the dollar and forecasted depreciation of the dollar. However, there is preponderant evidence to suggest that the UIRP does not hold in the short run. The past literature has discussed the violation of UIRP condition extensively, and pointed out two outstanding puzzles in the context of international macroeconomics, which are forward premium puzzle (see Chinn, 2006) and delayed overshooting puzzle (see Eichenbaum and Evans, 1995). By now, there is still no complete answer to these two puzzles, but some literature does provide meaningful explanations. For example, Gourinchas and Tornell (2004) show that if investor misperceived the persistence of interest rate shock, an increase in the interest rate can produce sustained exchange rates appreciation.

Therefore, based on both empirical and theoretical evidence, M&P argue that it is more reasonable to assume that any events cause the monetary authority to increase its interest rate will lead to immediate and forecasted appreciation of its domestic currency. It is clear that the signs of the coefficients in equation (1.8) violate the past empirical evidence of UIRP as it reflects the fact that any event that causes the monetary authority to raise the domestic interest rate will produce immediate appreciation and forecasted depreciation of the domestic currency. Hence, M&P show that the signs of the coefficients in equation (1.8) should be reversed, which give the following equation:

$$\Delta s_{t+1} = \theta_0 - \theta_1 \pi_t + \theta_2 \pi_t^f - \theta_3 y_t + \theta_4 y_t^f + \theta_5 q_t^f - \theta_6 i_{t-1} + \theta_7 i_{t-1}^f + \varepsilon_t \quad (1.9)$$

2.3.2 Augmented Taylor rule fundamentals

Past literature has demonstrated that the announcements of inflation rate have significant effects on the change of exchange rate and summarized two stylized facts of the exchange rate effects of inflation announcements. Firstly, the positive inflation surprises (when actual inflation is announced to have exceeded than its expected value) will be followed by an appreciation of the domestic currency (Conrad and Lamla, 2010). This fact clearly goes against the prediction of the Purchasing Power Parity (PPP), as the increase of the inflation should lead to a depreciation of the domestic currency. Such inconsistency could explain on the basis of a credible inflation-targeting monetary policy. If expectations are well anchored to a credible inflation target, positive inflation surprise triggers an increase in short-term domestic interest rate, which leads to an increase in the real return of the domestic currency. Then, in turns, cause a domestic currency appreciation. In addition, it should be noted that such effects have to be strong enough to counterbalance the PPP effects, which tends to depreciate the domestic currency on the impacts of positive inflation surprise.

Secondly, the relationship described above is not linear but subject to sign effects. The depreciations following the negative inflation surprise (actual inflation is less than its expected value) are larger in absolute values, and strong statistical significance, than the appreciations following the positive inflation surprise. Therefore, we call such non-linear relationship as asymmetric exchange rate responses under inflation surprises.

In particular, Clarida and Waldman (2008) evaluate these two stylized facts using a ten-country sample, which includes eight inflation targeting countries and two non-inflation targeting countries. Their empirical findings can be concluded as follows. Firstly, they found both stylized facts are significant for the inflation targeting countries. However, there are no significant effects of inflation announcements on the nominal exchange rate for the non-inflation targeting countries. In addition, there is evidence of regime change for the inflation targeting countries. In particular, the estimated coefficient between inflation rate and the exchange rate is only positive (the positive inflation surprise leads to an appreciation of the domestic currency) and significant during the inflation targeting period. However, prior to the inflation targeting period, the estimated coefficient becomes negative and statistically insignificant. Overall, the two stylized facts that described above are more significant for inflation targeting countries than non-inflation targeting countries.

Arghyrou and Pourpourides (2016) provide a theoretical explanation for the asymmetric exchange rate response. They show that such asymmetric exchange rate response is caused by the central bank's asymmetric monetary policy preference. To be specific, if central bank has larger aversions to inflation rate under its target level (and/or actual output gap under its potential level) than inflation rate greater than its target level (and/or actual output gap beyond its potential level). Then, under a credible inflation targeting regime, they will reduce the interest rate more heavily when interest rates need to be reduced to meet the inflation target than increase the interest rate when interest rate must be increased to meet the same target. Markets can anticipate the difference in the adjustment of the nominal interest rate, they will sell higher volumes of the domestic currency when the negative inflation surprise occurs than the volumes they are willing to buy when the positive inflation surprise occurs, and thus, such behaviours lead to asymmetric exchange rate response to inflation surprises.

It is clear that the Taylor rule (equation 1.3) assumes that the central bank only has a symmetric preference when setting the interest rate, which cannot capture the asymmetric monetary preference, and the potential asymmetric exchange rate response caused by the asymmetric monetary preference. Following A&P.s theoretical justification, we derive a forecasting equation for inflation targeting country under the assumption that policymakers have asymmetric. In order to derive such forecasting equation, we first adopt an interest rate reaction function suggest by Surico (2007). In detail, Surico (2007) derive an optimal monetary policy rule based on a linear exponential (Linex) loss function and a linear structure of the economy, the optimal policy rule reads[18]:

$$-d_1\left[e^{\alpha(\pi_t-\pi^*)}-1\right]-d_2(e^{\gamma y_t}-1)+d_3(i_t-i^*)=0 \quad (2.0)$$

By using the Taylor approximation to simplify the exponential terms in the optimal policy rule, we obtain the following interest rate reaction function for the inflation targeting country:

$$i_t=(1-\rho)*[c_0+c_1(\pi_t-\pi^*)+c_2(\pi_t-\pi^*)^2+c_3y_t+c_4(y_t)^2+c_5q_t]+\rho i_{t-1}+u_t \quad (2.1)$$

[18] See Appendix 3 for the derivation of optimal policy rule.

Where π^* is the inflation targeting rate and c_0 is the equilibrium interest rate i^*. Compared with equation (1.3), an important feature for equation (2.1) is that it allows central bank respond to the squared values of inflation and output gap, which is different from the conventional monetary policy rule suggested by Taylor rule (1983) where the central banks only respond the level of inflation and output gap. A negative coefficient on the squared terms means that the interest rate easing required by inflation rate below its target level (or output gap contraction) of a given size are greater than interest rate tightening caused by inflation rate greater than its target level (or output expansions) of the same magnitude, and such asymmetric interest responses lead to an asymmetric objective on the inflation rate (or output) for the central bank.

In addition, as the Fed does not have an explicit inflation target, the interest rate reaction function for the Fed remain the same, and follows equation (1.4). Then, through the UIRP condition, we can derive the following exchange rate forecasting equation between the US and inflation targeting country:

$$\Delta s_{t+1} = d_0 + d_1\pi_t - d_2(\pi_t^f - \pi^{f*}) + d_3 y_t - d_4 y_t^f - d_5(\pi_t^f - \pi^{f*})^2 - d_6(y_t^f)^2 - d_7 q_t^f + d_8 i_{t-1} - d_9 i_{t-1}^f + \varepsilon_t \quad (2.2)$$

If we follow M&P's presumptions that any events cause the monetary authority to increase its interest rate will lead to immediate and forecasted appreciation of its domestic currency. The signs of the coefficients in equation (2.2) should also be reversed. Accordingly, the forecasting equation for the augmented Taylor rule fundamentals reads:

$$\Delta s_{t+1} = d_0 - d_1\pi_t + d_2(\pi_t^f - \pi^{f*}) - d_3 y_t + d_4 y_t^f + d_5(\pi_t^f - \pi^{f*})^2 + d_6(y_t^f)^2 + d_7 q_t^f - d_8 i_{t-1} + d_9 i_{t-1}^f + \varepsilon_t \quad (2.3)$$

Where s_t is the log of the nominal exchange rate, the nominal exchange rate is expressed as the dollar price of one unit foreign currency, and therefore the increase in s_t denotes a depreciation of the dollar. The coefficients d_5 and d_6 are crucial for the augmented Taylor rule fundamentals. The negative value of d_5 (d_6) illustrates that the forecasted deprecation of the foreign currency caused by foreign inflation rate below its target level (foreign output contraction) of a given size are greater than the forecasted appreciation of the foreign currency caused by foreign inflation rate greater than its target level (foreign output expansion) of the same magnitude. Since the equation (2.3) is able to capture the asymmetric exchange rate responses, we call this equation (2.3) as an augmented Taylor rule fundamentals for the exchange rates while equation (1.9) can be labelled as a standard Taylor rule fundamentals models of the exchange rates.

It should be noted that the signs of coefficients for equation (2.3) have two problems. First, as the empirical work on UIRP and the existence of the carry trade suggest that UIRP does not hold in the short run and may only hold in the long run, it is not clear for the coefficients on the interest differentials in the UIRP condition. In addition, there is no strong prior information about the coefficients that govern the asymmetric monetary preferences (d_5 and d_6) as well as the coefficients for other variables. In other words, there is not a strong prior that the signs of the coefficients in equation (2.3) are correct. Consequently, we estimate equation (2.3) without restricting the signs of the coefficients.

Furthermore, as there is no consensus for interest rate smoothing and the real exchange rate targeting, we follow M&P's approach, and set four specifications for Taylor rule fundamentals. We call Taylor rule fundamentals as asymmetric if the foreign central bank targets the real exchange rate. Otherwise, it is symmetric. In addition, the model is smoothing if a lagged interest rate variable is included. Otherwise, it is no smoothing. Overall, we will have four specifications: asymmetric with no smoothing (where d_8 and d_9 are equal to zero), symmetric with no smoothing (where d_7, d_8 and d_9 are equal to zero), asymmetric with smoothing (identical to equation 2.3) and symmetric with smoothing (where d_7 is equal to zero).

2.3.3 Interest rate fundamentals

For comparison purposes, we also consider the interest rate fundamentals for out-of-sample forecasts. Under the UIRP condition, the nominal interest rate differential is equal to the expected change in the log exchange rate. Accordingly, the forecasting equation based on UIRP reads:

$$\Delta s_{t+1} = \varphi + \psi(i_t - i_t^f) + \xi_t \quad (2.4)$$

As we mentioned above, the past literature suggests that the UIRP may only hold in the long run, and clearly does not hold in short-run. Therefore, we follow Clark and West (2006), and equation (2.4) is estimated without restricting the coefficients on the interest rate differentials.

2.4 Data and Methodology

2.4.1 Data

We investigate out-of-sample exchange rate predictability of standard Taylor rule fundamentals and augmented Taylor rule fundamentals for the US dollar against six inflation targeting countries-Australia, Canada, New Zealand, Norway, Sweden and the UK. These countries are using formal frameworks of inflation targeting regime, which means the inflation targeting is set by secondary legislation or voluntary agreement with the government. Some central banks like European Central Bank or Bank of Japan also use the elements of the inflation targeting regime, but they either without official inflation targeting rate or have other policy goals such as economic growth or unemployment rate. As a result, we exclude the countries who only partially adopt the inflation targeting regime.

The models are estimated using monthly data. We use the bilateral nominal exchange rate (relative to US dollar) from the Federal Reserve Bank of St. Louis to represent the exchange rate term. The exchange rate is defined as the domestic price (US dollar) for a unit of foreign currency, therefore, an increase in the exchange rate is a depreciation of the domestic currency (US dollar). In addition, the inflation is measured as the annual change of the CPI,[19] and the interest rate is measured by the money market rate. Both inflation and interest rate are taken from the OECD database. Due to the GDP only available on the quarterly basis, we follow the previous literature by using the industrial production index as a proxy of GDP. We use the Hodrick-Prescott cyclical component (HP filter) of the industrial production index to constructing the output gap. For the empirical analysis, we evaluate three forecasting models, interest rate fundamentals (equation 2.4), standard Taylor rule fundamentals (equation 1.9) and augmented Taylor rule fundamentals (equation 2.3). The out-of-sample forecasts are computed by the rolling window approach.

[19] Although the BoE is using CPI measure to targeting inflation since 2003, we use RPI (Retail Price Index) inflation for UK as the Bank of England targeted the inflation by using RPI between 1992 and 2003, which accounts a longer period than CPI before the Financial Crisis.

2.4.2 Forecast comparison based on MSFE

We evaluate the out-of-sample forecasting performance by comparing the MSFE between the null model and the preferred model. The null model is a zero mean martingale difference process, and the alternative model is a linear model.

$$\text{The null model (Model 1): } y_t = e_t$$

$$\text{The alternative model (Model 2): } y_t = \beta X_t' + e_t \text{ where } E_t(e_{t+1}) = 0$$

The vector X represents the variables in the forecasting equation. Suppose the sample consists of $\mathrm{T} + 1$observations, and the last P (where $\mathrm{P} < \mathrm{T}$) observations are used for predictions. Estimating forecasting model by OLS from $t = 1, \ldots.., R$ (where R is the width of window), and therefore each model is initially estimated using the first R data points. Then, using the estimated coefficients to construct one-month-ahead out -of-sample forecast for the observation $R + 1$. After that, moving the window one period ahead ($t = 2, \ldots.., R + 1$) to re-estimate the forecasting model for the same width. By repeating this step, we can generate one-month-ahead forecast for the observation $R + 1$, $R + 2$ and so on. The number of out-of-sample forecasts is equal to the total sample size minus the window width ($P = \mathrm{T} + 1 - \mathrm{R}$).

Under the null, $\beta = 0$; Under the alternative, $\beta \neq 0$. The one step ahead prediction for the null model is a constant value of 0 while $\beta X_{t+1}'$ for the alternative model. The corresponding sample forest error for the null model and the alternative models are $\hat{e}_{1,t+1} = y_{t+1}$ and $\hat{e}_{2,t+1} = y_{t+1} - \hat{\beta}_t X_{t+1}'$ respectively. Accordingly, the MSFEs for the two models are follows:

$$\text{MSFE for the model 1: } \hat{\sigma}_1^2 = p^{-1} \sum_{t=T-P+1}^{T} y_{t+1}^2$$

MSFE for the alternative model 2: $\hat{\sigma}_2^2 = p^{-1}\sum_{t=T-P+1}^{T}(y_{t+1} - \hat{\beta}_t X'_{t+1})^2$

We are interested in testing whether the MSFE for the model 2 is statistically significant less than the MSFE for the model 1, consequently, the null hypothesis and the alternative hypothesis read:

$$H_0: \hat{\sigma}_1^2 - \hat{\sigma}_2^2 = 0$$

$$H_1: \hat{\sigma}_1^2 - \hat{\sigma}_2^2 > 0$$

The population MSFEs for the two models are equal when H_0 holds. Diebold and Mariano (1995) and West (1996) (DMW, hereafter) introduced a technique that can test the above null hypothesis, they construct a *t*-type statistic using sample MSFEs and use such statistic to draw the inference. Firstly, defining the following terms:

$$\hat{f}_t = \hat{e}_{1,t}^2 - \hat{e}_{2,t}^2$$

$$\bar{f} = p^{-1}\sum_{t=T-P+1}^{T}\hat{f}_{t+1} = \hat{\sigma}_1^2\text{-}\hat{\sigma}_2^2$$

$$\hat{V} = p^{-1}\sum_{t=T-P+1}^{T}(\hat{f}_{t+1} - \bar{f})^2$$

The DMW test statistic can be constructed as follows:

$$\text{DMW} = \frac{\bar{f}}{\sqrt{p^{-1}\hat{V}}}$$

However, Clark and West (2006) (CW, hereafter) demonstrate that the sample difference between the two MSFEs is biased downward from zero. In particular, the mean and median of $\hat{\sigma}_1^2 - \hat{\sigma}_2^2$ are negative rather than zero. We use the simple algebra to illustrate that the sample difference between two MSFE's is uncentered:

$$\hat{\sigma}_1^2 - \hat{\sigma}_2^2 = p^{-1} \sum_{t=T-P+1}^{T} \hat{f}_{t+1} = p^{-1} \sum_{t=T-P+1}^{T} y_{t+1}^2 - p^{-1} \sum_{t=T-P+1}^{T} \left(y_{t+1} - \hat{\beta}_t X'_{t+1}\right)^2$$

$$= 2\left\{p^{-1} \sum_{t=T-P+1}^{T} y_{t+1}\hat{\beta}_t X'_{t+1}\right\} - p^{-1} \sum_{t=T-P+1}^{T} \left(\hat{\beta}_t X'_{t+1}\right)^2$$

Under the null, the first term is equal to zero, however, the second term is positive by construction. Consequently, under the null, we expect the MSFE for the alternative model to be greater than that of the null model. This is due to the fact that the alternative model's MSFE is expected to be pushed upwards by the noise term $p^{-1}\sum_{t=T-P+1}^{T}\left(\hat{\beta}_t X'_{t+1}\right)^2$ in finite samples. CW propose a corrected test statistic to adjust the shift of DMW statistic. The adjusted statistic suggested by CW is asymptotically normally distributed for rolling regressions, and with more desirable size and power properties.

$$\hat{f}_{t+1}{}^{adj} = \hat{e}_{1,t+1}^2 - \left[\hat{e}_{2,t+1}^2 - \left(\hat{\beta}_t X'_{t+1}\right)^2\right]$$

$$\bar{f}^{adj} = p^{-1}\sum_{t=T-P+1}^{T} \hat{f}_{t+1}{}^{adj} = \hat{\sigma}_1^2 \text{-} \hat{\sigma}_2^2 + p^{-1}\sum_{t=T-P+1}^{T}\left(\hat{\beta}_t X'_{t+1}\right)^2$$

$$\hat{V} = p^{-1} \sum_{t=T-P+1}^{T} (\hat{f}_{t+1}{}^{adj} - \bar{f}^{adj})^2$$

$$\text{CW} = \frac{\bar{f}^{adj}}{\sqrt{p^{-1}\hat{V}^{adj}}}$$

In our study, we will report the result for both CW and DMW test statistics. However, it should be noted that CW test can only test whether the regression coefficient is different from zero, it cannot test whether the MSFE from a preferred model is smaller than the MSFE from the random walk model since CW test is not a minimum MSFE statistic (Rogoff and Stavakeva, 2008). It is possible to reject the null model even the MSFE for the alternative model is greater than the MSFE for the random walk model. The significant CW statistic only implies that the exchange rate movement can be described by the preferred model. Consequently, we also report the results of RMSFE to measure the forecast performance of the preferred model.

2.5 Empirical Analysis

As we mentioned above, the augmented Taylor rule fundamentals should mainly apply to the inflation targeting countries during the inflation targeting period. Therefore, we will investigate the short-term exchange rate predictability before and after the adoption of inflation targeting regime. In addition, monetary policy may have changed during the recent financial crisis, and therefore we also investigate the predictability before and after the financial crisis.

In detail, we divide the full available sample into three sub-periods for comparison purpose. The first sub-period covers the period from the adoption of inflation targeting regime but prior to the financial crisis, and we call this period as the conventional monetary policy period for the inflation targeting period. The second sub-period covers the whole inflation targeting era, and the third sub-period only includes the period after the financial crisis, and we call this period as unconventional monetary policy period. In addition, it is worth to note that the sample sizes are different across countries due to the data availability. The details of available sample size and the sub-periods have been reported in Table 2.1.

Table 2.1: Available sample sizes and sub-periods definition

Country	The full available sample	The conventional monetary policy period	The unconventional monetary policy period	The whole inflation targeting period
Australia	1975 Jan-2018 Mar	1993 Jun-2008 Sep	2008 Oct-2018 Mar	1993 June-2018 Mar
Canada	1981 Apr-2018 Feb	1991 Feb-2008 Sep	2008 Oct-2018 Feb	1991 Feb-2018 Feb
Norway	1981 Apr-2018 Mar	2001 Mar-2008 Sep	2008 Oct-2018 Mar	2001 Mar-2018 Mar
New Zealand	1977 Apr-2018 Mar	1990 Feb-2008 Sep	2008 Oct-2018 Mar	1990 Feb- 2018 Mar
Sweden	1981 Dec-2018 Mar	1993 Jan-2008 Sep	2008 Oct-2018 Mar	1993 Jan-2018 Mar
UK[20]	1978 Feb-2017 Jan	1992 Oct-2008 Sep	2008 Oct-2017 Jan	1992 Oct-2017 Jan

2.5.1 Out-of-sample forecasts for the conventional monetary policy period (The baseline case)

We define the period between the introduction of the inflation targeting regime and the financial crisis as the baseline case for our analysis. For this part, we set the window size equals to half of the total observations during this period. As the starting date for adopting inflation target regime varies by country, and therefore the size of the sample, rolling window and out-of-sample forecasts vary by country as well. We report the window size for each country in the following table.

Table 2.2: The window size for the baseline case

Country	Window size
Australia	92
Canada	106
Norway	45
New Zealand	112
Sweden	95

[20] The industrial production index data of the UK is not available for the post Jan 2017 period, and therefore we can only use data between Feb 1978 and Jan 2017 for the UK.

UK	96

For example, the size of the window for the UK is 96, which illustrate that we have 96 observations for each rolling regression (the first observation for rolling estimation starts in Oct of 1992, see Table 1). As the window size equals to half of the sample, then, in turns, there are 96 out-of-sample forecasts to constructing (the first forecast starts in 2002 Oct). And the same applies to other countries. For comparison purposes, the window size will remain the same for the following sub-periods forecasts unless specified.

It is well known that the Global Financial crisis has started in July of 2007. But we define the crisis started to affects the Taylor rule model from October of 2008 and regard the period before October of 2008 as the panic phase of the financial crisis for the monetary authority. There are two reasons behind such setting. Firstly, our forecasting model is based on the central bank's reaction function, but there is no evidence of contemporaneous structural change or reaction for the central bank's policy. For instance, the Fed has introduced the zero lower bound for the US in late 2008 instead of the immediate response. In addition, Molodtsova and Papell (2012) demonstrated that The Taylor rule fundamental model with the output gap can provide short-term predictability up to the second quarter of 2008, however, the model has lost its exchange rate predictability afterwards.[21] Based on the discussions above, we suspect our setting of the unconventional monetary policy periods to capture the policy shift of the financial crisis is plausible.

[21] Molodtsova and Papell (2012) have investigated the Taylor rules exchange rate model during the crisis period. The evidence suggests that the Taylor rule fundamental can only produce short term predictability from 2007Q1 to 2008Q2. For the period after 2008Q2, the results are in favour of random walk.

Table 2.3-2.6 report the one-month-ahead forecasts of the exchange rate for the conventional monetary policy period. As we mentioned above, there is no consensus for whether central bank targets the exchange rate and has interest rate smoothing behaviour, we estimate each type Taylor rule fundamentals with four specifications, namely, with and without targeting real exchange rate, and with and without interest rate smoothing. For example, the term asymmetric Taylor rule model with no smoothing (Table 2.3) refers to central bank targets the real exchange rate but does not have interest rate smoothing. The first and the second column report the CW and DMW p-values, and the third column presents the ratio of MSFE of the preferred model relative to that of the random walk model. The left panel depicts the results of the standard Taylor rule fundamentals while the right panel depicts the results of the augmented Taylor rule fundamentals.

For the augmented Taylor rule fundamentals, the model outperforms the random walk for 13 out of 24 cases. We can find short-term predictability at least for 3 countries regardless of the specifications. The strongest results are found in the symmetric model with smoothing, where 2 out of 6 countries outperforms the random walk at 1% significance levels (New Zealand and Sweden) with the RMSFEs for all the significant cases are smaller than unity.

The standard Taylor rule fundamentals provide similar results with the augmented Taylor rule fundamentals, but with only 10 significant CW statistics that are able to reject the no predictability null and none of them at 1 percent significance levels. The asymmetric Taylor rule model with no smoothing is the least powerful specification where only 1 out of 6 countries outperforms the random walk model, while the symmetric Taylor rule model with smoothing again provides the strongest results.

Combing the four different specifications for both models, there is no short-term predictability for Norway. We suspect this is because Norway only introduces the inflation targeting regime in the early 2000s. Such a short period may lead to less powerful results. For New Zealand and Sweden, the exchange rate predictability increases when we use the augmented Taylor rule fundamentals as the CW statistics are significant for all the specifications. However, the UK results show the opposite as we found 2 significant CW statistics for standard Taylor rule but only 1 significant CW statistic for augmented Taylor rule fundamentals. The performances for Australia are similar for both models as we only found exchange rate predictability in symmetric Taylor rule model with smoothing. Canada is the most contradicted case between these two models. For the augmented Taylor rule fundamentals, evidence of short-term predictability is found for three specifications with two cases at the 1% significance levels. On the other hand, we can only find one significant CW statistic for the standard Taylor rule fundamentals.

Overall, we find that the number of significant CW statistics for augmented Taylor rule fundamentals exceeds the standard Taylor rule fundamentals (13 versus 10). In addition, there are 16 cases with RMSFE smaller than unity for the augmented Taylor rule fundamentals compared with only 10 cases for the standard Taylor rule fundamentals. Hence, the assumption of asymmetric monetary preferences is important for using Taylor rule exchange rate forecasting model as augmented Taylor rule fundamentals can provide strong short-term predictability for the inflation targeting countries during the conventional monetary policy period.

Table 2.3: Asymmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.14	0.48	0.980	0.16	0.49	0.993
Canada	0.48	0.53	1.037	0.07*	0.51	1.007
Norway	0.45	0.56	1.035	0.74	0.59	1.184
New Zealand	0.15	0.51	1.007	0.05*	0.49	0.998
Sweden	0.03**	0.48	0.986	0.06*	0.47	0.941
UK	0.12	0.50	1.000	0.14	0.50	1.003

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.4: Symmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.11	0.46	0.961	0.12	0.47	0.973
Canada	0.40	0.52	1.010	0.00***	0.41	0.954
Norway	0.26	0.52	1.010	0.68	0.57	1.159
New Zealand	0.05*	0.48	0.991	0.02**	0.47	0.977
Sweden	0.02**	0.48	0.998	0.05*	0.47	0.943
UK	0.07*	0.46	0.961	0.12	0.48	0.976

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.5: Asymmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.13	0.48	0.965	0.14	0.51	1.019
Canada	0.02**	0.56	1.054	0.14	0.54	1.025
Norway	0.76	0.63	1.159	0.85	0.64	1.408
New Zealand	0.03**	0.50	1.003	0.02**	0.50	0.994

Sweden	0.12	0.53	1.035	0.04**	0.47	0.946
UK	0.10	0.55	1.168	0.08*	0.50	0.990

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.6: Symmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.07*	0.48	0.976	0.09*	0.49	0.993
Canada	0.13	0.50	1.003	0.00***	0.46	0.969
Norway	0.62	0.62	1.155	0.83	0.64	1.388
New Zealand	0.03**	0.49	1.001	0.00***	0.51	0.986
Sweden	0.01**	0.49	0.997	0.03**	0.46	0.936
UK	0.06*	0.47	0.965	0.11	0.49	0.988

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative model. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

2.5.2 Out-of-sample forecasts for the whole inflation targeting period

In this part, we extend the sample which covers the whole inflation targeting period. Table 2.7-2.10 report the one-month-ahead out-of-sample forecasts of the exchange rate for this period. The window size is the same as the baseline case, but the forecasting period extends from 2008Q3 to the most recent available point.

The results of augmented Taylor rule fundamentals are not successful for the whole inflation targeting period. There is a significant decrease in short-term predictability as the number of significant CW statistics have dropped from 13 to 8, and with all RMSFEs greater than unity. Although we can find short-term predictability for Norway, the predictability is disappeared for Australia and the UK. Overall, there is only limited evidence of exchange rate predictability for the augmented Taylor rule fundamentals.

On the other hand, the standard Taylor rule fundamentals provide even stronger predictability as the number of significant CW statistics has increased from 10 to 20 and the short-term predictability is found for all the countries. However, the RMSFEs are all greater than unity except for the UK in the case of symmetric Taylor rule model with no smoothing.

Furthermore, the symmetric Taylor rule with interest rate smoothing again provides the strongest evidence of predictability. For the standard Taylor rule fundamentals, we find predictability for all the countries. The same also holds for the augmented Taylor rule fundamentals as the exchange rate predictability are found for 3 out of 6 countries, which exceeds the other specifications.

However, the strong evidence of exchange rate predictability for standard Taylor rule is questionable. Based on our forecasting equation settings, one of important assumptions is the central bank should follow Taylor rule. As we mentioned in the previous section, after the financial crisis and followed by near-zero interest rates for the US, UK and other central banks, the advantages of the Taylor rule were bleak since we cannot regard the short-term interest rate as the main policy instrument. That is to say, the Taylor rule is not sufficient to capture the central bank’s interest rate setting behaviour during the unconventional monetary policy period. Hence, from the theoretical side, using the standard Taylor rule to forecasting the exchange rate should lose its power if the unconventional monetary policy period is included. It is clear that the standard Taylor rule fundamentals does not take into account the monetary policy shift in 2008, the implications of such strong exchange rate predictability are not clear.

There are two potential reasons for such strong performance of the standard Taylor rule. Firstly, the standard Taylor rule is regarded to be a good description of how central bank conducts its monetary policy in the past thirty years. And therefore, the larger the data sample is, the more forecasts can be characterised as standard Taylor rule. Secondly, the standard Taylor rule fundamentals shows the exchange rate can be determined by the output gap and inflation rate through the monetary policy channel. Our previous analysis shows that the monetary policy channel may be questionable during the unconventionally monetary policy period, but it does not rule out that there are other channels could link the exchange rate with the output gap and inflation rate. In addition, although the standard Taylor rule fundamentals can provide superior predictability results relative to the random walk model, with only 1 case for RMSFE less than unity and none of them are at 1 percent significance levels for all the significant CW statistics, we infer that such strong exchange rate predictability is not robust.

Table 2.7: Asymmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.06*	0.53	1.035	0.23	0.55	1.071
Canada	0.45	0.60	1.078	0.60	0.57	1.090
Norway	0.01**	0.51	1.019	0.04**	0.54	1.073
New Zealand	0.11	0.53	1.030	0.13	0.53	1.050
Sweden	0.05*	0.52	1.026	0.19	0.52	1.062
UK	0.04**	0.53	1.024	0.19	0.55	1.063

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.8: Symmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.04**	0.52	1.024	0.19	0.55	1.064
Canada	0.32	0.54	1.041	0.54	0.46	1.044
Norway	0.01**	0.51	1.009	0.04**	0.53	1.058
New Zealand	0.08**	0.52	1.022	0.09*	0.52	1.034
Sweden	0.06*	0.52	1.029	0.18	0.52	1.065
UK	0.06*	0.50	0.998	0.15	0.52	1.023

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.9: Asymmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.04**	0.53	1.059	0.10	0.56	1.104
Canada	0.01**	0.56	1.075	0.28	0.57	1.073
Norway	0.03**	0.54	1.128	0.06*	0.56	1.174
New Zealand	0.01**	0.54	1.060	0.01**	0.52	1.045
Sweden	0.23	0.56	1.091	0.18	0.53	1.095
UK	0.05*	0.56	1.176	0.11	0.55	1.072

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.10: Symmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.04**	0.53	1.056	0.10	0.56	1.094
Canada	0.04**	0.53	1.031	0.06**	0.53	1.035
Norway	0.02**	0.54	1.106	0.05*	0.56	1.161
New Zealand	0.01**	0.52	1.032	0.01**	0.52	1.040
Sweden	0.04**	0.54	1.055	0.13	0.53	1.074
UK	0.06*	0.52	1.039	0.12	0.54	1.055

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

2.5.3 Out-of-sample forecasts for the unconventional monetary policy period

In this part, we present the results for one month-ahead out-of-sample forecasts of the exchange rates for the unconventional monetary policy period only. Due to the fact that the sample size for this period is relatively short, we cannot keep the same window size. For instance, the total observations for New Zealand during the unconventional monetary policy period is 114, and if we keep the same window size as the baseline case -112, we only have 2 forecasts. Due to this reason, the window size for this section is equal to half of the total observations in the unconventional monetary policy period. Table 2.11 reports the detailed window size for each country. It is worth to note that the rolling regressions only represent the historical relationship between the Taylor rule fundamentals and the exchange rate for the post-unconventional monetary policy period. And the model does not use the pre-unconventional monetary policy period's information to forecast the exchange rate.

Table 2.11: The window size for the unconventional monetary policy period

Country	Window size
Australia	57
Canada	56
Norway	57
New Zealand	57
Sweden	57
UK	50

Compared with the previous two sub-periods estimations, the unconventional monetary policy period provides the weakest short-term predictability for both models (see Table 2.12-2.15). There are only 5 cases that we can reject the no predictability null by CW statistics for both models, and with only one case for RMSFE smaller than unity. Overall, there are only three countries with short-term predictability for both models. This should not be surprising since the Taylor rule model does not have enough features to capture the central bank's interest rate setting behaviour during the unconventional monetary policy period.

And, it is interesting to note that both models generate almost exactly the same results. Although there is a slight difference for the significance levels, we find that the countries with short-term predictability are identical for both models across different specifications. This situation reflects the fact that the central bank's monetary preference to inflation and output gap (either symmetric or asymmetric) becomes a less relevant component to describe the exchange rate movement during the unconventional monetary policy period, and suggesting there are other variables or behaviours affect the interest rate reaction function.

Furthermore, the symmetric Taylor rule model with no smoothing once again provide the strongest predictability as there are 2 countries with short-term predictability, and there is only one significant CW statistic for other three specifications.

Table 2.12: Asymmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.51	0.57	1.064	0.29	0.58	1.105
Canada	0.69	0.58	1.104	0.53	0.57	1.110
Norway	0.74	0.62	1.112	0.77	0.64	1.147
New Zealand	0.41	0.56	1.048	0.83	0.61	1.223
Sweden	0.03**	0.50	1.004	0.03**	0.52	1.045
UK	0.14	0.53	1.032	0.23	0.56	1.060

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift

Table 2.13: Symmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.82	0.61	1.103	0.88	0.65	1.146
Canada	0.93	0.61	1.081	0.90	0.61	1.082
Norway	0.93	0.62	1.066	0.97	0.65	1.125
New Zealand	0.86	0.60	1.068	0.90	0.61	1.186
Sweden	0.16	0.53	1.040	0.14	0.55	1.077
UK	0.06*	0.51	1.006	0.09*	0.54	1.025

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.14: Asymmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.51	0.65	1.588	0.30	0.57	1.109
Canada	0.83	0.63	1.311	0.67	0.62	1.198
Norway	0.25	0.57	1.191	0.28	0.57	1.127
New Zealand	0.55	0.64	1.386	0.22	0.59	1.172
Sweden	0.05*	0.55	1.092	0.07*	0.55	1.094
UK	0.64	0.66	1.638	0.19	0.59	1.170

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.15: Symmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.29	0.56	1.098	0.65	0.61	1.187
Canada	0.35	0.57	1.089	0.34	0.58	1.142
Norway	0.12	0.52	1.043	0.21	0.55	1.095

New Zealand	0.02**	0.50	1.000	0.04**	0.53	1.055
Sweden	0.01**	0.5	0.995	0.05*	0.54	1.081
UK	0.19	0.6	1.132	0.36	0.62	1.167

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

2.5.4 Out-of-sample forecasts for the full available sample

In this part, we perform the Taylor rule forecasting for the full available sample. Although we made an inference that the augmented forecasting model should mainly apply to the normal monetary policy period, it does not mean that there are no asymmetric preferences before the inflation targeting period. Indeed, there is some empirical evidence of asymmetric preference prior to the inflation targeting regime. For instance, Baxa *et al.* (2014) illustrate that the response of interest rates to positive inflation gap is particularly high for the BoE in early 1980. Hence, investigating the full sample is also crucial for the augmented Taylor rule fundamentals. Table 2.16-2.19 report the one-month-ahead out-of-sample forecasts of the exchange rate for the full sample.

It should be noted that the window size is the same as the baseline case (see Table 2.2). Overall, the standard Taylor rule fundamentals can provide more evidence of short-term predictability for the inflation targeting countries as there are 10 more significant CW statistics compared with the augmented Taylor rule fundamentals (18 versus 8).

It is clear that the results of augmented Taylor rule fundamentals are not as successful as the baseline case. But, the short-term predictability has increased compared with the results for the unconventional monetary policy period. The results for the full sample period are similar to the whole inflation targeting period. In particular, there are 8 significant CW statistics which can reject the no predictability null for both periods. In addition, the short-term predictability is founded in Canada, New Zealand, and Norway for both sub-periods. The full sample can provide an additional country with short-term predictability (Australia) in the case of symmetric Taylor rule model with smoothing, but only at 10 percent significance levels.

The standard Taylor rule fundamentals has maintained its power of predictability when we extend the sample to the pre-inflation targeting period. Apart from the unconventional monetary policy period, the length of the sample does not have strong impacts on the short-term predictability as the number of significant CW statistics are relatively stable compared with the augmented Taylor rule fundamentals. The performances of the standard Taylor rule fundamentals for the full sample period are also similar with the whole inflation targeting period, especially for the specification of symmetric Taylor rule with interest rate smoothing as there are short-term exchange rate predictability for all the inflation targeting countries.[22]

Table 2.16: Asymmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.10	0.53	1.037	0.34	0.55	1.070
Canada	0.31	0.54	1.065	0.39	0.55	1.077
Norway	0.01**	0.54	1.056	0.35	0.52	1.536

[22] Furthermore, we also report the results of the full available sample by using the same window size as the M&P (see Appendix 4). Our full available sample covers a similar period with the data sample of M&P. Therefore, we can evaluate whether the exchange rate predictability is consistent under the different window sizes. Overall, our full sample results are robust under different window sizes.

New Zealand	0.06*	0.53	1.021	0.11	0.54	1.038
Sweden	0.14	0.54	1.044	0.25	0.53	1.073
UK	0.08*	0.54	1.048	0.17	0.55	1.071

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.17: Symmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.03**	0.52	1.022	0.13	0.54	1.052
Canada	0.19	0.54	1.036	0.14	0.53	1.043
Norway	0.01**	0.53	1.050	0.36	0.52	1.534
New Zealand	0.04**	0.53	1.016	0.06*	0.52	1.021
Sweden	0.07*	0.53	1.029	0.10	0.53	1.061
UK	0.16	0.53	1.036	0.25	0.55	1.051

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.18: Asymmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.02**	0.55	1.093	0.16	0.56	1.095
Canada	0.00***	0.58	1.131	0.09**	0.55	1.060
Norway	0.01**	0.58	1.216	0.05*	0.54	1.303
New Zealand	0.02**	0.53	1.022	0.01**	0.53	1.029
Sweden	0.11	0.55	1.094	0.24	0.55	1.116
UK	0.08*	0.57	1.167	0.27	0.55	1.103

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.19: Symmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.03**	0.53	1.044	0.08*	0.55	1.074
Canada	0.03**	0.53	1.030	0.02**	0.53	1.036
Norway	0.00***	0.55	1.113	0.04**	0.54	1.267
New Zealand	0.01**	0.51	1.002	0.00***	0.52	1.014
Sweden	0.05*	0.54	1.069	0.13	0.53	1.085
UK	0.07*	0.54	1.072	0.20	0.55	1.091

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

2.5.6 Out-of-sample forecasts for the interest rate fundamentals

Table 2.20 reports the results for one-month-ahead forecasts of exchange rate using the interest rate fundamentals. Compared with standard Taylor rule fundamentals and augmented Taylor rule fundamentals, the evidence of predictability is much weaker. It is clear that we do not find short-term exchange rate predictability for the conventional monetary policy period and the whole inflation targeting period. In terms of the unconventional monetary policy period, there is only one case where the interest rate fundamentals significantly outperforms the random walk (New Zealand at the 5% significance level). However, the exchange predictability increase when we use the full available sample, the interest rate fundamentals significantly outperforms the random walk for 3 out of 6 countries (Canada at and Norway at 10% significance level, New Zealand at 10% significance level) but the RMSFEs for all three cases are greater than zero.

Table 2.20: One-month-ahead out-of-sample forecasts for the interest rate fundamentals

Panel A: The conventional monetary policy period			
Country	CW	DMW	RMSFE
Australia	0.23	0.52	1.013
Canada	0.38	0.51	1.005
Norway	0.37	0.55	1.040
New Zealand	0.35	0.51	1.011
Sweden	0.29	0.52	1.012
UK	0.54	0.53	1.022
Panel B: The whole inflation targeting period			
Country	CW	DMW	RMSFE
Australia	0.28	0.52	1.013
Canada	0.13	0.50	0.999
Norway	0.14	0.53	1.026
New Zealand	0.11	0.53	1.021
Sweden	0.22	0.52	1.010
UK	0.90	0.56	1.034
Panel C: The unconventional monetary policy period			
Country	CW	DMW	RMSFE
Australia	0.26	0.53	1.029
Canada	0.61	0.54	1.027
Norway	0.10	0.50	0.999
New Zealand	0.02**	0.50	0.998
Sweden	0.22	0.53	1.036
UK	0.17	0.55	1.058
Panel D : The full available sample			
Country	CW	DMW	RMSFE
Australia	0.16	0.51	1.011
Canada	0.06*	0.50	1.000
Norway	0.07*	0.54	1.032
New Zealand	0.04**	0.53	1.003
Sweden	0.40	0.53	1.011
UK	0.48	0.54	1.038

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the interest rate differentials fundamentals is the alternative model. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

2.5.7 Summary of the results

To sum up, we evaluate the out-of-sample exchange rate forecasting performances for standard Taylor rule fundamentals, augmented Taylor rule fundamentals and interest rate fundamentals. For the augmented Taylor rule fundamentals, we find relatively strong evidence of exchange rate predictability during the conventional monetary period, and the exchange rate predictability of the augmented Taylor rule fundamentals is more robust than that of the standard Taylor rule fundamentals. Consequently, incorporating the central bank's asymmetric preference into the interest reaction function and modelling the exchange rate movement under the assumption of asymmetric exchange rate responses are important for the conventional monetary policy period. In addition, out-of-sample exchange rate predictability for the augmented Taylor rule fundamentals decrease if we include the pre-inflation targeting period or the unconventional monetary policy period, which illustrate that the asymmetric monetary preference and the subsequent asymmetric exchange rate responses become less relevant during the pre-inflation targeting period and the unconventional monetary policy period. On the other hand, the out-of-sample exchange rate predictability for standard Taylor rule fundamentals does not decrease if we include the pre-inflation targeting period, the change of the monetary policy has less impacts on the exchange rate predictability for the standard Taylor rule fundamentals. According to the results for the whole inflation targeting period, the exchange rate predictability for standard Taylor rule fundamentals has survived during the unconventional monetary policy period, which is in line with the Ince *et al*. (2016) findings. However, one thing to note that is such predictability also use the historical relationship between Taylor rule fundamentals and the exchange rates prior to the unconventional monetary policy period. Once we exclude such historical relationship, the short-term predictability falls apart during the unconventional monetary policy period.

In addition, the baseline analysis (the conventional monetary policy period) provides the most interpretable results as the results for RMSFE are consistent with the

CW statistics. For the augmented Taylor rule fundamentals, the null hypothesis was rejected at the 10 percent level or higher for most of the cases where the RMSFE was less than one. For the standard Taylor rule fundamentals, there are 7 cases where the RMSFEs are less than unity and the random walk null are rejected.

However, the situations are different for the other estimation periods, there are only 2 cases where the RMSFEs are less than unity and the random walk null are rejected (see Table 2.21 for detail). For our previous analysis, we rely on a less severe metric and say that we find evidence in favour of the preferred model if CW statistic is significant at 10 percent level (or higher). However, if we use a more strict metric, and say that the evidence of predictability can only be confirmed when both RMSFE is less than one and the CW statistic is significant at the 10 percent level (or higher), then we obtain a different conclusion. By using such metric, the evidence of exchange rate predictability for both types of Taylor rule fundamentals fall apart, except for the conventional monetary policy period. Consequently, we suspect the evidence that in favour of the Taylor rule fundamentals are robust for the conventional monetary policy period only.

Table 2.21: Summary Table

Model	Significant CW statistics	RMSFE smaller than unity	Country with evidence of short-term predictability at 5% significance levels or higher
A: The conventional monetary policy period			
Standard Taylor rule fundamentals	10	10	Canada, New Zealand, Sweden
Augmented Taylor rule fundamentals	13	16	Canada, New Zealand, Sweden
B: The whole Inflation targeting period			
Standard Taylor rule fundamentals	20	1	Australia, Canada, New Zealand, Norway, Sweden, UK
Augmented Taylor rule fundamentals	8	0	Canada, New Zealand, Norway
C: The unconventional monetary policy period			
Standard Taylor rule fundamentals	5	1	New Zealand ,Sweden,
Augmented Taylor rule fundamentals	5	0	New Zealand, Sweden
D: The full available sample			
Standard Taylor rule fundamentals	18	0	Australia, Canada, Norway, New Zealand
Augmented Taylor rule fundamentals	8	0	Canada, New Zealand, Norway

The inconsistency between RMSFE and CW statistics are also mentioned in Rogoff and Stavrakeva (2008), by replicating M&P's results, although there are 10 out 12 countries with short-term predictability by using CW statistics, only 1 out of them has RMSFE less than unity. This issue arises because the CW test can only test whether the coefficient β is significantly different from zero, but it cannot test whether the MSFE for the preferred model is smaller than the MSFE for the random walk model. Therefore, the significant CW test only implies that the exchange rate movement can be better described by the preferred model. However, such inconsistence beyond the scope of this paper, and there is no econometric tool can investigate the discrepancy currently. We leave this point as further research.

2.5.8 Forecast coefficients

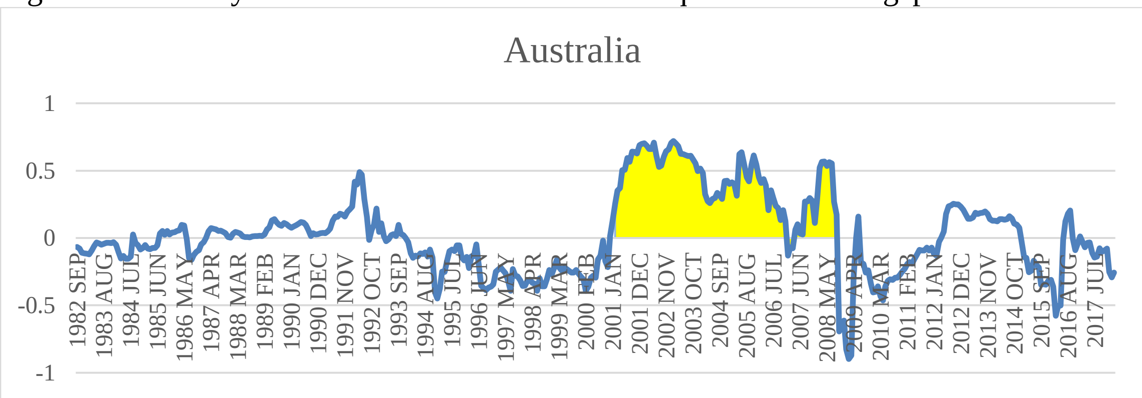
In previous sections, it is clear that the model with augmented Taylor rule fundamentals provides strong evidence of exchange rate predictability during the inflation target period but prior to the financial crisis (conventional monetary policy period). The interesting questions to explore are whether the pattern of the estimated coefficients for the asymmetric exchange rate responses are different for each sub-sample period, and whether the estimated coefficients are more significant for the conventional monetary policy period.

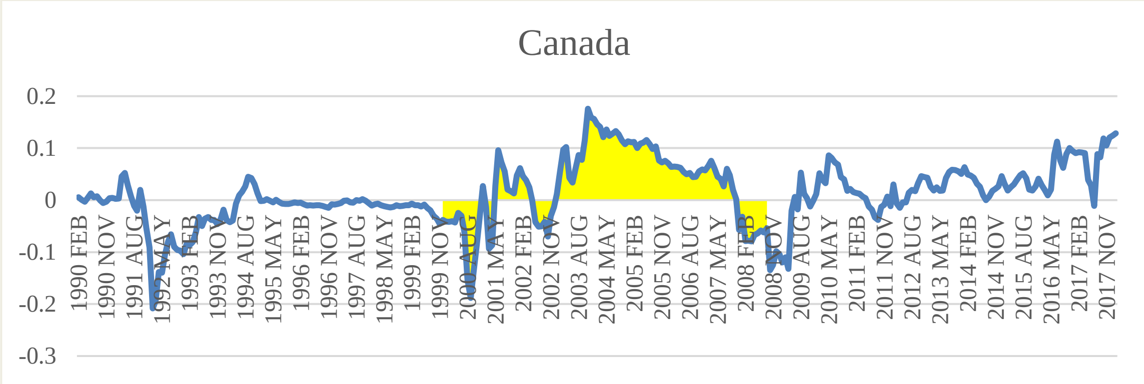
Consequently, we plot the dynamics of the coefficients on the squared term based on the augmented Taylor rule fundamentals. As the most successful specification for our empirical results is the symmetric Taylor rule model with smoothing, we only show the coefficient for this specification. Since the data availability and the rolling window size vary by country, the start date of the plots vary by country as well. For example, the data availability for Australia starts in 1975 Jan and the window size is 92 forecasting, therefore the plot starts in Sep 1982 when the first prediction is made. The same logic applies to the rest of the countries. Generally speaking, the asymmetric exchange rate response to the inflation gap can be neglected before the inflation targeting period, as the estimated coefficients are extremely close to zero for all the countries.

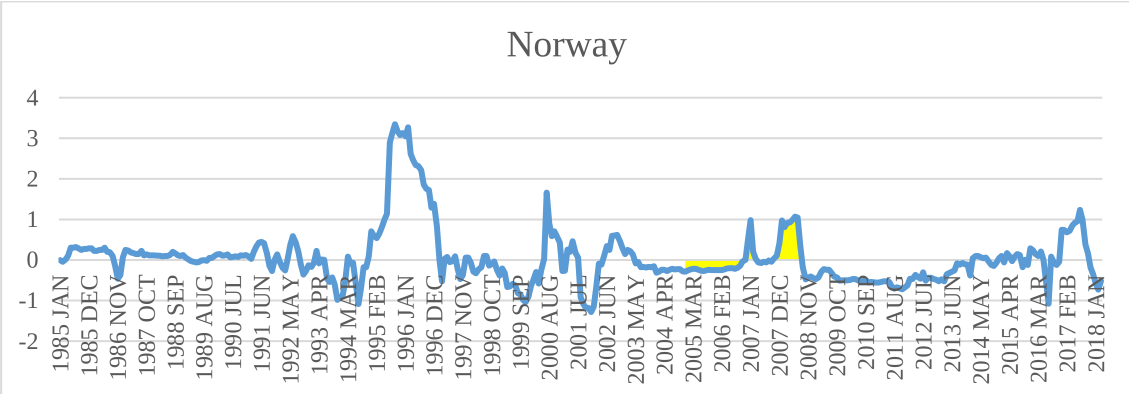
In addition, for 4 out of 6 countries (Australia, Canada, New Zealand and the UK), the patterns are similar. The coefficients on the squared inflation gap near zero before the end of the 1990s (or the early 2000s). As the estimation window move forward during the inflation targeting period and more data is characterised by the augmented

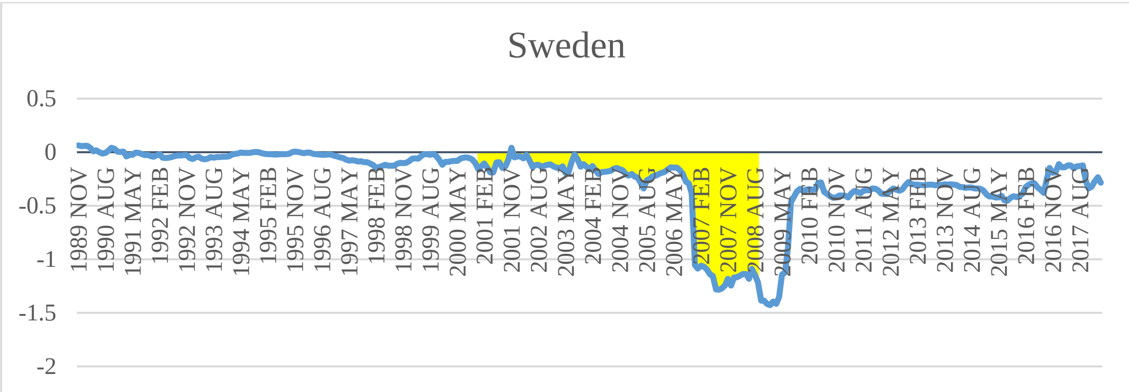
Taylor rule fundamentals, the coefficients start to affect the exchange rate movement and become positive around 2000. However, such positive coefficients approach to zero again during the unconventional monetary policy period. Here, we use yellow area chart to highlight the coefficients from the data of the conventional monetary policy. As we can see from the figure 1.1, for those four countries, it is clear that the patterns of the coefficients to the squared inflation gap are different for each sub-sample periods- before the introduction of the inflation targeting, the conventional monetary policy period and the unconventional monetary policy period, which are consistent with our presumption that the asymmetric monetary preference are more significant for exchange rate forecasting during the conventional monetary policy period. In addition, the pattern of the coefficients during the conventional monetary policy period suggest that the forecasted appreciation caused by the inflation rate above its target is higher than the forecasted depreciation caused by the inflation rate below its target during the conventional monetary policy period. On the other hand, the pattern of Norway and Sweden are not clear as the coefficients are near zero for most of the forecasts, which suggest there is less evidence of the asymmetric exchange rate responses to the inflation gap.

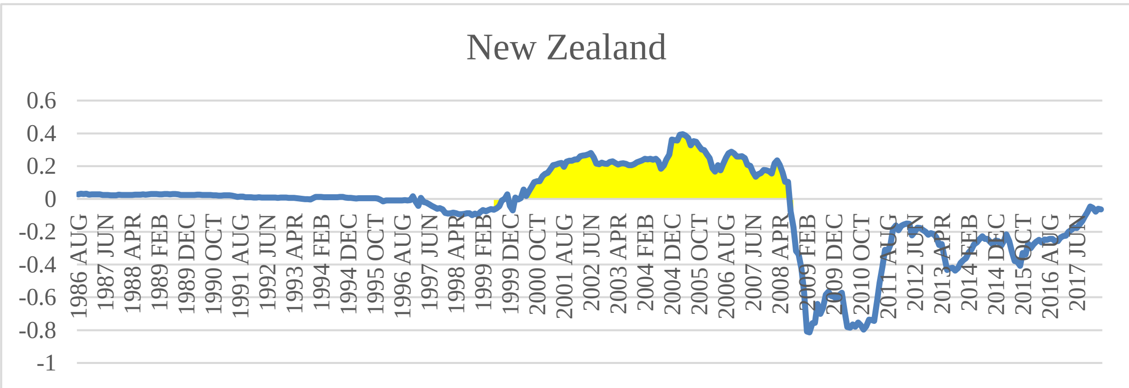
Figure 1.1: The dynamics of the coefficient on the squared inflation gap

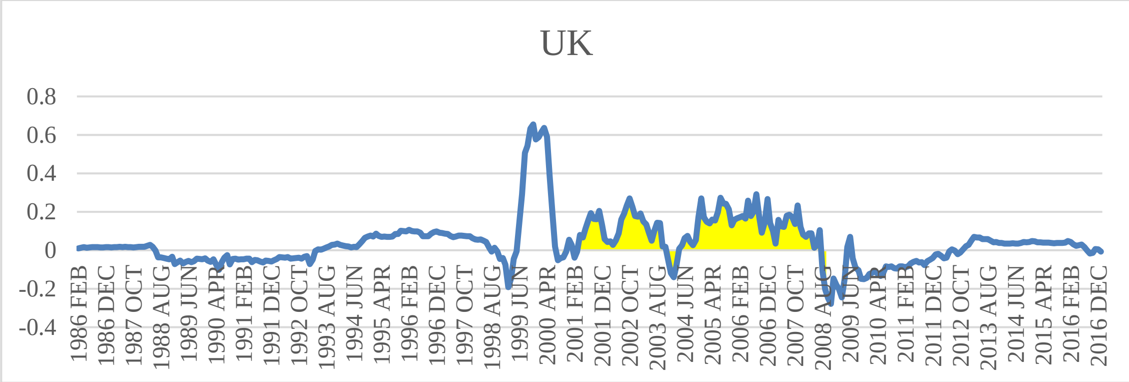



Canada
0.2
0.1
0
-0.1
-0.2
-0.3


Norway
4
3
2
1
0
-1
-2


Sweden
0.5
0
-0.5
-1
-1.5
-2

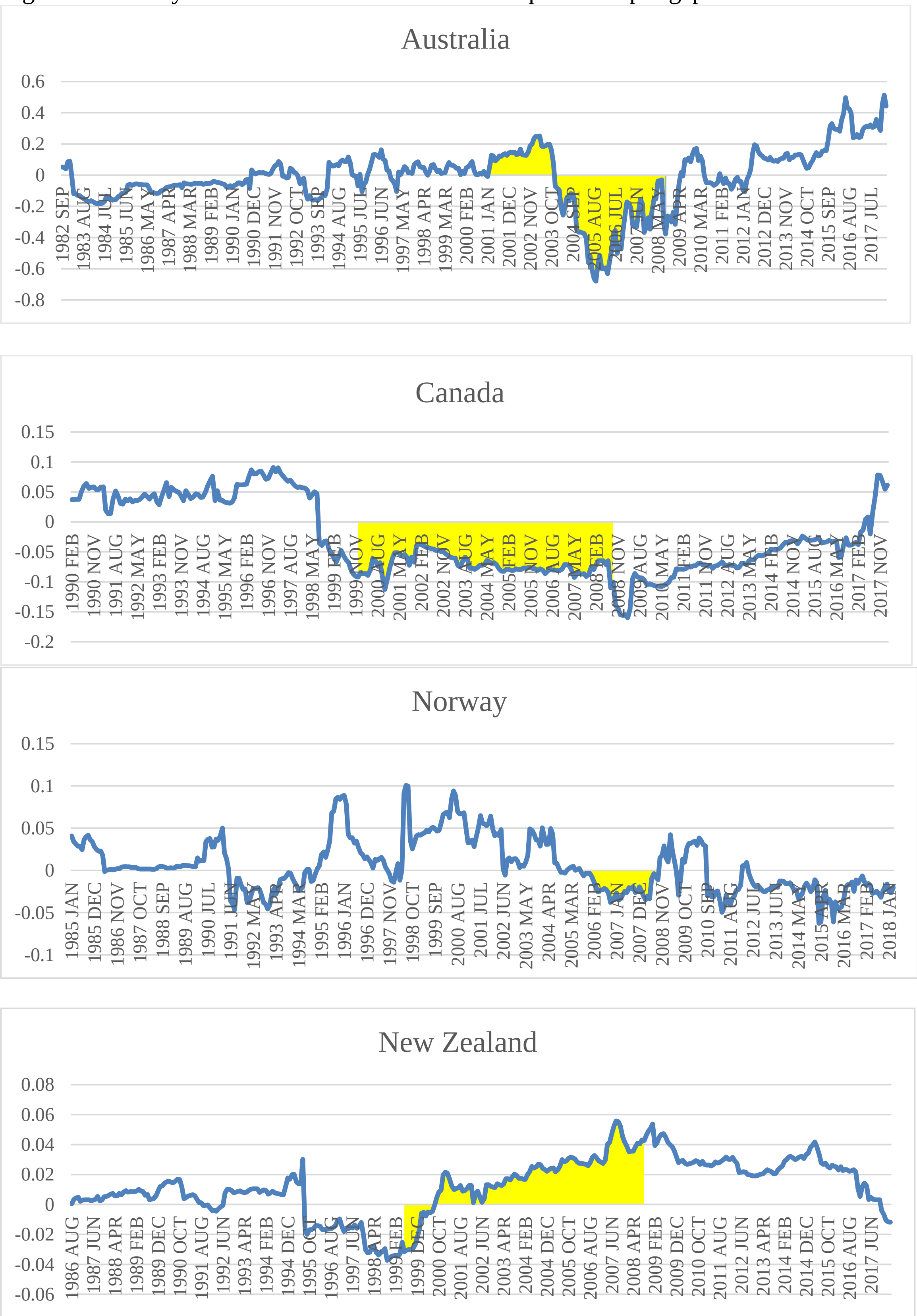

New Zealand
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

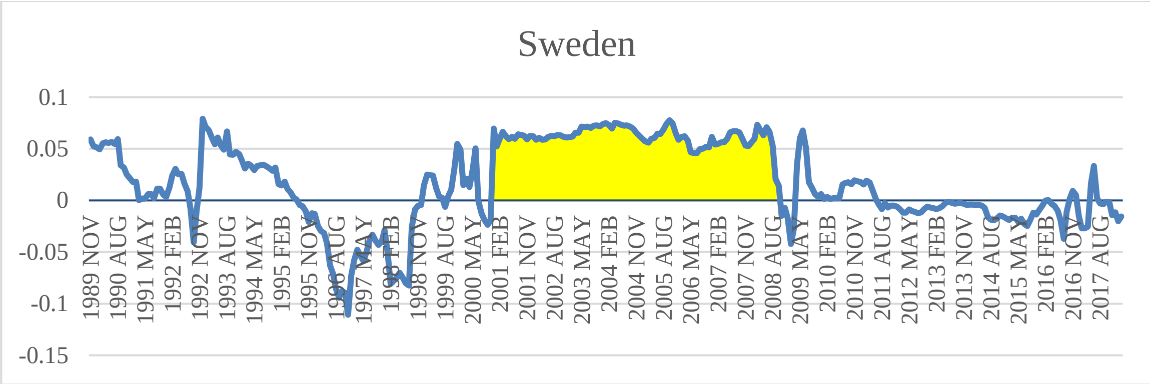


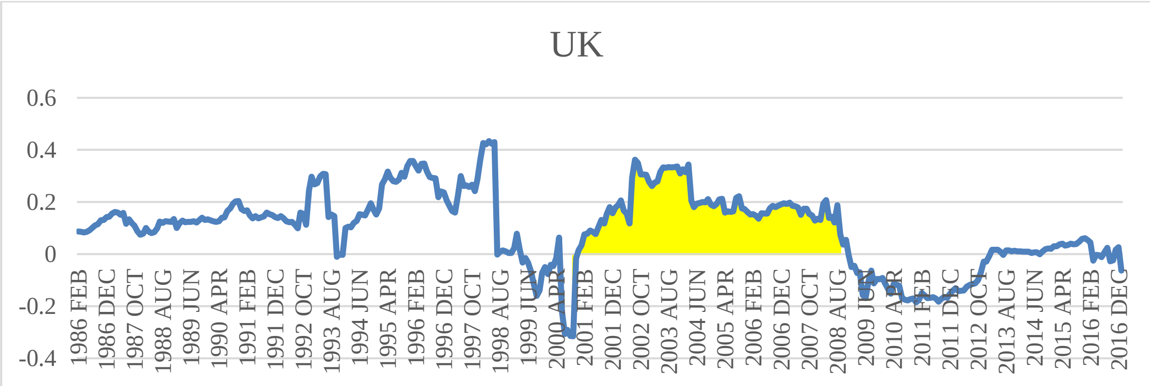
Compared with figure 1.1, the dynamics of the estimated coefficients on the output gap (Figure 1.2) are less precise. For figure 1.2, the yellow area chart also represents the estimated coefficients from the data of the conventional monetary policy period. Overall, Sweden is the only country has clear three different patterns, which correspond to each monetary policy shift.

The asymmetric exchange rate responses to output appeared even before the introduction of inflation targeting regime for Canada and the UK. We found that the coefficients are continuously positive for New Zealand and the UK during the conventional monetary policy period, however, the coefficients remain positive for New Zealand after the financial crisis while approach to zero for the UK. The coefficients for Canada are negative throughout the whole inflation targeting period, which suggest the Canadian dollar react more aggressively when the negative output gap occurs. In addition, For Australia, the estimates are not clear as there is no clear pattern for each sub-sample period and the estimated coefficients are near zero throughout the sample.

Figure1.2: The dynamics of the coefficient on the squared output gap







2.6 Conclusion

Past literature has shown strong evidence of out-of-sample exchange rate predictability for Taylor rule fundamentals. Such strong evidence are mainly due to the fact that the Taylor rule has achieved great success for describing the monetary policy during the last two decades. When the monetary policy and exchange rate are strongly related, the exchange rate should be determined by the fundamentals in the Taylor rule rather than the traditional macroeconomic fundamentals. However, the Taylor rule only assumes that the central bank responds evenly to the positive and negative deviations of inflation and output gap from the target values. This setting is not consistent with the fact that some credible central banks have asymmetric interventions to those deviations. Therefore, the Taylor rule based exchange rate model cannot reflect the asymmetric monetary preferences and the potential asymmetric exchange rate responses caused by the asymmetric monetary preferences. Hence, we derived an augmented Taylor rule fundamentals, which is able to capture the asymmetric monetary preferences and the subsequent asymmetric exchange rate responses. Prior to the estimates, we suspect the augmented Taylor rule fundamentals should more suitable for inflation targeting country during the conventional monetary policy period but will lose its explanatory power for the unconventional monetary policy period and the pre-inflation targeting period.

In order to test this hypothesis, we use four sub-sample periods, the full available sample, the whole inflation targeting period, the conventional monetary policy period, and the unconventional monetary policy period. Our results confirm this presumption, indeed, the augmented Taylor rule fundamentals can generate relatively stronger evidence of out-of-sample exchange rate predictability than the standard Taylor rule fundamentals during the conventional monetary policy period, and such strong evidence is robust. However, the role of asymmetric exchange rate responses become less relevant when we included the pre-inflation targeting period or the unconventional monetary policy period. In addition, the structural change of the monetary policy does not have strong effects on short-term exchange rate predictability for the standard Taylor rule fundamentals as the evidence of short-term exchange rate predictability is relatively stable compared with the augmented Taylor rule.

Furthermore, there is a clear inconsistency between the CW statistic and RMSFE. Apart from the conventional monetary policy period, there are only two cases where the RMSFEs are less than unity and the random walk null are rejected. This issue arises because the null hypothesis for these two statistics are different. Molodtsova *et al*. (2010)

argue that the CW statistic is a test for whether the exchange rate is a random walk, and the significant CW statistic only implies exchange rate predictability rather than forecast ability. However, this augment is subject to Rogoff and criticism, they state that ***"if the true model is something other than a random walk, one can still perfectly well ask if the random walk model produces a lower MSFE."*** In order to address this criticism, we use a strict metric to evaluating the exchange rate predictability that the random walk null can only be rejected when the RMSFE is less than one and the CW statistic is significant. By using the strict metric, we found the exchange rate predictability of standard Taylor rule fundamentals also fall apart when we included the pre-inflation targeting period or the unconventional monetary policy period, and the evidence of exchange rate predictability is only robust for the conventional monetary policy period.

This paper suggests a number of directions for future research. First, our empirical analysis is based on revised data. This is due to the fact that the real-time data is not available for all the inflation targeting countries. However, the real-time data is available for the UK and US, and therefore the future research could evaluate the augmented Taylor rule fundamentals with real-time data for the dollar/pound exchange rate. In addition, the theoretical framework of A&P suggests that the asymmetric monetary preference, and the subsequent asymmetric exchange rate response mainly applies to a county with credible inflation targeting regime. For this study, we only recognise a country who formally adopt the inflation targeting regime as a credible inflation targeting regime. However, other central banks such as ECB also implement an inflation stabilisation objective. Hence, we could relax the assumption of a credible inflation targeting regime and expand the sample to the country who does not formally adopt the inflation targeting regime but has a clear inflation stabilisation objective. Furthermore, the augmented Taylor rule fundamentals assumes that the central bank follows a nonlinear Taylor rule. However, our empirical analysis does not use the estimated coefficients from the nonlinear Taylor rule, and it is still unclear that whether the evidence of exchange rate predictability is related to central bank follows a nonlinear Taylor rule. Therefore, the assumption of the augmented Taylor rule fundamentals lacks empirical support, which can be regarded as the main limitation of this chapter.

Concluding Remarks

In contrast with existing literature, this thesis investigates the effects of asymmetric monetary preference within an open economy framework. The main findings can be summarised as follows. Firstly, under an open economy framework, we find that the BoE has recession avoidance in which the policymakers react more aggressively to output contractions than to the output expansions. The asymmetric policy responses reflect that the BoE is more averse to negative than to positive output gaps of equal size. This finding is differential from the conventional view that the BoE may be more concerned about the inflation rate exceeds its target rate during periods of inflation stabilisation.

Secondly, we suspect that the asymmetric monetary preference is the main cause of the reported asymmetries in exchange rate responses. Consequently, we derive an augmented Taylor rule fundamentals for the exchange rate in chapter 2, in which the exchange rate respond not only to the level of inflation and output gaps as suggested by standard Taylor rule fundamentals but also to their squared values. We test the out-of-sample exchange rate predictability using augmented Taylor rule fundamentals for 6 inflation targeting countries. Our empirical results suggest that the augmented Taylor rule fundamentals can better capture the dynamics of the exchange rate than the standard Taylor rule fundamental during the conventional monetary period. To the best of my knowledge, chapter 2 is the first empirical study in the literature to link the asymmetric exchange rate responses with the exchange rate predictability.

In addition, findings from both chapters support the view that policy function and the asymmetry properties change in line with the regime and the main macroeconomic problem of the day. In particular, the empirical evidence confirms that our theoretical framework mainly applies to the conventional monetary policy period, and it is not adequate to capture the dynamics of interest rate and exchange rate during the unconventional monetary policy period due to the monetary policy shift. It is clear that the evidence of asymmetries in monetary policy preference and the subsequent asymmetries in exchange rate responses are much weak after the financial crisis. Indeed, a number of studies argue that the Taylor rule without consideration of financial conditions could not explain the aggressive monetary policy of central banks from early 2008 (see, Meyer, 2008, Mishkin, 2008). Consequently, a possible way to address the weak evidence of asymmetry after the financial crisis is to include the indicators of financial stress in the optimal monetary policy rule and the augmented Taylor rule fundamentals. Furthermore, our theoretical frameworks mainly apply to a credible inflation targeting monetary policy. However, several central banks in developing countries also achieve policy credibility in anchoring inflation expectations. As a result, it would be fruitful to examine our research questions for developing countries. These can be taken as future research.

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Appendix 1 The derivation of the first order condition for A&P 2016

IS equation:

$$y_t = -\phi[i_t - \pi^e_{t+1}] + \theta S_t + y^e_{t+1} + \varepsilon_t \quad (1.1)$$

Phillips equation:

$$\pi_t = \lambda y_t + \beta\pi^e_{t+1} + \eta_t \quad (1.2)$$

UIRP condition:

$$(1 + i_t) = \frac{s^e_{t+1}}{s_t}(1 + i^f_t) \quad (1.3)$$

Following Surico (2007), the monetary authority chooses the interest rate that minimizes the loss function, L:

$$L = \frac{e^{\alpha(\pi_t - \pi^*)} - \alpha(\pi_t - \pi^*) - 1}{\alpha^2} + \delta\left(\frac{e^{\gamma y_t} - \gamma y_t - 1}{\gamma^2}\right) + \frac{\mu}{2}(i_t - i^*)^2 \quad (1.4)$$

The monetary authority minimizes L in (1.4) subject to (1.1), (1.2) and (1.3). In order to get the first order condition, we rewrite the equation (1.1), (1.2) and (1.3) as follows:

IS equation: $y_t = -\phi[i_t - \pi^e_{t+1}] + \theta S_t + g_t$, where $g_t = y^e_{t+1} + \varepsilon_t$ (1.5)

Phillips equation: $\pi_t = \lambda y_t + f_t$, where $f_t = \beta\pi^e_{t+1} + \eta_t$ (1.6)

Interest rate parity: $s_t = \frac{A}{1+i_t}$, where $A = S^e_{t+1}(1 + i^f_t)$ (1.7)

Then, substituting (1.5) and (1.6) into the loss function, we get:

$$L = \frac{e^{\alpha(\lambda y_t + f_t - \pi^*)} - \alpha(\lambda y_t + f_t - \pi^*) - 1}{\alpha^2} + \delta\left(\frac{e^{\gamma y_t} - \gamma y_t - 1}{\gamma^2}\right) + \frac{\mu}{2}(i_t - i^*)^2$$

$$L = \frac{1}{\alpha^2}\left[e^{\alpha(\lambda\{-\phi[i_t - \pi^e_{t+1}] + \theta S_t + g_t\} + f_t - \pi^*)} - \alpha(\lambda\{-\phi[i_t - \pi^e_{t+1}] + \theta S_t + g_t\} + f_t - \pi^*) - 1\right] + \frac{\delta}{\gamma^2}\left(e^{\gamma\{-\phi[i_t - \pi^e_{t+1}] + \theta S_t + g_t\}} - \gamma\{-\phi[i_t - \pi^e_{t+1}] + \theta S_t + g_t\} - 1\right) + \frac{\mu}{2}(i_t - i^*)^2$$

Taking the derivative w.r.t. i_t, we can write the first order condition as:

$$\frac{\lambda}{\alpha}\left[-\phi-\theta\frac{A}{(1+i_t)^2}\right]\left(e^{\alpha(\lambda\{-\phi[i_t-\pi_{t+1}^e]+\theta S_t+g_t\}+f_t-\pi^*)}-1\right)+$$

$$\frac{\delta}{\gamma}\left[-\phi-\theta\frac{A}{(1+i_t)^2}\right]\left(e^{\gamma\{-\phi[i_t-\pi_{t+1}^e]+\theta S_t+g_t\}}-1\right)+\ \mu(i_t-i^*)=0$$

Since $s_t=\frac{A}{1+i_t}$:

$$\frac{\lambda}{\alpha}\left[-\phi-\theta\frac{s_t}{1+i_t}\right]\left(e^{\alpha(\lambda\{-\phi[i_t-\pi_{t+1}^e]+\theta S_t+g_t\}+f_t-\pi^*)}-1\right)+$$

$$\frac{\delta}{\gamma}\left[-\phi-\theta\frac{s_t}{1+i_t}\right]\left(e^{\gamma\{-\phi[i_t-\pi_{t+1}^e]+\theta S_t+g_t\}}-1\right)+\ \mu(i_t-i^*)=0$$

Using (1.5) and (1.6), we can get:

$$\frac{\lambda}{\alpha}\left[-\phi-\theta\frac{s_t}{1+i_t}\right]\left(e^{\alpha(\pi_t-\pi^*)}-1\right)+$$

$$\frac{\delta}{\gamma}\left[-\phi-\theta\frac{s_t}{1+i_t}\right](e^{\gamma y_t}-1)+\ \mu(i_t-i^*)=0$$

By rearranging the equation, the first-order condition reads:

$$\left[\phi+\theta\left(\frac{s_t}{1+i_t}\right)\right]Z_t=\mu(i_t-i^*) \qquad (1.8)$$

Where $Z_t=\lambda\frac{e^{\alpha(\pi_t-\pi^*)}-1}{\alpha}+\delta\frac{e^{\gamma y_t}-1}{\gamma}$ (1.9)

Appendix 2 The derivation of the reduced-form policy function

Using Taylor series expansion, we can simplify the exponential parts from (1.8), to get:

$$e^{\alpha(\pi_t-\pi^*)}-1=\alpha(\pi_t-\pi^*)+\frac{(\alpha(\pi_t-\pi^*))^2}{2}+\frac{(\alpha(\pi_t-\pi^*))^3}{6}+\frac{(\alpha(\pi_t-\pi^*))^4}{2}+\cdots \qquad (1.81)$$

$$e^{\gamma y_t}-1=\gamma y_t+\frac{(\gamma y_t)^2}{2}+\frac{(\gamma y_t)^3}{6}+\frac{(\gamma y_t)^4}{24}+\cdots \qquad (1.82)$$

Firstly, rewrite (1.8) by using Taylor series products (1.81) and (1.81):

$$Z_t\approx\lambda(\pi_t-\pi^*)+\lambda\frac{\alpha(\pi_t-\pi^*)^2}{2}+\delta y_t+\delta\frac{\gamma(y_t)^2}{2} \quad (1.83)$$

Then, Substitutes Z_t out by using (1.83), we can rewrite equation (1.7) in respect to i_t:

$$i_t = \frac{\left[\phi+\theta\left(\frac{s_t}{1+i_t}\right)\right]}{\mu} * \left[\lambda(\pi_t - \pi^*) + \lambda\frac{\alpha(\pi_t-\pi^*)^2}{2} + \delta y_t + \delta\frac{\gamma(y_t)^2}{2}\right] + i^* \quad (1.71)$$

We can split the right hand set of equation (1.71) into the following parts:

1): $\frac{\phi}{\mu}* \lambda(\pi_t - \pi^*)+\frac{\theta}{\mu}*\frac{s_t}{1+i_t}* \lambda(\pi_t - \pi^*)$

2): $\frac{\phi}{\mu} * \lambda\frac{\alpha(\pi_t-\pi^*)^2}{2} + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} * \lambda\frac{\alpha(\pi_t-\pi^*)^2}{2}$

3): $\frac{\phi}{\mu} * \delta y_t + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} * \delta y_t$

4): $\frac{\phi}{\mu} * \delta\frac{\gamma(y_t)^2}{2} + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} * \delta\frac{\gamma(y_t)^2}{2}$

Adding those 4 parts together, equation (1.71) becomes:

$$i_t = \frac{\phi}{\mu} * \lambda(\pi_t - \pi^*) + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} * \lambda(\pi_t - \pi^*) + \frac{\phi}{\mu} * \lambda\frac{\alpha(\pi_t-\pi^*)^2}{2} + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} *$$
$$\lambda\frac{\alpha(\pi_t-\pi^*)^2}{2} + \frac{\phi}{\mu} * \delta y_t + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} * \delta y_t + \frac{\phi}{\mu} * \delta\frac{\gamma(y_t)^2}{2} + \frac{\theta}{\mu} * \frac{s_t}{1+i_t} * \delta\frac{\gamma(y_t)^2}{2} + i^*$$

By rearranging the above equation, we can get the central bank response function as follows:

$$i_t = i^* + \left[\frac{\lambda\phi}{\mu} + \frac{\lambda\theta}{\mu} * \frac{s_t}{(1+i_t)}\right] * (\pi_t - \pi^*) + \left[\frac{\alpha\lambda\phi}{2\mu} + \frac{\alpha\lambda\theta}{2\mu} * \frac{s_t}{(1+i_t)}\right] * (\pi_t - \pi^*)^2$$
$$+ \left[\frac{\phi\delta}{\mu} + \frac{\theta\delta}{\mu} * \frac{s_t}{(1+i_t)}\right] * y_t + \left[\frac{\gamma\phi\delta}{2\mu} + \frac{\delta\theta\gamma}{2\mu} * \frac{s_t}{(1+i_t)}\right] * {y_t}^2 \quad (1.9)$$

The equation 1.9 can be reparametrized as follows:

$$i_t = i^* + d'_1 * \left[\phi(\pi_t - \pi^*) + \theta\frac{s_t}{(1+i_t)}(\pi_t - \pi^*)\right] + d'_2\left[\phi(\pi_t - \pi^*)^2 + \theta\frac{s_t}{(1+i_t)}(\pi_t -\right.$$
$$\left.\pi^*)^2\right] + d'_3 * \left[\phi y_t + \theta\frac{s_t}{(1+i_t)}y_t\right] + d'_4 * \left[\phi {y_t}^2 + \theta\frac{s_t}{(1+i_t)}{y_t}^2\right] + v_t \quad (2.0)$$

Where $d'_1 = \frac{\lambda}{\mu}, d'_3 = \frac{\delta}{\mu}\ d'_2 = \frac{\alpha d'_1}{2}\ d'_4 = \frac{\gamma d'_3}{2}$.

Appendix 3 The derivation of the optimal monetary policy rule

IS equation: $y_t = -\phi[i_t - \pi^e_{t+1}] + \theta S_t + y^e_{t+1} + \varepsilon_t$ (1.91)

Phillips equation $\pi_t = \lambda y_t + \beta\pi^e_{t+1} + \eta_t$ (1.92)

The monetary authority chooses the interest rate that minimizes the loss function L:

$$L = \frac{e^{\alpha(\pi_t-\pi^*)} - \alpha(\pi_t-\pi^*)-1}{\alpha^2} + \delta(\frac{e^{\gamma y_t} - \gamma y_t - 1}{\gamma^2}) + \frac{\mu}{2}(i_t - i^*)^2 \quad (1.93)$$

The monetary authority minimizes L in (1.93) subject to (1.91), (1.92). In order to get the first order condition, we rewrite the equation (1.91), (1.92) as follows:

IS equation: $y_t = -\phi[i_t - \pi^e_{t+1}] + g_t$, where $g_t = y^e_{t+1} + \varepsilon_t$ (1.94)

Phillips equation: $\pi_t = \lambda y_t + f_t$, where $f_t = \beta\pi^e_{t+1} + \eta_t$ (1.95)

Then, substituting (1.94) and (1.95) into the loss function, we get:

$$L = \frac{e^{\alpha(\lambda y_t + f_t - \pi^*)} - \alpha(\lambda y_t + f_t - \pi^*) - 1}{\alpha^2} + \delta(\frac{e^{\gamma y_t} - \gamma y_t - 1}{\gamma^2}) + \frac{\mu}{2}(i_t - i^*)^2$$

$$L = \frac{1}{\alpha^2}\left[e^{\alpha(\lambda\{-\phi[i_t - \pi^e_{t+1}] + g_t\} + f_t - \pi^*)} - \alpha(\lambda\{-\phi[i_t - \pi^e_{t+1}] + g_t\} + f_t - \pi^*) - 1\right]$$
$$+ \frac{\delta}{\gamma^2}(e^{\gamma\{-\phi[i_t - \pi^e_{t+1}] + g_t\}} - \gamma\{-\phi[i_t - \pi^e_{t+1}] + g_t\} - 1) + \frac{\mu}{2}(i_t - i^*)^2$$

Taking the derivative w.r.t. i_t, we can write the first order condition as:

$$0 = \frac{-\lambda\phi}{\alpha}\left[e^{\alpha(\lambda\{-\phi[i_t - \pi^e_{t+1}] + g_t\} + f_t - \pi^*)} - 1\right] + \frac{-\delta\phi}{\gamma}(e^{\gamma\{-\phi[i_t - \pi^e_{t+1}] + g_t\}} - 1) + \mu(i_t - i^*)$$

Using (1.94) and (1.95), the first order condition reads:

$$-d_1\left[e^{\alpha(\pi_t - \pi^*)} - 1\right] - d_2(e^{\gamma y_t} - 1) + d_3(i_t - i^*) = 0 \quad (2.0)$$

Where $d_1 = \frac{\lambda\phi}{\alpha}$, $d_2 = \frac{\delta\phi}{\gamma}$ and $d_3 = \mu$

Using Taylor series expansion, we can simplify the exponential terms in (2.0), to get:

$$e^{\alpha(\pi_t - \pi^*)} - 1 = \alpha(\pi_t - \pi^*) + \frac{(\alpha(\pi_t - \pi^*))^2}{2} + \frac{(\alpha(\pi_t - \pi^*))^3}{6} + \frac{(\alpha(\pi_t - \pi^*))^4}{2} + \cdots \quad (2.01)$$

$$e^{\gamma y_t} - 1 = \gamma y_t + \frac{(\gamma y_t)^2}{2} + \frac{(\gamma y_t)^3}{6} + \frac{(\gamma y_t)^4}{24} + \cdots \quad (2.02)$$

Then, substitutes $e^{\alpha(\pi_t-\pi^*)}-1$ and $e^{\gamma y_t}-1$ out using (2.01) and (2.02), we can rewrite equation (2.0) in respect to i_t:

$$i_t = c_0 + c_1(\pi_t - \pi^*) + c_2(\pi_t - \pi^*)^2 + c_3 y_t + c_4(y_t)^2 + u_t \quad (2.1)$$

Where c_0 is the equilibrium interest rate, $c_1 = \frac{\lambda\phi}{\mu}$, $c_2 = \frac{\lambda\phi\alpha}{2\mu}$, $c_3 = \frac{\delta\phi}{\mu}$ and $c_4 = \frac{\delta\phi\gamma}{2\mu}$

Appendix 4 Out-of-sample forecasts for the full available sample using the same window size as M&P (window size is 120 for all the country)

Table 2.22: Asymmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.06*	0.51	1.015	0.18	0.52	1.033
Canada	0.29	0.54	1.054	0.27	0.54	1.057
Norway	0.03**	0.51	1.015	0.05*	0.51	1.025
New Zealand	0.07*	0.53	1.036	0.12	0.53	1.049
Sweden	0.05*	0.52	1.025	0.08*	0.52	1.034
UK	0.19	0.55	1.046	0.35	0.57	1.067

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.23: Symmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.05*	0.51	1.015	0.14	0.52	1.031
Canada	0.19	0.53	1.030	0.15	0.52	1.033
Norway	0.01**	0.50	0.995	0.03**	0.50	1.009
New Zealand	0.06*	0.53	1.035	0.09*	0.52	1.040
Sweden	0.05*	0.51	1.013	0.08*	0.52	1.030
UK	0.02**	0.51	1.010	0.05*	0.53	1.025

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.24: Asymmetric Taylor rule model with no smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.06*	0.56	1.148	0.06*	0.54	1.048
Canada	0.01**	0.58	1.120	0.02**	0.53	1.030
Norway	0.00***	0.51	1.021	0.02**	0.52	1.050
New Zealand	0.00***	0.54	1.067	0.01**	0.53	1.050
Sweden	0.56	0.54	1.110	0.60	0.55	1.102
UK	0.03**	0.56	1.147	0.35	0.56	1.090

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Table 2.25: Symmetric Taylor rule model with smoothing

	Standard Taylor rule fundamentals			Augmented Taylor rule fundamentals		
Country	CW	DMW	RMSFE	CW	DMW	RMSFE
Australia	0.03**	0.52	1.027	0.07*	0.53	1.042
Canada	0.03**	0.53	1.028	0.03**	0.53	1.028
Norway	0.02**	0.52	1.029	0.03**	0.51	1.035
New Zealand	0.01**	0.52	1.029	0.01**	0.53	1.044
Sweden	0.29	0.54	1.027	0.55	0.55	1.094
UK	0.13	0.54	1.074	0.21	0.55	1.080

Note: The Table reports p-values for one-month-ahead forecasts of the following tests: Clark and West (2006) ("CW"), Diebold and Mariano (1995) and West (1996) ("DMW"). The random walk without drift serves as the null model while the standard Taylor rule fundamentals and the augmented Taylor rule fundamentals are the alternative models. The script ***, ** and * denote the alternative model significantly outperforms the random walk model without drift at the 1%, 5% and 10 % significance levels. RMSFE denotes the ratio of the root mean squared forecast error of the alternative model relative to that of the random walk without drift, the values smaller than unity indicate the model forecasts better than the random walk without drift.

Appendix 5 Data description and summary statistics

Table 3.1: Data description of Chapter 1

Symbol	Variable	Source	Description
y_t	Output Gap	ONS: AMBI	HP cyclical component of the log real GDP
i_t	UK nominal interest rate	BoE:IUQAAJ NB	3-months Treasury Bills
s_t	Nominal exchange rate	BIS	Inverse of pounding sterling nominal effective exchange rate
$\pi_t(1)$	UK CPI inflation rate	ONS	CPI, percentage changes over 12 months
$\pi_t(2)$	UK RPI inflation rate	ONS	RPI, percentage changes over 12 months
i_t^f	Foreign nominal interest rate	Calculation	Weighted average of 3-months Treasury Bills of US, Germany and Japan

Table 3.2: Summary statistics of Chapter 1

Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.0360	-3.0253	3.5315	1.1540
i_t	3.7382	0.2357	7.1269	2.3454
s_t	8.7492	7.6517	10.3122	0.8535
$\pi_t(1)$	2.0665	-0.0200	4.7835	0.9966
$\pi_t(2)$	2.7613	-1.4000	5.3000	1.2884
i_t^f	2.3714	0.2217	4.9596	1.6628

Table 3.3: Data description of Chapter 2

Symbol	Variable	Source	Description
y_t	Output Gap	Federal Reserve Bank of St. Louis	HP cyclical component of the seasonally adjusted industrial production index
i_t	Nominal interest rate	OECD	Money market rate
s_t	Nominal exchange rate	Federal Reserve Bank of St. Louis	The domestic price (US) of one unit foreign currency
q_t	Real exchange rate	BIS	Log of the real effective exchange rate
π_t	CPI inflation rate	OECD	CPI, percentage changes over 12 months

Table 3.4: Summary statistics of Chapter 2

US				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.0497	-5.6172	3.5954	1.2726
i_t	5.1875	0.1100	18.6500	3.9138
π_t	3.8290	-2.0972	14.7565	2.9124
Australia				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.0243	-4.5803	3.6919	1.1885
i_t	7.9377	1.7000	21.3900	4.5344
s_t	0.8376	0.4998	1.3584	0.1904
q_t	4.4559	4.1304	4.7563	0.1618
π_t	2.9211	-0.2788	9.5890	1.8908
Canada				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	0.0105	-4.8343	4.8352	1.4948
i_t	5.5164	0.3758	22.0125	4.3126
s_t	0.8042	0.6249	1.0459	0.1020
q_t	4.4776	4.2379	4.6534	0.1118
π_t	2.9396	-0.9499	12.8959	2.4472
Norway				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.0054	-9.7843	8.2292	3.1140
i_t	6.8047	0.7800	17.1000	4.6699
s_t	0.1465	0.1056	0.1978	0.0200
q_t	4.5498	4.4180	4.6653	0.0496
π_t	3.5359	-1.8315	14.6429	2.8878
New Zealand				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.6754	-8.7284	9.4420	3.3832
i_t	9.0062	1.8800	27.2000	5.6152
s_t	0.6760	0.3995	1.0736	0.1505
q_t	4.5355	4.2518	4.7821	0.1174
π_t	5.2789	-0.6308	19.3178	5.4670
Sweden				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.0101	-8.8004	6.7168	2.0160
i_t	5.5725	-0.7900	20.1800	4.7627
s_t	0.1373	0.0926	0.1891	0.0199
q_t	4.7201	4.4821	4.9868	0.1196
π_t	3.0248	-1.8716	13.0804	3.1378
UK				
Variable	Mean	Minimum	Maximum	Standard Deviation
y_t	-0.0286	-6.3213	4.9511	1.3009
i_t	6.7193	0.2977	17.9933	4.6335
s_t	1.6750	1.0954	2.4198	0.2418
q_t	4.7711	4.5315	5.0654	0.1050
π_t	5.5854	-1.6000	26.9000	5.2164