Taylor Rules and Exchange Rate Forecasting for Inflation Targeting Regimes

– PhD Thesis –

to be awarded

PhD in Economics

submitted by

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Abstract

This thesis mainly deals with relationship between Taylor rules and exchange rate predictability for different inflation targeting(IT) countries. I first consider in Chapter 2 an exchange rate forecasting model in which movements in exchange rates are related to short-term nominal interest rates based on monetary policy rules. In this chapter, using forecasted data for the U.K. since instrument independence (1997- 2015), I find that a Taylor rule with expected inflation and expected output gap growth substantially improves short-run out-of-sample pound/dollar exchange rate predictability. This finding is firmly in line with intuition that under an IT regime where the central bank is largely forward looking, what matters for its monetary policy making is expected future variables.

In Chapter 3, I propose the degree of central bank independence (CBI) as an explanation for the long-standing exchange rate disconnect puzzle in international macroeconomics, which is, the failure of macroeconomic fundamentals to predict exchange rates. To explore how changes in CBI influences the connection between exchange rates and macroeconomic variables, I first identify historical changes in CBI levels in the United Kingdom and compare them with structural changes in monetary responses to inflationary pressure. Considering CBI improvements in empirical models of the USD/GBP nominal exchange rate substantially improves their predictive power. In particular, over the whole sample period (October 1986-September 2008) the exchange rate disconnect puzzle remains dominant. However, when focusing on sub-periods following CBI increases, the Taylor rule model with UK forecasted variables helps predict exchange rates significantly better than the random walk model. These results support the hypothesis that CBI "reconnects" the exchange rate with macroeconomic variables through shifts of monetary policy regimes.

Chapter 4 focuses on the exchange rate predictability in developing countries. I find that real exchange rate solely offers stronger evidence of out-of-sample predictability of nominal exchange rate than random walk and Taylor rule fundamentals model. Regarding the forecasts methodology, I also find that individual regression provides better forecasting accuracy than using the panel data regression. As different countries share same coefficient when using panel data estimation, the superior outcomes with individual regression implies that nominal exchange rate respond heterogeneously to initial movements in real exchange rate in developing countries. I use a robust set of out-of-sample statistics incorporating Diebold-Mariano Statistics, the Clark and West Statistics and Theil's U ratio. This finding is robust for one-month, six-month and twelve-month ahead forecasts.

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Contents

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List of Acronyms

AE	Advanced economy
BoE	Bank of England
CW	Clark and West
CBI	Central bank independence
DMW	Diebold, Mariana and West
EME	Emerging market economy
IT	Inflation targeting
LIC	Lower income country
MSPE	Mean squared prediction error
RER	Real exchange rate
RMSE	Root of mean squared forecast error
NER	Nominal exchange rate
ZLB	Zero lower bound

1 Introduction

1.1 Background and Motivation

The inability of empirical exchange rate models to consistently beat a random walk in forecasting exchange rates out-of-sample has troubled researchers since the seminal papers of Meese & Rogoff (1983a, 1983b). Although financial theory states that there is a relationship between exchange rates and traditional macroeconomic fundamentals, the empirical research does not support favorable evidence for their connection, which is known as "exchange rate disconnect puzzle". The weak empirical relationships between exchange rates and macro variables provides too little help for policymakers and academics on which macroeconomic models to use. An excellent review of exchange rate predictability by Rossi (2013) shows that the puzzle still exists in most advanced country currencies. Especially for the USD/GBP nominal exchange rate, no evidence of out-of-sample predictability is found with any economic models, regardless of the length of forecast horizons(see figure 1 copied from the review). Although some progress has been made, the problem is still far from been solved.

While previous studies displayed some evidence of out-of-sample predictability in developed countries, the estimated coefficients in economic models are usually unsatisfactory for exchange rate forecasts in EMEs [1]. In a later research, Eichenbaum et al. (2021) argue

[1] Studies like Salisu et al. (2022) plot the estimated parameters without confidence interval. Dynamic coefficients in Alba et al. (2015) are insignificant more than half the sample period. Other studies did not present dynamic coefficients.

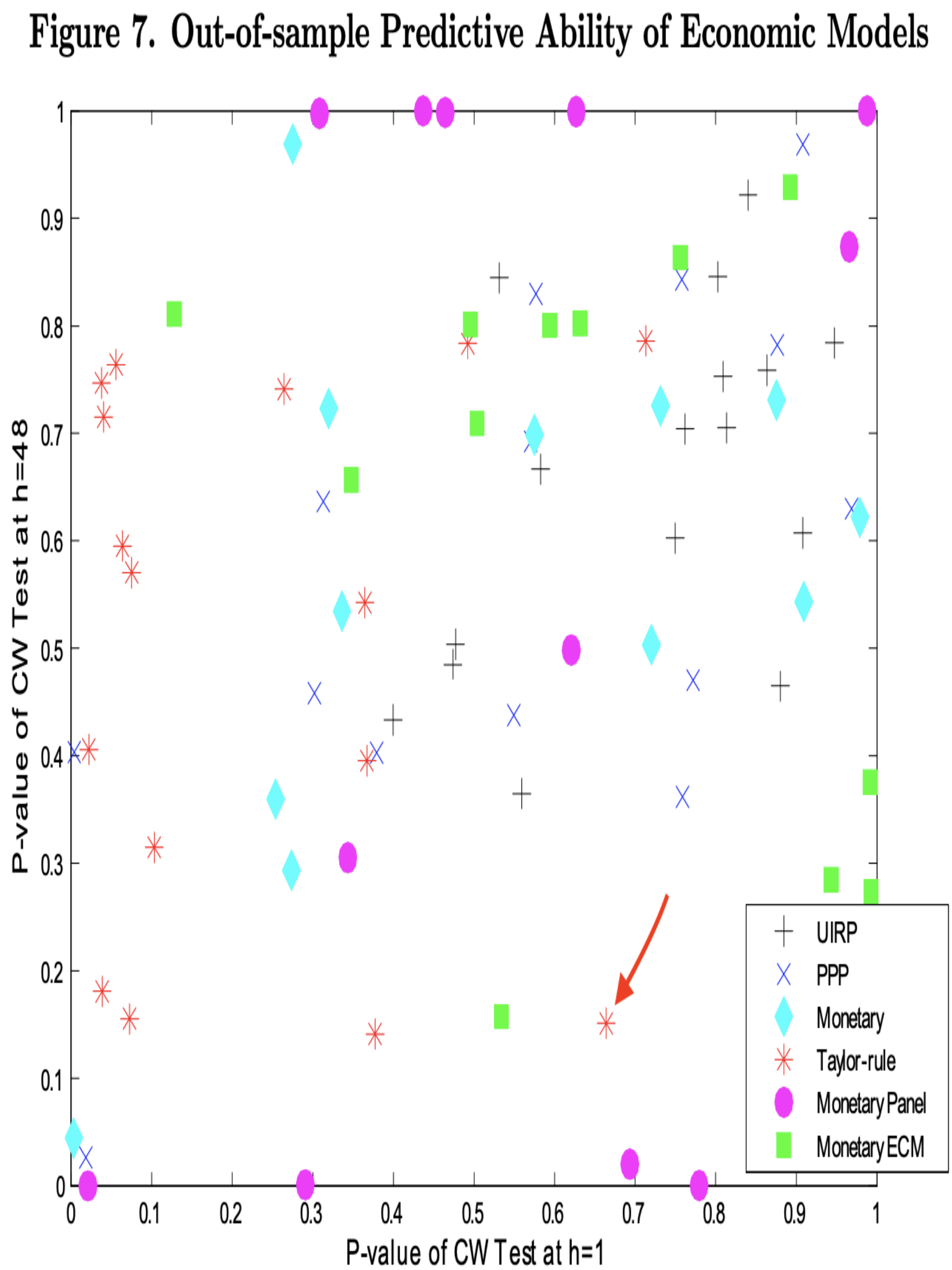


Figure 1: Rossi (2013)'s review of Mease and Rogoff Puzzle (Red arrow: GBP/USD exchange rate predictability using Taylor-rule model)

that real exchange rate (RER) must adjust through changes in the nominal exchange rate (NER) as long as the home and foreign central banks adopt inflation-targeting(IT) regimes and consumers have home bias in consumption [2]. In their work, the current RER provides out-of-sample predictability for six advanced IT countries in horizons greater than one year. On the other hand, the RER is usually incorporated into the Taylor rule specification when presenting evidence of predictability by previous studies. This makes me to conjecture that previous evidence of predictability for Taylor rule fundamentals mainly comes from the use of RER. It is even possible that RER alone is sufficient to provide superior out-of-sample predictability for NERs of countries that adopted inflation targeting. In addition, Morozumi et al. (2020) found that CBI and democracy have interaction effect with IT to help reducing inflation in LICs and EMEs[3]. In other words, IT with high level of CBI/democracy is more effective in reducing inflation. Recall the mechanism generated by Eichenbaum et al. (2021), if the inflation becomes more stable under high level of CBI/democracy, RER is expected to adjust through movements in the NER in a more efficient way. This drives me to investigate whether more significant evidence of predictability with RER exists under high level of CBI/democracy after IT adoption.

[2]Regarding a negative shock to the domestic endowment, the domestic good becomes more expansive. For consumers with home bias and having both domestic and foreign good in their consumption basket, the price of the foreign consumption basket becomes cheaper relative to the domestic consumption basket-i.e. the RER declines. If maintaining inflation stability is the target for domestic and foreign country, the RER can only adjust to shocks through movements in the NER.

[3]The categorization of countries into different income levels is made by Morozumi et al. (2020) using per capita real GDP in PPP terms (in 2011 international dollars, from IMF's World Economic Outlook) over the 1980-2016 period, which overlaps most times in our study (1989-2021)

1.2 Thesis Contribution and Outline

In this thesis I consider several macroeconomic fundamentals that might provide the out-of-sample NER forecasting performance in AEs, EMEs and LICs. I also examine some of the major factors that might influence exchange rate models' predictive ability. The contribution is laid out in three self-contained chapters.

Chapter 2 demonstrates that macroeconomic variables that drive the co-movement between Taylor rule fundamentals and GBP/USD exchange rates, are expectations of UK inflation and GDP growth over time. Specifically, using forecasted data for the U.K. since instrument independence (1997- 2015), a Taylor rule with expected inflation and expected output gap growth substantially improves short-run out-of-sample GBP/USD exchange rate predictability. This is different from previous literature which only use actual inflation as a key factor in the model for GBP/USD exchange rate predictability.

In Chapter 3, I employ a historical approach to examine the role of CBI in rebuilding the exchange rate connection with macroeconomic variables. To explore how changes in CBI influences the connection between exchange rates and macroeconomic variables, I first identify historical changes in CBI levels in the UK and compare them with structural changes in monetary responses to inflationary pressure. Considering CBI improvements in empirical models of the USD/GBP nominal exchange rate substantially improves their predictive power. In particular, over the whole sample period (October 1986-September 2008) the exchange rate disconnect puzzle remains dominant. However, when focusing on sub-periods following CBI increases, the Taylor rule model with UK forecasted variables helps predict exchange rates significantly better than the random walk model. Both in-sample and out-of-sample tests reject the no-predictability null hypothesis. These results support the hypothesis that CBI "reconnects" the exchange rate with macroeconomic variables through shifts of monetary policy regimes.

Chapter 4 focuses on the exchange rate predictability in developing countries. I find that real exchange rate solely offers stronger evidence of out-of-sample predictability of nominal exchange rate than random walk and Taylor rule fundamentals model. Regarding the forecasts methodology, I also find that individual regression provides better forecasting accuracy than using the panel data regression. As different countries share same coefficient when using panel data estimation, the superior outcomes with individual regression implies that nominal exchange rate respond heterogeneously to initial movements in real exchange rate in developing countries. I use a robust set of out-of-sample statistics incorporating Diebold-Mariano Statistics, the Clark and West Statistics and Theil's U ratio. This finding is robust for one-month, six-month and twelve-month ahead forecasts.

2 Chapter 2

Taylor rules and exchange rate predictability for the UK Pound/US Dollar Exchange Rate

2.1 Introduction

The inability of empirical exchange rate models to consistently beat a random walk in forecasting exchange rates out-of-sample has troubled researchers since the seminal papers of Meese & Rogoff (1983a, 1983b). Although financial theory states that there is a relationship between exchange rates and traditional macroeconomic fundamentals, the empirical research does not provide favorable evidence for their connection, which is known as "exchange rate disconnect puzzle". More recent works such as Molodtsova & Papell (2008),Rossi (2013) find some fundamentals that claim to have persistently better forecasting performance than the random walk. One of them is the Taylor rule fundamentals model.

This model is constructed by reflecting how central banks make their interest rate decisions based on Taylor (1993) rules set by domestic and foreign countries. As fundamentals for evaluating out-of-sample predictability of the nominal exchange rate, the specifications of Taylor rule are usually modified in order to better characterise the central bank monetary policy. Following inflation forecast targeting of inflation targeting (IT) regime implied by Svensson (1997), it has been widely accepted that forecast information like expected inflation is important for IT economy to make monetary policy decisions. For example, empirical studies on UK monetary policy shows that forecasts variables such as expected inflation play a significant role in describing its interest rate decisions(see Gorter et al. (2008), Paez-Farrell (2009), Adam et al. (2005) and Neuenkirch & Tillmann (2014)). Although using forecast information to estimate interest rate reaction functions for IT economies seems a compelling choice in the context of exchange rate forecasting with Taylor rule fundamentals model, almost all existing literature suggests no superiority of using forecast-based policy rule for IT economies when assessing the out-of-sample predictability of Taylor rule exchange rate model[5](see e.g. Molodtsova et al. (2008), Molodtsova et al. (2011)). This seems contrary to the evaluation of IT countries monetary policy that Taylor rules using expectations variables provides a superior description of their policy decisions.

This raises a concern about whether forecast information could contribute to the out-of-sample predictability of Taylor rule fundamentals model for IT economies. To examine this issue, this paper uses the U.K. as a case study, which has followed an IT regime since the early 1990s. First, I estimate conventional and forecast-based Taylor rule monetary policy reaction functions for the U.S. and U.K. from 1997, the independence of the BoE, through September 2008[6], the collapse of Lehman Brothers, and then I use these specifications

[5]Following previous literature (e.g. Molodtsova et al. (2011)), Out-of-sample predictability associates whether variables in the fundamental have explanatory power for *ex post* exchange rate return. Out-of-sample forecastability indiciates whether one macro fundamental have better forecasts accuracy than a benchmark model(see discussion in Rogoff & Stavrakeva (2008))

[6]As monetary policy evaluation with shadow rate is controversial during the ZLB period (see Hakkio & Kahn (2014); D. H. Kim & Priebsch (2013); Krippner (2012, 2013)), we only evaluate the policy before the crisis.

as fundamentals for investigating out-of-sample predictability of the British pound/United States dollar (GBP/USD) nominal exchange rate. Additionally, I examine the out-of-sample predictability of Taylor rule fundamentals models for the time when the use of conventional monetary policy is severely restricted under the ZLB period (October 2008- December 2015).

By taking various combinations of arguments - actual inflation, output gap, inflation forecasts and output gap growth forecasts - into the estimated policy rule, I find that the Taylor rules using inflation forecast provide a better description of the U.K.'s monetary policy than the other rules. The estimated long-run response of interest rates to increases in expected inflation is significant and greater than unity, while the estimated coefficient on actual inflation is less than unity. This means the Taylor principle is followed only when forecasts variables are used. In other words, the BoE was stabilizing inflation in a forward-looking perspective. For the U.S. monetary policy, I focus on low deviations era (1997:05-2000:12) and high deviations era (2001:01-2008:09) relative to the original Taylor (1993) rule [7]. During the low deviations era, only estimated coefficients from original Taylor rule specifications imply the following of Taylor principle. In the high deviations era, while estimated coefficients on actual inflation and the output gap become insignificant, forecast-based rules provide appropriate description of the U.S. monetary policy. The estimated coefficients for macroeconomic variables are consistent with the Taylor rule advocated by central bankers like Yellen (2012).

[7] Nikolsko-Rzhevskyy et al. (2014b) identify low and high deviations eras from the original Taylor (1993) rule for the U.S. based on Bai & Perron (1998) tests.

In this paper, out-of-sample predictability is treated as superior explanatory power of Taylor rule fundamentals in explaining one-month-ahead nominal exchange rate movements. Two types of metrics are used to evaluate the out-of-sample predictability of the Taylor rule exchange rate models. The first one is the ratio of Mean Square Prediction Error(MSPE) (or Theil's U ratio). It is calculated as the MSPE of the Taylor rule model divided by the MSPE of the driftless random walk. The second one is the CW statistic developed by Clark & West (2006). By rejecting the null hypothesis of CW test, the significance result indicates that variables in Taylor rule fundamentals are jointly significant in explaining the movements of one-month-ahead nominal exchange rate. The results of Theil's U ratio and CW test support the importance of the U.K. forecasted variables in improving out-of-sample predictablity for GBP/USD exchange rate. No evidence of predictability is found for the models without forecasts variables. However, Models that include the UK forecasts variables provide significant evidence of out-of-sample predictability for exchange rate changes. These results are in accord with the estimations of the U.K. Taylor rules, where the forecasts variables enter significantly into the BoE monetary policy reaction function[8].

The finding of exchange rate predictability in this paper contributes to the empirical literature of exchange rate modelling especially for the IT countries. Previous research did not find significant evidence for forecasts variables in improving out-of-sample predictability of

[8] All comparisons are made between the specific model and the random walk model, rather than between alternative models.

currencies in IT states. By taking UK as a case study, this paper finds that UK forecasts variables play the decisive role in improving the out-of-sample predictability of GBP/USD nominal exchange rate.

The remainder of paper is organized as follows: Section 2.2 reviews previous literature of this issue. Section 2.3 introduces methodology used in this paper; Section 2.4 contains empirical results from Taylor rule estimation; Section 2.5 discusses out-of-sample exchange rate predictability. At the end, a summary of main findings is provided.

2.2 Literature review

Taylor (1993) rule has been widely applied in the literature on monetary policy evaluation. As fundamentals for evaluating out-of-sample predictability of the nominal exchange rate, the specifications of Taylor rule are usually modified in order to better characterise the central bank monetary policy. Following inflation forecast targeting of inflation targeting (IT) regime implied by Svensson (1997), forecast information like expected inflation has been widely emphasized in IT economy when making monetary policy decisions. By employing expected inflation and expected output growth, Gorter et al. (2008) finds that forecast-based rule has superior description of the ECB's monetary policy than conventional specification, where the coefficient of actual inflation is insignificantly different from zero. Paez-Farrell (2009) finds that the Taylor rule that best describes the U.K.'s monetary policy is forecast-based rule incorporating expectations of future inflation and output gap. Adam et al. (2005) finds that the BoE's monetary policy since independence is well fitted by forward-looking rules in terms of inflation forecast, but reacts to current output gap. Neuenkirch & Tillmann (2014) estimated a non-linear forward-looking Taylor rule for five IT regimes and find significant coefficients for both expected inflation gap and expected GDP growth in most countries. Being different with the IT economies, both maximum sustainable employment and price stability are congressionally-given objectives for the U.S. Federal Reserve. Previous studies did not reach a consistent conclusion about the efficacy of forecast information in estimating U.S. Taylor rules. On the one hand, authors like Orphanides (2003), Fuhrer et al. (2018) emphasize the better description of actual policy by forecast-based rule with inflation expectations since the early 1990s. Some other exercises such as Molodtsova et al. (2008) suggest that there are no big differences of the Taylor rule estimation between using actual and forecasted inflation, supported by Taylor (1999)'s argument that forecasted data are merely based on current and lagged data. According to Orphanides (2007), the uncertain performance about the U.S. forecast-based Taylor rules can be due to its sensitivity towards the quality of the forecasts. The conclusions from the forecast-based Taylor rule estimation can be changed or even overturned, once different horizons of forecasts or different data sources are used[9].

Although using forecast information to estimate interest rate reaction functions for IT economies seems a compelling choice in the context of exchange rate forecasting with Taylor rule fundamentals model, almost all existing literature suggests no superiority of using

[9]See Levin et al. (2003a) for a general discussion on the performance of forecast-based rules.

forecast-based policy rule for IT economies when assessing the out-of-sample performance of Taylor rule fundamentals model. The first paper using forecast information to evaluate the nominal exchange rate predictability of Taylor rule models is Molodtsova et al. (2008). They find that the Taylor rule models with inflation forecasts and output gap growth forecasts for the U.S. perform worse than the models with actual inflation and output gap when evaluating out-of-sample predictability of the Dollar/Deutsche Mark nominal exchange rate. Molodtsova et al. (2011) then investigate the out-of-sample predictability of Dollar/Euro nominal exchange rate using Taylor rule fundamentals model, similar conclusion is made that evidence of predictability only show comparable strength as with the actual inflation and output gap when inflation forecasts and output gap forecasts are used for both countries. This seems contrary to the evaluation of the ECB's monetary policy by Gorter et al. (2008) that forecast-based rule using expectations of inflation and output growth provides a superior description of the ECB's policy decision than conventional specifications.

To verify the efficacy of forecasts information in improving GBP/USD nominal exchange rate predictability, I firstly identified which Taylor rules (with or without forecasts variables) have better description of US and UK's monetary policy. As following, both conventional and forecast-based Taylor rule models' exchange rate predictability are investigated. The superior predictability with forecasts data are expected to contribute new evidence to the exchange rate determination in IT countries.

2.3 Methodology

2.3.1 Rolling Window Forecast

To make an out-of-sample forecast with Taylor rule fundamentals model, I now introduce an estimation method called rolling window estimation. The right hand side of Taylor rule fundamentals (without constant) can be expressed as a linear combination of coefficients:

$$E_t(s_{t+1}) - s_t = \beta f_t, t = 1, 2, ..., T - 1 \tag{1}$$

where T is the total number of observations, β is a vector containing different coefficients, f_t is a data matrix including inflation, output gap and the lagged interest rate. To estimate the parameters β, the total sample observations are divided into two portions which include in-sample observations from 1 to R and out-of-sample observations from R+1 to T. To estimate as a rolling scheme, β_t is reestimated using the most recent R observations until $t = T - 1$. R is also called rolling window size. The estimation form is written as:

$$\hat{\beta}_t = \left(\sum_{j=t-R+2}^{t+1} f_{j-1}^2 \right)^{-1} \times \left(\sum_{j=t-R+2}^{t+1} f_{j-1}(s_j - s_{j-1}) \right), t = R, R{+}1, ..., T - 1 \tag{2}$$

With each $\hat{\beta}_t$, one-step-ahead out-of-sample prediction error is calculated as $\epsilon_t^f \equiv s_{t+1} - s_t - \hat{\beta}_t f_t$, $t = R, R + 1, ..., T - 1$, while the prediction error for the random walk without drift is $\epsilon_t^{rw} \equiv s_{t+1} - s_t$.

One typical loss function to measure the forecast accuracy is Root

Mean Square Prediction Error (MSPE). MSPE can be expressed as:

$$MSPE_f = \sqrt{\frac{1}{T-R}\sum_{t=R}^{T-1}(\epsilon_t^f)^2}. \tag{3}$$

If model a has better accuracy than model b, then $MSPE_a < MSPE_b$ (i.e. $\frac{MSPE_a}{MSPE_b} < 1$).

2.3.2 Tests of equal predictability

To decide whether the out-of-sample predictability of nominal GBP/USD exchange rate with our model is statistically better than the random-walk, we use the Clark & West (2006) (CW) test of equal predictability. The null and alternative hypothesis can be shown as following:

$$H_0 : s_{t+1} - s_t = \epsilon_t \tag{4}$$

$$H_1 : s_{t+1} - s_t = \beta_t f_t + \epsilon_t, \text{where } E_t(\epsilon_{t+1}) = 0. \tag{5}$$

CW test can be treated as a modification based on Diebold & Mariano (1995) and West (1996) (DMW) test, in order to compare the accuracy of two nested models. By defining

$$\hat{l}_t = (\epsilon_t^{rw})^2 - (\epsilon_t^{f})^2$$
$$\bar{l} = \frac{1}{T-R}\sum_{t=R}^{T-1}\hat{l}_t$$
$$\hat{V} = \frac{1}{T-R}\sum_{t=R}^{T-1}(\hat{l}_t - \bar{l})^2, \quad (6)$$

the DMW test statistic can be expressed as:

$$DMW = \frac{\bar{l}}{\sqrt{(T-R)^{-1}\hat{V}}} \quad (7)$$

Although the DMW test has been shown as a powerful test for non-nested models, Clark & West (2006) found that the extra sampling error in the linear model may bias the results and lead to underestimation of its predictability. This is important in this paper since the random walk is always nested inside the Taylor rule fundamentals model.

As the DMW statistic has been shown to be severely undersized when comparing nested models, which makes it inappropriate in this case.

To emphasize the bias, the sample difference between the two mean sqaure prediction errors is expanded as:

$$\bar{l} = \frac{1}{T-R}\sum_{t=R}^{T-1}\hat{l}_t = \frac{1}{T-R}\sum_{t=R}^{T-1}(s_{t+1}-s_t)^2 - \frac{1}{T-R}\sum_{t=R}^{T-1}(s_{t+1}-s_t-\hat{\beta}f_t)^2$$
$$= \frac{2}{T-R}\sum_{t=R}^{T-1}(s_{t+1}-s_t)\hat{\beta}f_t - \frac{1}{T-R}\sum_{t=R}^{T-1}(\hat{\beta}f_t)^2 \quad (8)$$

Under null hypothesis of equal predictability, the first term is zero, however the second term is always positive as a squared term. As a result, the $MSPE_{rw}$ is expected to be smaller than $MSPE_f$ under the null. In order to fix this bias and suit for the nested models, Clark & West (2006) adds a simple correction term and results in an adjusted CW statistic for rolling regressions as following:

$$\hat{l}_t^{ADJ} = (\epsilon_t^{rw})^2 - [(\epsilon_t^f)^2 - \left(\hat{\beta}f_t\right)^2]$$
$$\bar{l}^{ADJ} = \frac{1}{T-R}\sum_{t=R}^{T-1}\hat{l}_t^{ADJ} = \bar{l} + \frac{1}{T-R}\sum_{t=R}^{T-1}(\hat{\beta}f_t)^2$$
$$\hat{V}^{ADJ} = \frac{1}{T-R}\sum_{t=R}^{T-1}\left(\hat{l}_t^{ADJ} - \bar{l}^{ADJ}\right)^2$$
$$CW = \frac{\bar{l}^{ADJ}}{\sqrt{(T-R)^{-1}\hat{V}^{ADJ}}} \quad (9)$$

2.3.3 Data

Real-time monthly data is used from May 1997 to December 2015. The start of the period was dictated by the legal independence of the

BoE. The end of the period was chosen to correspond with an end of ZLB for the monetary policy in the U.S.. As the BoE's inflation target has changed from 2.5% as measured by RPIX to 2% as measured by CPI after December 2003, RPIX and CPI are bonded together to measure inflation for the U.K.. Core CPI is used to measure inflation for the U.S.. Monthly vintages for quarterly real GDP are used to measure output for both the U.K. and the U.S.. Federal funds rate is used for the U.S. and three-month treasury bill rate is used for the U.K. until September 2008, and the shadow rates of Wu & Xia (2016) are used for both countries thereafter. The interest rates and GBP/USD nominal exchange rate are for the last day in the month. Following Taylor (1993), the inflation rate is the rate of inflation over the previous twelve months.

As real-time datasets, first-time released core inflation and real GDP for the United States are extracted from the Philadelphia Fed Real-Time Data set for Macroeconomists. Real-time GDP for the U.K. are available from the BoE website. As real time inflation data starting from May 1997 are unavailable for the U.K., RPIX/CPI revised in December 2015 are used instead.

Real-time expected output growth and expected inflation time series for the U.K. have been constructed from a summary of private sector forecasts collected by the U.K. HM treasury[10]. For the U.S., expected inflation are collected from the OECD website, the expected output growth are collected from the Survey of Professional Forecasters (SPF) on the Philadelphia Fed website. As the data are unique

[10]The definitions of expectations data are provided in Appendix B.

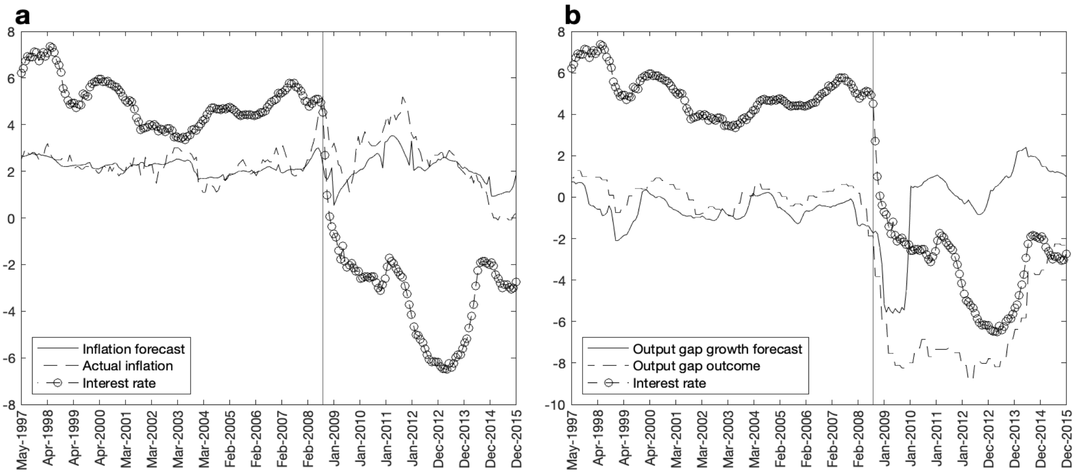


Figure 2: U.K. inflation, output gap and interest rate

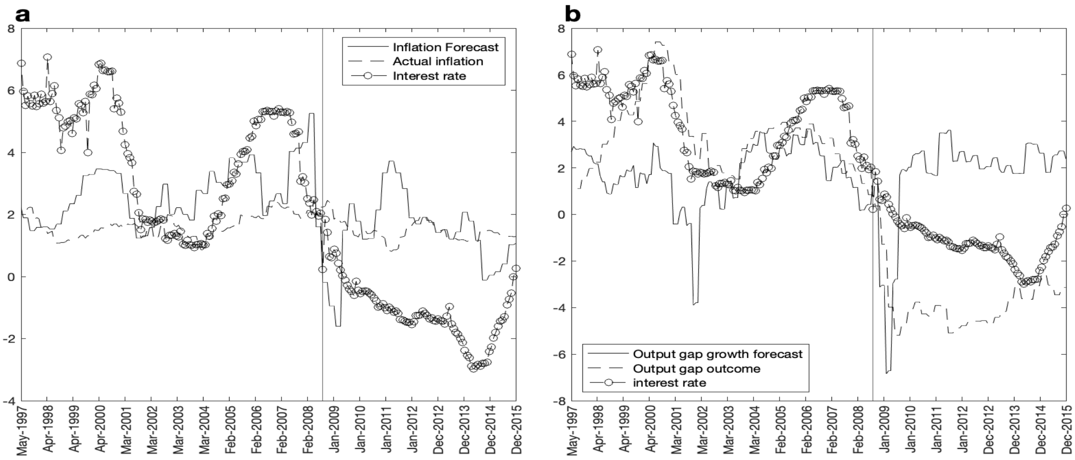


Figure 3: U.S. inflation, output gap and interest rate

and not revised later on, the critique of ex-post data by Orphanides (2001) is not applied. Nominal exchange rate are collected from the FRED website.

In the context of Taylor rules estimation, we apply the quadratic detrending to the U.S. real-time output starts in October 1986 and the output gap is defined as percent deviation of actual output from

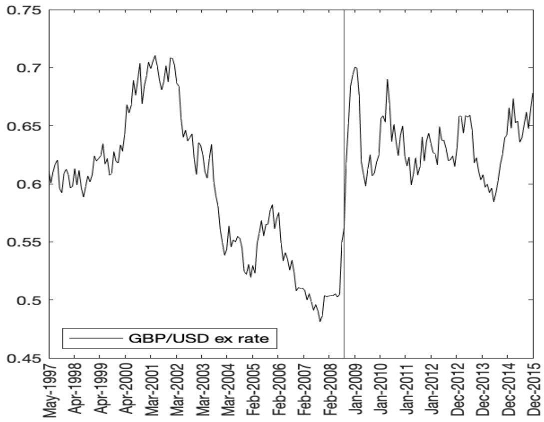


Figure 4: GBP/USD nominal exchange rate

the estimated trend[11]. The U.K. output gap and potential output growth is constructed based on the real GDP with quadratic detrending. By subtracting the estimated potential output growth from the expectation of output growth, we construct the forecasted rate of growth of the output gap.

For exchange rate forecasting with Taylor rule fundamentals, the output gap is estimated in real-time in order to construct real-time forecasting. At each point in time, potential output is estimated using only information from October 1986 to the vintage date for which the information is available as it appeared at that point. By using this method, it can most closely mimic the information available to market participants at the moment the forecasts would have been made. Therefore, in each month the regression is re-estimated after including one additional observation to the sample.

[11]Comparing with the detrending techniques such as linear and Hodrick-Prescott(HP)-filtering, we find that applying quadratic detrending over output provides a better description of U.S. monetary policy with the data here. Similar methodology is used in Molodtsova et al. (2008);Nikolsko-Rzhevskyy et al. (2014b).

The real-time expected inflation and expected output growth variables are firstly investigated by observing the graphs of both series for the U.K. Figure 2 compares U.K. inflation rates and the output gap with those available from their expectations surveys. The left panel depicts U.K. expected and actual inflation, while the right panel graph the expected change and actual outcomes of output gap for the U.K.. Interest rates are plotted on both panels. The solid vertical line indicates the outbreak of financial crisis (September 2008). Two observations are evident. First, the differences between expected inflation and inflation target are smaller than those between actual inflation and the target. Second, the discrepancies between expected and observed variables are pronounced for both the inflation and output gap. In particular, the actual inflation are more extreme during the peaks and troughs. Figure 3 presents time series of macroeconomic variables for the U.S.. Forecasted inflation is more volatile than actual inflation throughout the period. The differences between the actual output gap and its forecasted growth rate become larger after the financial crisis. According to figure 4, the US dollar appreciated on a large scale while U.S. and U.K. interest rates remained negative during the ZLB period.

To interpret these variables in a more formal way, Table 1 presents summary statistics of forecasted and observed data. The difference between the average U.K. expected and actual inflation is 0.12 percentage points before the crisis and 0.38 percentage points during the ZLB period. The standard deviation of U.K. actual inflation is about one time higher than that of the forecasted inflation for both periods.

Table 1: **Summary statistics**

May 1997 - Sep 2008	U.K.				U.S.			
	Mean	SD	Min	Max	Mean	SD	Min	Max
(A) *Forecast data*								
Inflation forecast	2.22	0.29	1.60	3.01	2.66	0.96	-0.18	5.25
Output gap growth forecast	-0.61	0.61	-2.1	0.75	1.7	1.32	-3.9	3.67
(B) *Observed data*								
Actual inflation	2.34	0.61	1.1	5.20	1.66	0.37	0.86	2.41
Output gap outcome	0.12	0.64	-1.87	1.27	3.35	1.61	0.84	7.41
Interest rate	5.01	1.00	3.33	7.36	3.83	1.88	0.22	7.06
Oct 2008 - Dec 2015	U.K.				U.S.			
	Mean	SD	Min	Max	Mean	SD	Min	Max
(A) *Forecast data*								
Inflation forecast	2.08	0.69	0.55	3.53	1.39	1.2	-1.61	3.72
Output gap growth forecast	-0.17	2.24	-5.59	2.4	1.66	2.16	-6.85	3.61
(B) *Observed data*								
Actual inflation	2.46	1.37	-0.10	5.20	1.46	0.34	0.81	2.45
Output gap outcome	-6.44	2.01	-8.82	-2.24	-3.8	1.15	-5.18	0.36
Interest rate	-3.29	1.91	-6.51	2.7	-1.14	0.99	-2.99	1.84

Notes: The statistics summarized for each variable are: mean, the mean, SD, the standard deviation, min, and max, the minimum and maximum values. The data is for Pre-crisis (May 1997 - September 2008) and ZLB (October 2008 - December 2015) period.

Furthermore, there exists opposite signs between the mean of output gap growth forecast and output gap outcomes before the crisis, and about 6.3 percentage points difference during the ZLB period. For the U.S. variables, the mean of inflation forecast is 1 percentage points higher than that of the actual inflation before the crisis. Inflation forecast is more volatile than actual inflation throughout the period. The mean value of output gap growth forecast is about 1.7 percentage points smaller than output gap before the crisis, and they even have different signs during the ZLB period. These differences suggest that both the BoE and the Fed monetary policy decisions may differ greatly depending on the type of variables used.

2.4 Taylor rules

Taylor (1993) proposes the following simple monetary policy rule:

$$i_t^* = \pi_t + \rho(\pi_t - \pi_t^*) + \gamma y_t + r^*, \tag{10}$$

where i_t^* is referred to as the target for the short-term nominal interest rate, r^* is the equilibrium real interest rate, $(\pi_t - \pi_t^*)$ is the deviation of actual inflation (π_t) from its target (π_t^*), y_t is the output gap, or percent deviation of actual output from an estimate of its potential level. As the target for the short-term nominal interest rate is assumed to be achieved within the period, there is no distinction between the target and actual nominal interest rate under the simple rule.

According to the Taylor rule, the central bank increases the target for the short-term nominal interest rate when facing higher inflation above its target level and/or output above its potential level. The target level of the output gap y_t is 0 as output cannot exceed potential output in the long run regarding the natural rate hypothesis. The target level of actual inflation is positive because deflation is generally regarded as a worse phenomenon for an economy than low inflation. Taylor assumed that the deviations of inflation and output enter the monetary policy reaction function with equal weights of 0.5 and that the inflation target and the equilibrium real interest rate were both equal to 2 percent[12].

If parameters r^* and π_t^* in equation (10) are combined into one constant term $c = r^* - \rho\pi_t^*$, equation (10) can transform into the following form:

$$i_t^* = c + \lambda\pi_t + \gamma y_t, \tag{11}$$

where $\lambda = 1 + \rho$.

In order to increase the real interest rate when inflation exceeds its target level, the central bank raises its actual nominal interest rate more than one-for-one in response to higher inflation. This is known as the Taylor Principle which represent as $\lambda = 1 + \rho > 1$ in equation (11). Many academics and policymakers such as Greenspan (2004) have emphasized the importance for economic stability of this condition.

In addition to the simple Taylor rule, which only contains inflation and the output gap, an augmented specification is estimated which, based on the results of CGG, adds the interest rate smoothing regarding the possibility that the interest rate adjusts gradually to achieve the rate advised by the rule. The dynamics of adjustment of the actual nominal interest rate i_t to the target are given by

$$i_t = (1 - \phi)i_t^* + \phi i_{t-1} + \nu_t. \tag{12}$$

[12] The BoE's inflation target was formulated as 2.5 % in terms of the Retail Prices Index excluding mortgage interest payments(RPIX) mesure before the end of 2003 and 2 % in terms of the Consumer Prices Index(CPI) measure thereafter. Taylor rules estimations with the data here suggested subtle changes when inflation target becomes a variable, which makes it unnecessary to take explicit account of the change in inflationary objective for present purposes.(for similar findings, see Cobham (2006))

Substituting (11) into (12) yields the following equation:

$$\begin{aligned} i_t &= (1-\phi)c + (1-\phi)\lambda\pi_t + (1-\phi)\gamma y_t + \phi i_{t-1} + \nu_t \\ &= \alpha + \beta\pi_t + \delta y_t + \phi i_{t-1} + \nu_t \end{aligned} \tag{13}$$

When equation (13) is estimated, $(1-\phi)\lambda = \beta$ is the short-run response of the target rate to inflation combining its adjustment speed $(1-\phi)$ and long-run response λ. Researchers such as CGG have shown that the short-run response will be much smaller than the implied long-run effect when the adjustment speed is relatively slow.

There exists a distinction between the use of revised and real-time data, even when estimating the standard Taylor rule. Contemporaneous values are used for inflation and the output gap while employing the revised data. In the case of real-time data, one-month lagged values are used since the variables are not known simultaneously. Variables dated time t actually measure data at time $t-1$ as those variables are known only to policymakers at or after time t.

As argued by Svensson (2003), IT central bank should not only consider inflation and the output gap but also the forecast information when making monetary policy decisions. According to his simple forward-looking model of the transmission mechanism, the optimal interest rate decision should be based on the forecasts for inflation and the output gap. Using real-time data, one specification of forward-looking monetary rules [13]targeting the forecasts of both inflation and output gap growth[14] is shown as

$$\begin{aligned} i_t &= (1-\phi)c + (1-\phi)\lambda E_{t-1}\pi_{t+i} + (1-\phi)\gamma E_{t-1}\Delta y_{t+j} + \phi i_{t-1} + \nu_t \\ &= \alpha' + \beta' E_{t-1}\pi_{t+i} + \delta' E_{t-1} y_{t+j} + \phi i_{t-1} + \nu_t. \end{aligned} \tag{14}$$

where $E_{t-1}\pi_{t+i}$ is i months-ahead forecasts of inflation, and $E_{t-1}\Delta y_{t+j}$ is j months-ahead forecasted growth of the output gap based on the information set released through period $t-1$, are estimated for the U.S. and U.K.. In equation 14, the horizons of inflation and output gap growth forecast depend on the lag of transmission process and surveyed data for each country, which are demonstrated in the next section and appendix. The only difference with the specification considered by Orphanides (2003) is that monetary policy rules here are estimated with various inflation and output gap growth horizons rather than fixing at twelve months ahead. As the real-time forecasts are made up with information before the current period t, the issue of endogeneity is largely alleviated.

2.4.1 Taylor rules estimation

In this section, we evaluate the U.K. and U.S. monetary policy based on Taylor rules estimation with observed and forecasted data. We choose to evaluate the U.K. and U.S. monetary policy rules only before the 2008 financial crisis. During the ZLB peirod after the crisis,

[13] Also called natural growth variant by Orphanides (2003)

[14] With imperfect information about the output gap, the policy rules including its change have been shown to provide superior descriptions of historical policy for U.S. and Euro. See, for example,Walsh (2004), Orphanides (2003), Gorter et al. (2008)

although shadow rate can be used since financial participants may consider longer-term interest rate incorporating expectations during the ZLB period, the shadow rate is not directly observed as an indicator of the stance of monetary policy. In addition, economists may have different estimates of the shadow rate. For example, the rates provided by Wu & Xia (2016) and Krippner (2013) differ considerably. For these reasons, it is controversial to use shadow interest rate to evaluate central bank monetary policy. Estimates of the BoE and the Fed interest rate reaction functions from May 1997 to September 2008 obtained using forecasted and observed data are shown in Tables 2 and 3. The estimates with observed data are for variants of equation (13), which includes actual inflation, the output gap and (possibly) the lagged interest rate. As described above, output gap for both the U.S. and U.K. are calculated as the percentage deviation of actual output from potential estimated by quadratic filter. The estimates with forecasted data are for variants of equation (14), which includes forecasts of both inflation and output gap growth, and (possibly) the lagged interest rate. Forecasted output gap growth is equivalent to the expected output growth minus the potential output growth derived by quadratic filter using actual output growth.

We firstly explain estimation results of Taylor rules for the U.K. monetary policy. The first two columns in Table 2 present the estimates based on conventional Taylor rules using observed data. The estimated short-run inflation coefficient is 0.74 without partial adjustment of the short-term nominal interest rate($\rho = 0$ in equation 13) and 0.64 in the long-run with interest rate smoothing, which dis-

Table 2: **Estimates of monetary policy reaction function for the United Kingdom**

Inflation coefficient, β	0.74*** (0.09)	0.06** (0.03)	-	-	-	-
Output gap coefficient, δ	1.36*** (0.08)	0.17*** (0.04)	1.15*** (0.08)	0.15*** (0.03)	-	-
Expected inflation coefficient, β'	-	-	1.38*** (0.17)	0.13** (0.05)	1.52*** (0.24)	0.11** (0.05)
Expected output gap growth coefficient, δ'	-	-	-	-	0.84*** (0.11)	0.13*** (0.02)
Lagged interest rate, ϕ	-	0.90*** (0.02)		0.90*** (0.02)		0.94*** (0.02)
Long-run inflation coefficient	-	0.64	-	1.34	-	1.86
Long-run output gap coefficient	-	1.76	-	1.58	-	2.21
Adj R-squared	0.67	0.98	0.66	0.98	0.37	0.98

Notes: The table reports ordinary least-square estimates of the variants of the following equations: $i_t = \alpha + \beta\pi_t + \delta y_t + \phi i_{t-1} + \nu_t$, where i is 3-month treasury bill rate, π is actual inflation, and y is the output gap; $i_t = \alpha' + \beta' E_{t-1}\pi_{t+i} + \delta' E_{t-1} y_{t+j} + \phi i_{t-1} + \nu_t$, where $E_{t-1}\pi_{t+i}$ is forecasted inflation, $E_{t-1}y_{t+j}$ is forecasted output gap growth; The sample size is $1997 : M5 - 2008 : M9$. Standard errors are in parentheses. *,** and *** significant at the 10, 5 and 1% levels, respectively. The long-run coefficient is the short-run coefficient divided by one minus the lagged interest rate coefficient when they are statistically significant.

obeys the Taylor principle in either case. Based on the estimated inflation coefficients in conventional Taylor rules, it may imply that U.K. monetary policy was not stabilizing inflation during the period. Estimates of the lagged interest rate ϕ is highly significant and close to one, while the adjusted R^2 rises from 0.67 to 0.98 after the inclusion of lagged interest rate. These evidence confirm the existence of partial adjustment about the BoE's interest rate decisions. The estimated long-run coefficient for the output gap is statistically significant and greater than unity with interest rate smoothing. It implies that the BoE react aggressively to the output gap after the operational independence. However, it seems unsatisfactory to describe the BoE's monetary policy regarding the violation of the Taylor principle.

To verify the importance of expected inflation and expected output gap growth in the U.K.'s monetary policy, we firstly replace the actual inflation in original specification by the expected inflation, and estimate the Taylor rules in the second two columns of Table 2. The estimated inflation coefficient is significant and above the unity without partial adjustment of the short-term nominal interest rate. Long-run estimated coefficient for expected inflation is also consistent with the Taylor principle regarding the interest rate smoothing. The coefficients of expected inflation imply that the BoE raise the interest rate in response to an increase in expected inflation, and therefore stabilising inflation in a forward-looking perspective.

The fifth and sixth columns in Table 2 show the estimates when actual inflation and the output gap are both replaced by forecasted inflation and forecasted output gap growth. The estimated coefficient for expected inflation is 1.52 without partial adjustment of the short-term nominal interest rate and 0.11 with interest rate smoothing, which in the latter case yields a long-run coefficient of 1.86. Both figures are significant and following the Taylor principle. These results provide evidence in support of Svensson (1997)'s argument that inflation targeting central banks like the BoE aim to align expected future inflation with its public announced target rate. The estimated coefficients for expected output gap growth are similar as in the second two columns, from which the figures are positive and significant both with and without interest rate smoothing. But from the specifications without the interest rate smoothing, the adjusted R-squared decreases from 0.66 to 0.37 after the replacement of output gap by expected output gap growth. Likewise in the results of fourth column with interest rate smoothing, the long- run output gap coefficient is greater than long-run inflation coefficient ($2.21 > 1.86$). This once again imply stronger response of the BoE's monetary policy to the output gap after the operational independence. One explaination (by Mihailov (2006)) treat this outcome as a reasonable reaction during a stage of business cycle when actual output is above or close to potential output. The inflationary pressures during such a stage could threaten IT regimes like U.K. to keep low and stable inflation and prompts a stronger reaction towards the output gap. From our summary statistics in Table 1, the mean output gap in 1997:5–2008:9 is 0.12, which also support that aggregate demand has been, on average, above potential during the period.

In comparing all specifications, the estimated coefficients on inflation imply the following of Taylor principle only when actual inflation is replaced by the forecasted inflation. On the other hand, there is no conclusive evidence that using expected output gap growth can lead to major differences about the estimated results.

When estimating monetary policy reaction functions for the U.S. over the same period, estimated coefficients for inflation are insignificant over most specifications with interest rate smoothing, no matter using actual values or its forecast (see table 11 in appendix A). As lagged interest rate coefficients are always positive and significant, this may lead us to conclude that the Fed did not react to deviations of actual or forecasted inflation over the period. However, if using Nikolsko-Rzhevskyy et al. (2014b)'s structural break analytical results[15], a significant shift of monetary policy regime can be assumed during 2000:Q4. This produces low deviations era from 1985:Q2-2000:Q4 and high deviations era from 2001:Q1-2013:Q4. Because our first forecast is in May 1997 and there is a break in 2000:Q4, we evaluate monetary policy reaction functions for the U.S. over 1997:M5-2000:M12 and 2001:M1- 2008:M9 separately in table 3. As the coefficients on lagged interest rate are always positive and significant, we only report results for specifications with interest rate smoothing.

The first three columns of table 3 report estimates of monetary policy reaction functions for the U.S. over 1997:M5-2000:M12, which is also

[15] Nikolsko-Rzhevskyy et al. (2014b) used Bai & Perron (1998) structural break test on Taylor rule deviations between the federal funds rate and the rate prescribed by the original Taylor (1993) rule.

Table 3: **Estimates of monetary policy reaction function for the United States before and after December 2000**

	May 1997- Dec 2000			Jan 2001- Sep 2008		
Inflation coefficient, β	0.77** (0.30)	-	-	-0.21 (0.2)	-	-
Output gap coefficient, δ	0.12** (0.05)	0.03 (0.10)	-	-0.001 (0.05)	0.05 (0.03)	-
Expected inflation coefficient, β'	-	0.10 (0.27)	0.22** (0.11)	-	0.10*** (0.04)	0.07* (0.04)
Expected output gap growth coefficient, δ'	-	-	0.35** (0.14)	-	-	0.04* (0.03)
Lagged interest rate, ϕ	0.33** (0.14)	0.52*** (0.13)	0.37** (0.16)	1.01*** (0.05)	0.94*** (0.03)	0.95*** (0.02)
Long-run inflation coefficient	1.15	-	0.36	-	1.70	1.40
Long-run output gap coefficient	0.18	-	0.58	-	-	0.96
Adj R-squared	0.42	0.33	0.42	0.95	0.95	0.95

Notes: The table reports ordinary least-square estimates of the variants of the following equations: $i_t = \alpha + \beta\pi_t + \delta y_t + \phi i_{t-1} + \nu_t$, where i is 3-month treasury bill rate, π is actual inflation, and y is the output gap; $i_t = \alpha' + \beta' E_{t-1}\pi_{t+i} + \delta' E_{t-1} y_{t+j} + \phi i_{t-1} + \nu_t$, where $E_{t-1}\pi_{t+i}$ is forecasted inflation, $E_{t-1}y_{t+j}$ is forecasted output gap growth; The sample size is $1997: M5 - 2000: M12$ and $2001: M1 - 2008: M9$. Standard errors are in parentheses. *,** and *** significant at the 10, 5 and 1% levels, respectively. The long-run coefficient is the short-run coefficient divided by one minus the lagged interest rate coefficient when they are statistically significant.

the low deviations era from the original Taylor rule. it can be seen that the long-run coefficient on inflation is significant and greater than unity when actual inflation is used in the specification, while the estimated coefficient on expected inflation is insignificant or less than unity in the long-run. From our results, Taylor principle holds only for conventional rules with actual inflation during the low deviations era. While the estimates of the output gap coefficient obtained with actual outcomes are smaller than with forecasted growth rate, they are positive and significant in both cases. This would indicate that the U.S. monetary policy was stabilizing output during the period. Following the Taylor principle, conventional Taylor rule has a better description of the U.S. monetary policy over 1997:M5-2000:M12, which is consistent with the characteristic of low-deviations era from the original Taylor rule.

From 2001:M1- 2008:M9, both estimated coefficients on actual inflation and output gap become negative and insignificant. This is consistent with the characteristic of the period as high-deviations era from the original Taylor rule. Both estimated coefficients are significant only when expected inflation and expected output gap growth are used. It leads to a long-run coefficient of 1.4 for the forecasted inflation, and about 1.0 for the forecasted output gap growth. These estimated long-run coefficients are close to the modified Taylor rule advocated by Yellen (2012), with a coefficient on inflation equals 1.5 and a coefficient of 1.0 on the output gap.

From the results of estimation for both countries, we can deduce both visible differences and significant similarities in the conduct of monetary policy. The first important similarity is that coefficient on expected inflation in the Taylor rule is above the unity for both countries although it only holds true for the U.S. during the high-deviations era. This implies that both the Fed and the BoE was stabilizing inflation in a forward-looking perspective. The second similarity is that coefficients on the lagged interest rate were large and significant for both countries, which indicates interest rate smoothing behaviour from both central banks. The most important difference is that the output gap coefficients were significant and greater than unity for the U.K. while small and statistically significant for the U.S. during the low deviations era.

2.5 Out-of-sample exchange rate predictability

When estimating Taylor rules for the United Kingdom and the United States, at least for some period of time, we find that rules based on forecasted data provide a better description of both countries' monetary policy. At the same time, the magnitude of responses over the inflation and the output gap are different between the BoE and the Fed. When Taylor rule for the U.K. is subtracted from that of the U.S., a Taylor rule fundamental model can be obtained to forecast the GBP/USD nominal exchange rate. As the significant differences in estimated coefficients of Taylor rules between the countries, we focus on the Taylor rule fundamentals with heterogeneous coefficients which allows the inflation and output gap coefficients in both countries to be different.

2.5.1 Taylor rule fundamentals

One of the major concerns raised in this paper is how the use of forecasted data affects out-of-sample predictability of exchange rate. Two models with Taylor rule fundamentals are considered to evaluate the GBP/USD nominal exchange rate predictability. Firstly, following the estimated results, we postulate that both the Federal Reserve and the BoE make interest rate decisions based on a Taylor rule where the nominal interest rate reacts to deviations of expected inflation from its target, expected output gap growth and the lagged interest rate. Alternatively, for comparative purposes, both central banks are assumed to follow a conventional Taylor rule where the nominal interest rate responds to actual inflation, output gap and the lagged interest rate. The latter one is also the Taylor rule specification mostly used by previous authors to evaluate the exchange rate predictability. With the forecast-based Taylor rules taken by both countries, the former specification can be treated as a forecast-based exchange rate model in comparison with the standard one. Specifications are also estimated with forecasted data where only actual inflation and output gap of one country (U.K. or U.S.) are replaced with the forecasts.

We firstly introduce the standard Taylor rule fundamental model mostly used by authors. Substituting the conventional monetary policy reaction functions for both the U.K. and the U.S. into the interest rate differential between the countries, one could derive the equation as:

$$i_t - \tilde{i}_t = \alpha + \alpha_{u\pi}\pi_t - \alpha_{k\pi}\tilde{\pi}_t + \alpha_{uy}y_t - \alpha_{ky}\tilde{y}_t + \rho_u i_{t-1} - \rho_k \tilde{i}_{t-1} + \eta_t, \quad (15)$$

where ˜ denotes the U.K. variables, k and u denote coefficients for the U.K. and the U.S respectively, α is a constant, and $\alpha_\pi = \lambda(1-\rho)$, $\alpha_y = \gamma(1-\rho)$ for both countries. Based on the estimated results of Taylor rules, U.S. and U.K. variables are not restricted to share same coefficients.

Assuming that the expected rate of depreciation responses proportionally to the interest rate differential, a forecasting equation of exchange rate can be written as:

$$E(s_{t+1}) - s_t = \beta(i_t - \tilde{i}_t). \quad (16)$$

In the case when UIP holds, $\beta = 1$ and the right hand side of Equation 15 can be put into 16, which leads to following standard specification:

$$E(s_{t+1}) - s_t = \alpha + \alpha_{u\pi}\pi_t - \alpha_{k\pi}\tilde{\pi}_t + \alpha_{uy}y_t - \alpha_{ky}\tilde{y}_t + \rho_u i_{t-1} - \rho_k \tilde{i}_{t-1} + \eta_t \quad (17)$$

Suppose the U.K. and the U.S. determine their interest rate according to a forecast-based Taylor rule, in which actual inflation and output gap are replaced by forecasts of inflation and output gap growth, this produces a forecasting equation as:

$$E(s_{t+1}) - s_t = \alpha + \alpha_{u\pi} E_{t-1}\pi_{t+i} - \alpha_{k\pi} E_{t-1}\tilde{\pi}_{t+\tilde{i}} + \alpha_{uy} E_{t-1}\Delta y_{t+j} - \alpha_{ky} E_{t-1}\Delta \tilde{y}_{t+\tilde{j}} + \rho_u i_{t-1} - \rho_k \tilde{i}_{t-1} + \eta_t \quad (18)$$

But this model does not guarantee that the coefficients in equations 17 and 18 are matched with the estimated Taylor rules. First, previous literature suggest that UIP does not hold in a short period such like one month. $\beta = 1$ based on UIP has been seriously challenged in empirical studies on UIP and carry trade. Second, as suggested by the significant coefficients of interest rate smoothing in Tables 2 and 3, U.K. and U.S. may not fully adjust their interest rates to the target level within the period. Suppose there is a surprise increase in U.K. inflation rate above its target, the BoE may respond by raising the interest rate but also expected to further increase the interest rate in the future. Since the rise of interest rate is not guaranteed to cause expected depreciation of the exchange rate immediately, and the exchange rate may be expected to appreciate as the interest rate is expected to have further increases, signs of the coefficients in equations 17 and 18 may not be the same as in empirical outcomes. Similar logic applies to other variables such as U.S. inflation rates. For these reasons, we should not restrict the signs and magnitudes of the coefficients when estimating the equations 17 and 18 as Taylor rule exchange rate models.

2.5.2 Forecast comparison based on ratio of the MSPEs

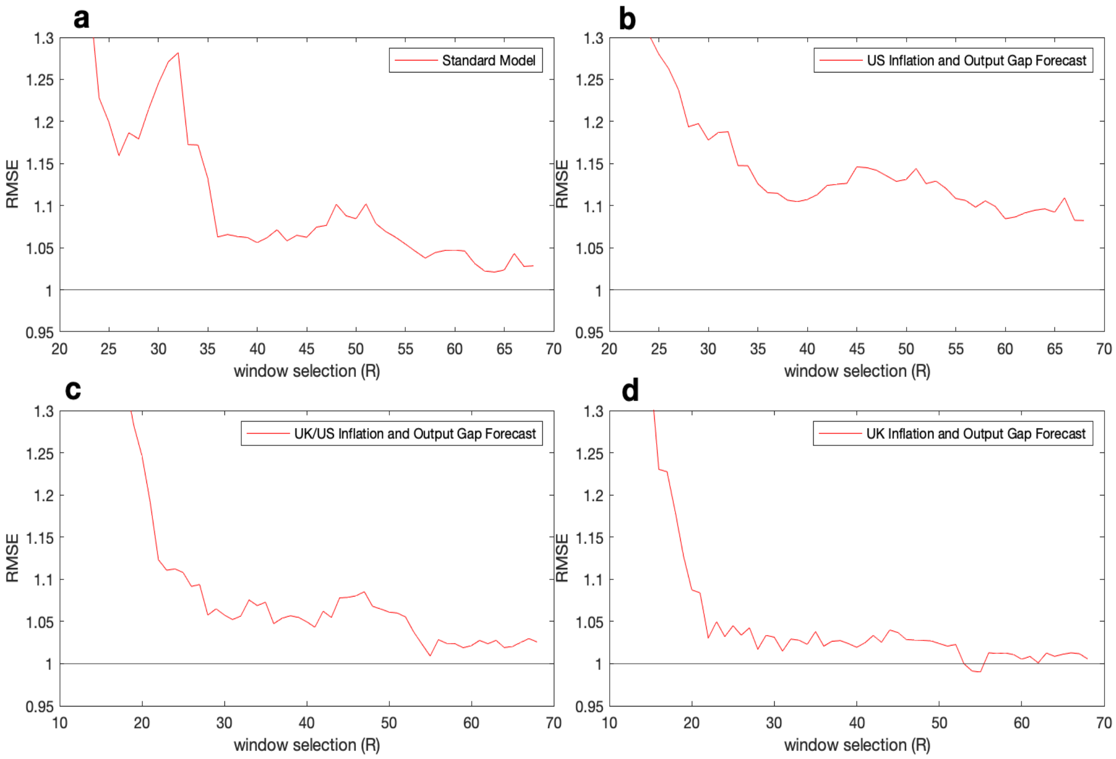
To evaluate the short-run out-of-sample predictability of forecast-based Taylor rule exchange rate models, and compare with the standard models using observed data, we use the Ratio of Root Mean Square Prediction Error (RMSE) between the model for Taylor rule fundamentals and the driftless random walk. Since the substantial differences existed in the estimated coefficients of U.K. and U.S. Taylor rules, we concern the Taylor rule fundamentals with heterogeneous coefficients which allows the inflation and output gap coefficients in both countries to be different. To construct the output gap for both countries, actual output is detrended by quadratic filtering technique. Figure 5 reports results for models with interest rate smoothing before the financial crisis. Figures 6 and 7 report RMSE results of Taylor rule fundamentals model during low and high deviations era from the U.S. original Taylor rule. Figure 8 is associated with out-of-sample predictability of models during the ZLB period. In each figure, Panel a presents forecasting results of standard model (equation (17)) without any use of forecasted data. Panel b illustrates forecasting results when U.S. actual inflation and output gap are replaced by expected inflation and expected output gap growth, while actual inflation and output gap still apply on the U.K.'s side. Following the estimation of the Taylor rules in tables 2 and 3, panel c shows results of forecast-based model (equation (18)) which use forecasted variables for both countries. In panel d, results are presented for Taylor rule fundamentals model which only use forecasted variables for the U.K. and not for the U.S.

In previous studies about rolling-window forecast of exchange rate, many researchers select an 'ad-hoc' window size based on economic rationale or experience. This leads to two concerns about the forecasting results. First, due to the single choice of window, researchers may ignore the other window selections which suppose to provide evidence of predictability. The chosen window size may therefore lead to underestimation of the out-of-sample predictability. Second concern is that a window size may be selected on purpose, in order to highlight the predictability of one specific model. This can be realised by data snooping over different window selections before presenting the results. In this case, the predictability is actually exaggerated. Considering these issues, we report RMSEs from the model forecasts based on rolling regressions of window size R, which varies from one to half of total sample observations [16]. When investigating out-of-sample performance of models before the financial crisis, the first regression is estimated on a sample of length R that starts in May 1997. After estimating the coefficients from Taylor rule forecasting regression of the change in the log exchange rate, one month out of sample is then forecasted using the estimated coefficients combined with the *actual* Taylor rule fundamentals one month out of sample. The estimation and forecast process is then repeated for a window size R that begins one month later, in June 1997, and so on until September 2008. Accordingly, R begins in October 2008 and the

[16] Bacchetta et al. (2010) also use RMSEs based on different rolling window selections to report out-of-sample relationship between five currencies (including GBP/USD exchange rate) and economic fundamentals. As data matrix for estimation is close to singular or badly scaled when R is too small, in actual computation R starts with 14 for models with the smoothing, ends with 68 before the crisis and 43 during the ZLB period.

process is repeated until December 2015 when evaluating the out-of-sample performance of models after the crisis.

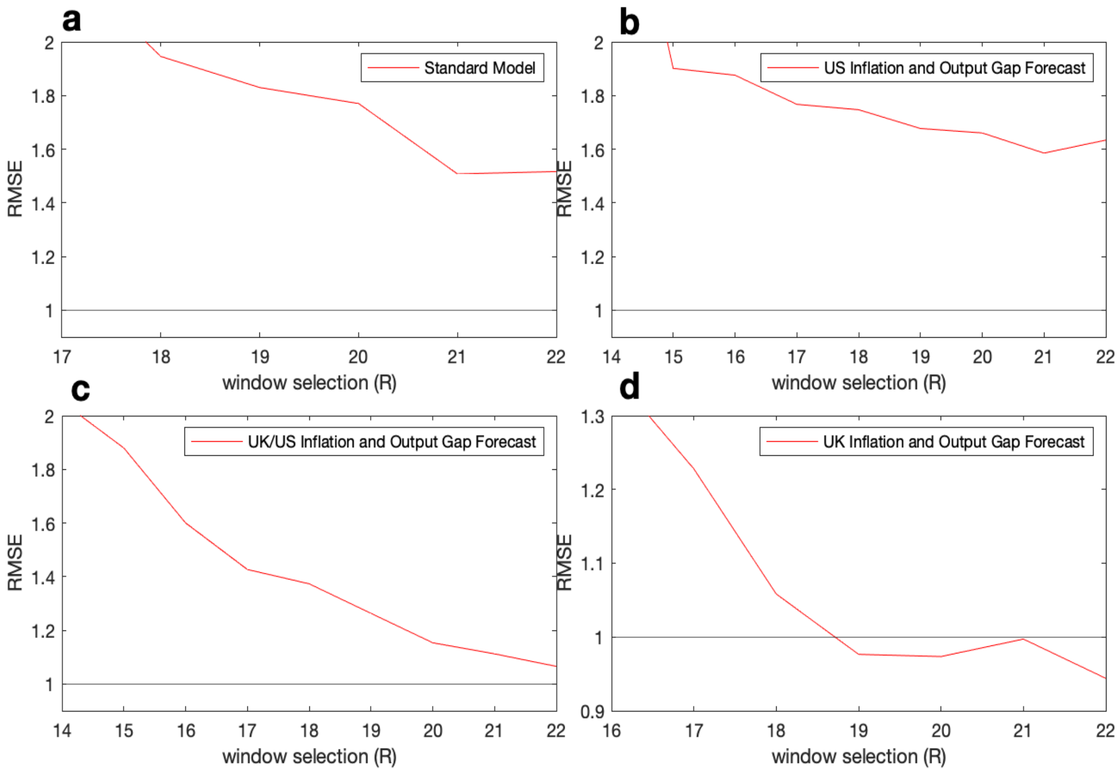
Figure 5: Out-of-sample Predictability of Taylor rule fundamentals model before the financial crisis (1997:05 - 2008:09)



Notes: Each panel reports the Ratio of Root Mean Square Forecast Error of one month ahead forecast of the model relative to Random walk(RMSE). Estimations are based on rolling regression of window selection R (horizontal axis). The model includes the following regressors: (a) Standard model without any forecasts; (b) Model with only US inflation and output gap growth forecasts; (c) Model with both UK and US inflation and output gap growth forecasts; (d) Model with only UK inflation and output gap growth forecasts. The sample period is 1997M5-2008M9.

Figure 5 reports findings for RMSE results of Taylor rule fundamentals model with interest rate smoothing relative to random walk before the financial crisis. Model in panel (a) with only actual outcomes does not outperform the random walk regardless of the window selection. Evidence of out-of-sample predictability is only found when expected inflation and the output gap growth forecasts from the U.K. are used in the model (as shown in panel d), from which minimum RMSE equals to 0.99 for $R = 55$. From the results reported in figure 5, the main finding is that U.K. expected inflation and output gap growth forecasts are the key determinants in influencing the out-of-sample predictability of the Taylor rule fundamentals model. This is consistent with the estimated results in the Taylor rules that forecast-based rule provides a better description of the U.K. monetary policy. On the other hand, from panels (a) and (b) there is no clear evidence of out-of-sample predictability for Taylor rule fundamentals model no matter using actual outcomes or forecasted variables for the U.S. This may be caused by the structural break on U.S. Taylor rule deviations during the end of 2000. We further investigate the out-of-sample predictability of Taylor rule fundamentals model over low and high deviations era separately.

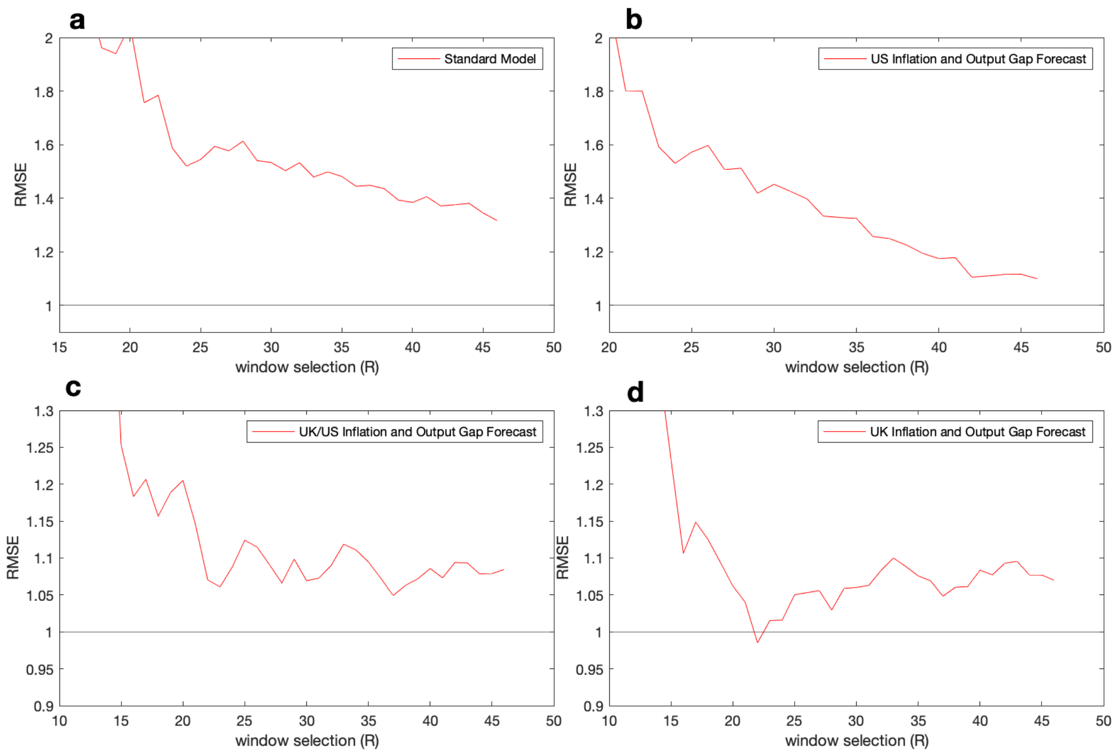
Figure 6: Out-of-sample Predictability of Taylor rule fundamentals model over low deviations era (1997:05 - 2000:12)



Notes: Each panel reports the Ratio of Root Mean Square Forecast Error of one month ahead forecast of the model relative to Random walk(RMSE). Estimations are based on rolling regression of window selection R (horizontal axis). The model includes the following regressors: (a) Standard model without any forecasts; (b) Model with only US inflation and output gap growth forecasts; (c) Model with both UK and US inflation and output gap growth forecasts; (d) Model with only UK inflation and output gap growth forecasts. The sample period is 1997M5-2000M12.

During the low deviations era from the original Taylor rule (1997:M5-2000:M12), figure 6 shows that evidence of out-of-sample predictability is only found for the Taylor rule fundamentals model incorporating forecasted variables for the U.K. and actual outcomes for the U.S.. For the models without forecasted variables for the U.K. in panels (a) and (b), no evidence of out-of-sample predictability is found in both cases. This implies that U.K. expected inflation and output gap growth forecasts are the key determinants in influencing the out-of-sample predictability of the Taylor rule fundamentals model during the low deviations era. When comparing panels (c) and (d), we can find some contributions from the U.S. actual outcomes to the out-of-sample predictability when it is implemented in the model. This is in accord with the Taylor rules estimation that conventional Taylor rule with actual outcomes best describes the U.S. monetary policy during the low-deviations era,

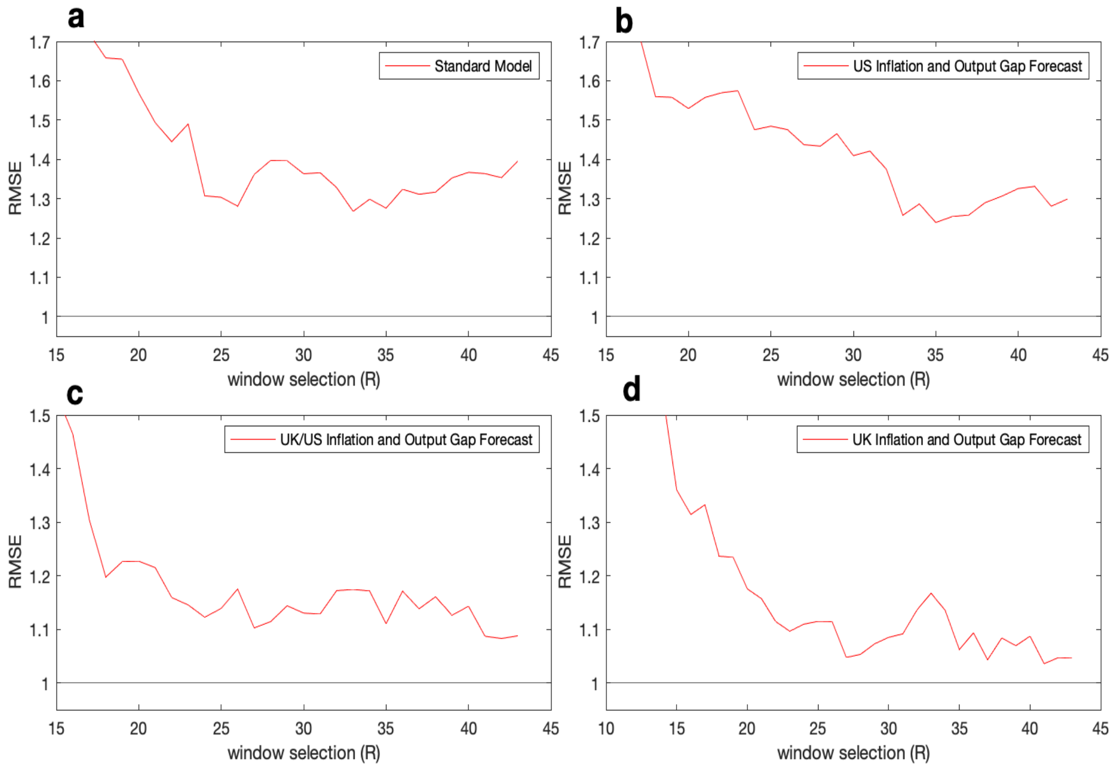
Figure 7: Out-of-sample Predictability of Taylor rule fundamentals model over high deviations era (2001:01 - 2008:09)



Notes: Each panel reports the Ratio of Root Mean Square Forecast Error of one month ahead forecast of the model relative to Random walk(RMSE). Estimations are based on rolling regression of window selection R (horizontal axis). The model includes the following regressors: (a) Standard model without any forecasts; (b) Model with only US inflation and output gap growth forecasts; (c) Model with both UK and US inflation and output gap growth forecasts; (d) Model with only UK inflation and output gap growth forecasts. The sample period is 2001M1-2008M9.

Over the high deviations era from 2001M1:2008M9, RMSE is less than unity only for the Taylor rule fundamentals model with forecasted variables for the U.K. and actual outcomes for the U.S. in panel (d) of figure 7. From panels (a) and (b) to panels (c) and (d), RMSE generally decreases as the inclusion of U.K. forecasted variables in the model. This implies that expected inflation and output gap growth forecasts from the U.K. are the key determinants in influencing the out-of-sample predictability of the Taylor rule fundamentals model. Results are mixed when investigating influences of U.S. variables over the out-of-sample predictability. On the one hand, RMSE generally decreases when U.S. actual outcomes are replaced by forecasts from panel (a) to (b). On the other hand, evidence of out-of-sample predictability (i.e. RMSE < 1) can only be found when actual inflation and the output gap from the U.S. are used, as shown in panel (d). This might be in accord with the Taylor (1999)'s argument that forecasted data are merely based on current and lagged data, which provides no superior position of forward-looking rules for the U.S. in Taylor rule exchange rate forecasting. Although forecast-based Taylor rule provides a reasonable description of the U.S. monetary policy over the high-deviations era, this does not mean that the U.S. forward-looking rules could make a better contribution to the out-of-sample predictability of the exchange rate model.

Figure 8: Out-of-sample Predictability of Taylor rule fundamentals model during the ZLB period(2008:10-2015:12)



Notes: Each panel reports the Ratio of Root Mean Square Forecast Error of one month ahead forecast of the model relative to Random walk(RMSE). Estimations are based on rolling regression of window selection R (horizontal axis). The model includes the following regressors: (a) Standard model without any forecasts; (b) Model with only US inflation and output gap growth forecasts; (c) Model with both UK and US inflation and output gap growth forecasts; (d) Model with only UK inflation and output gap growth forecasts. The sample is 2008M9-2015M12.

As both the U.K. and the U.S. monetary policies are constrained by ZLB after the financial crisis, an interesting question to explore is whether there still exists evidence of GBP/USD exchange rate predictability for any Taylor rule specifications. Using shadow rate calculated by Wu & Xia (2016) during the ZLB, no evidence of out-of-sample predictability is found for any specifications since none of the RMSEs are less than unity. At the same time, we can still see RMSEs decrease a lot after using the U.K. forecasted variables in Taylor rule fundamentals model in panels (c) and (d) of figure 8. This is supported by standard macroeconomic theory(see Woodford (2011)) and empirical evidence provided by Swanson & Williams (2014) that USD/GBP nominal exchange rate responds to news about British inflation and output even under ZLB period. With the observed or forecast information, market participants may expect the BoE and Federal Reserve to change longer-term yields through unconventional measures and trade currencies.

The main findings are robust to whether the output gap is constructed by HP, quadratic or linear detrending techniques. Results when output gap is constructed by linear or HP detrending techniques are not reported but available upon request.

2.5.3 Testing for Out-of-sample Predictability

The one-month ahead out-of-sample predictability of Taylor rule fundamentals models are evaluated using the CW test statistics for GBP/USD exchange rate over the low-deviations era (May 1997 - December 2000), high-deviations era (January 2001- September 2008), pre-crisis (May 1997 - September 2008) and ZLB(October 2008 - December 2015) period. We use the rolling window which provides the minimum RMSE in each Taylor rule forecasting regression, to estimate the coefficients and forecast the exchange rate one month ahead.

Results for one-month-ahead forecast comparisons are reported in Table 4. The first row of each panel presents the RMSE from the Taylor rule fundamentals model and second row reports the rolling window selected for estimation. The third row reports CW statistic and its corresponding p-value (in parentheses). For the specifications with actual outcomes, real economic activity is approximated by the output gap constructed by the quadratic filtering. For the specifications with forecasted variables, forecasted output gap growth is equivalent to the expected output growth minus the potential output growth derived by quadratic detrending. Panel A presents results with the observed data for the standard model (equation 17), which uses actual inflation and the output gap for both countries. Panel B presents forecasting results that use the actual inflation and the output gap for the U.K., with the forecasts of both inflation and output gap growth for the U.S.. Panel C presents results for the forecast-based model (equation 18), which use expected inflation and output gap growth forecasts for both countries. Panel D presents results when forecasted variables are only used for the U.K. and not for the U.S.

No evidence of out-of-sample predictability is found with the standard model, as none of the outcomes in panel A significantly outperform the random walk based on the RMSE and the CW statistic. This holds true even when discussing the out-of-sample predictability over the low and high deviations era. When U.S. forecasted variables are used in the model during high deviations era, the null hypothesis of no predictability is rejected at 10 % significance level. The results

Table 4: **CW statistics: one-month-ahead GBP/USD exchange rate forecasts using conventional and forecast-based Taylor rules**

	low-deviations	high-deviations	pre-crisis	post-crisis
A. Observed data				
RMSE	1.508	1.316	1.021	1.268
Window selected	21	46	64	33
CW statistics	-0.014	0.830	0.700	1.172
	(0.51)	(0.20)	(0.24)	(0.12)
B. US inflation and output gap growth forecasts				
RMSE	1.585	1.099	1.082	1.239
Window selected	21	46	64	33
CW statistics	-0.514	1.507*	0.628	0.962
	(0.70)	(0.07)	(0.27)	(0.17)
C. UK/US inflation and output gap growth forecasts				
RMSE	1.066	1.049	1.009	1.083
Window selected	22	37	55	42
CW statistics	1.200	0.682	1.379*	-0.035
	(0.12)	(0.25)	(0.08)	(0.51)
D. UK inflation and output gap growth forecasts				
RMSE	0.944	0.985	0.990	1.036
Window selected	22	22	55	41
CW statistics	2.410***	2.415***	1.798**	1.091
	(0.008)	(0.008)	(0.04)	(0.14)

Notes: The table report CW tests of equal predictive ability between the null of a martingale difference process and the alternative of a linear model with Taylor rule fundamentals. Forecast-based Taylor rules include forecasts of both inflation and output gap growth. The sample starts in May 1997 and rolling regressions are estimated with a window size providing lowest RMSE among all available selections. The p-values in parentheses,*,** and *** significant at the 10, 5 and 1% levels, respectively, based on critical values for the one-sided test. The sample periods are 1997M5-2000M12(low-deviations), 2001M1-2008M9(high-deviation),1997M5-2008M9(Pre-crisis) and 2008M10-2015M12(post-crisis).

change drastically if U.K. forecasted variables are used to estimate the model. The RMSE is less than unity, so that the Taylor rule fundamentals model has a smaller MSPE relative to the random walk model, only for cases where U.K. inflation and output gap growth forecasts are used. Without forecasted variables for the U.K., none of the models in panels A and B significantly outperform the random walk at the 1% level, and the Taylor rule fundamentals model with U.K. forecasted variables in panel D outperform the random walk at the 1% level over low and high deviations eras and whole pre-crisis period. During the post-crisis period when both countries were constrained by ZLB, the last column in table 4 indicates that no evidence of exchange rate predictability can be found for any Taylor rule specifications based on CW tests.

Overall, only 1 out of 8 cases for Taylor rule fundamentals model without U.K. forecasted variables have CW test result significant at 10 % level, while the models with the U.K. forecasted variables outperform the random walk at the 10% level in 4 out of 8 cases. Null hypothesis is rejected at the 1% level while RMSE is less than unity for both low and high deviations eras only when using the U.K. forecasted variables in the Taylor rule fundamentals. After the adoption of inflation targeting regime and legal independence of the BoE in May 1997, we find no evidence of out-of-sample predictability for standard Taylor rule fundamentals model before the financial crisis. Over the same period, evidence is only found when the U.K. expected inflation and output gap growth forecasts are used in the Taylor rule fundamentals. Under the constraint of ZLB, we observe a certain degree of increase in forecasting power from decreases in RMSE when taking the U.K. forecasted variables, although it is not strong enough to beat the random walk model. These evidence in favour of the argument that Taylor rule fundamentals model with the U.K. forecasted variables have stronger out-of-sample GBP/USD exchange rate predictability than those with only actual outcomes over the BoE postindependence period.

2.6 Conclusions

It has been widely accepted that inflation targeting central banks (such as the Bank of England(BoE)) aim to align expected future inflation with its public announced target rate. With such concern, monetary policy evaluation of the BoE is by now well conducted via forecast-based rule where the short-term nominal interest rate responds to expected inflation and expected output gap growth. Although previous literature has shown that a Taylor rule, together with uncovered interest parity, can be used to forecast nominal exchange rates especially like pound/dollar exchange rates, the previous works use actual inflation and output gap as key determinants of Taylor rule fundamentals.

In this paper, we analyse whether the variables that normally enter inflation targeting central banks' interest-rate-setting rules, which include inflation forecasts and output gap growth forecasts, can provide evidence of out-of-sample predictability of the pound/dollar exchange rate. By using forecasted data from the U.K. and U.S., we firstly investigate how estimated forecast-based rules differ from the conventional Taylor rules with actual outcomes. As followed, we compare the out-of-sample predictability of the GBP/USD exchange rate between forecast-based Taylor rule fundamentals model and the models with actual outcomes.

Before the financial crisis, the estimation results suggest that the U.K. only follows the Taylor principle if evaluated by forecast-based Taylor rules. The expected output gap growth coefficients are large and highly significant for the U.K.. For the U.S., there exists non-linearity in the Fed's monetary policy rule, in which estimated expected inflation coefficients are significant and greater than unity (i.e. follows the Taylor principle) only during the high-deviations era from the original Taylor rule for the U.S.. In addition, the estimated coefficients of expected output gap growth are positive and significant over the pre-crisis period.

During the pre-crisis period, the null hypothesis of equal predictability with random walk can be rejected against an alternative hypothesis of predictability only for the Taylor rule fundamentals model with the U.K. forecasted variables. From MSPE comparisons, evidence of predictability is substantially improved when U.K. actual inflation and the output gap are replaced by their expected values. U.K. inflation and output gap growth forecasts are the key determinants in influencing the out-of-sample predictability of the Taylor rule fundamentals model, which is in accord with the results from the U.K. monetary policy evaluation. While estimating forecast-based rules produces significant coefficients on the expected inflation for the U.S. during the high deviations era, there is no clear evidence that out-of-sample predictability of the GBP/USD exchange rate has been improved with the U.S. forecasted variables. Furthermore, based on decreases of RMSEs, there is an increase of forecasting power during the ZLB period for the model in which the U.K. forecasted variables are implemented.

As the convincing evidence of predictability for Taylor rule fundamentals using forecast-based rule for the U.K., similar investigations may also be meaningful for other inflation targeting countries. Therefore, this paper can be treated as a contribution to the framework of modelling exchange rate determination for inflation targeting countries.

3 Chapter 3

Exchange Rate Reconnect? Central Bank Independence and the USD/GBP Exchange Rate

3.1 Introduction

Since the publication of the influential paper by Meese & Rogoff (1983a, 1983b), the failure to find macroeconomic fundamentals that could predict exchange rates, especially in out-of-sample forecasting (referred to as 'exchange rate disconnect puzzle'), concerns many researchers of international macroeconomics. The weak empirical relationship between exchange rates and macro variables provides too little help for policymakers and academics on which macroeconomic models to use. An excellent review of exchange rate predictability by Rossi (2013) shows that the puzzle still exists in most advanced country currencies. Especially for the USD/GBP nominal exchange rate, no evidence of out-of-sample predictability is found with any economic models, regardless of the length of forecast horizons. Although some progress has been made, the problem is still far from been solved.

This paper examines the exchange rate predictability with macroeconomic variables before and after the increase of CBI levels. The exchange rate disconnect puzzle is dominant across the entire sample period, from October 1986 to September 2008, for the USD/GBP nominal exchange rate. However, following the adoption of an inflation targeting(IT) regime, analysis indicates that the predictability of uncovered interest rate parity (UIP) specification is significant across in-sample tests. Predictability also remains constant in both in-sample and out-of-sample tests when using the Taylor rule model. After achieving instrument independence, there is still evidence of out-of-sample predictability when using the Taylor rule fundamentals. The empirical results support the role of CBI in rebuilding a connection between exchange rate and macroeconomic fundamentals.

The pace of central bank reform, in terms of institutional independence, has been particularly rapid over the past two decades. While most previous studies have focused on the influence of CBI on the macroeconomic variables (e.g. inflation and output growth) and exchange rate volatility (Bodea & Hicks (2015); Spyromitros & Tuysuz (2008); Weber (2019)), few works have considered its impact on the predictability of the exchange rate using macroeconomic fundamentals. On the one hand, previous literature indicates that CBI revolutions have a direct influence on the dynamic behaviour of U.K. monetary policy regimes (e.g.,Baxa et al. (2014); Cobham (2003); Kuttner & Posen (1999)). On the other hand, since the proposition of Meese & Rogoff (1983a, 1983b)'s exchange rate disconnect puzzle, many empirical studies have explained the violation of the UIP condition (Bacchetta & van Wincoop (2010); Gourinchas & Tornell (2004)). The exercise by Y. S. Kim & Seol (2016) suggests that the failure of the UIP condition can be caused by excessive monetary policy interventions to tackle inflationary fluctuation. These two aspects suggest that, with a reduction in monetary policy interventions due to CBI improvements, the USD/GBP nominal exchange rate can be predicted using UIP specification. Another macro fundamental model following the UIP condition is the Taylor rule model, in which central banks change interest rates in response to inflation and output fluctuations [10]. If UIP specification can provide predictions of the nominal exchange rate, the Taylor rule fundamentals model may have a similar out-of-sample performance.

To scrutinise the influence of CBI revolutions over exchange rate predictability, I firstly review the historical development of CBI in the UK from 1986 to 2008. Three periods of change in the CBI level are identified based on Cukierman et al. (1992)'s CBI index in monthly frequency [11]. These are the signing of the Maastricht Treaty in February 1992, IT adoption in October 1992 and instrument independence in May 1997. Previous researchers have treated IT adoption and instrument independence as the periods during which the UK monetary policy regime made significant change[12]. This is consistent with the structural breaks identified by Bai & Perron (2003)'s test in this paper. As a preliminary analysis, I reproduce the well-known disconnect between the USD/GBP nominal exchange rate and a variety of macroeconomic variables for the period 1986-2008. However, the relationship between the exchange rate and interest rate differential becomes significant after the IT adoption. I then investigate the exchange rate predictability with UIP and Taylor rule fundamentals

[10] An excellent review of exchange rate predictability by Rossi (2013) shows that Taylor rule model can provide stronger evidence of one-month-ahead exchange rate predictability than other economic models.

[11] Based on criterions of the Cukierman index, degree of CBI for the U.K. remains unchanged after 1997.

[12] For influence of IT adoption, see Kuttner & Posen (1999); Creel & Hubert (2015); Baxa et al. (2014) and Sekine & Teranishi (2008). For instrument independence, see Adam et al. (2005); Cobham (2003).

under different levels of CBI. Both in-sample explanatory power and out-of-sample predictability are investigated for each sub-period. I employ 24-month and 36-month rolling regressions of exchange rate movements on macroeconomic fundamentals and test in-sample explanatory power along the sample period. The test statistics become significantly increased for UIP specification instantly after the IT adoption. Moreover, test results indicate stronger in-sample explanatory power for Taylor rule fundamentals relative to UIP specification. Theil's U ratio and Clark & West (2006) test statistics are used to investigate the out-of-sample predictability of Taylor rule fundamentals/UIP specifications relative to a random walk. Although UIP specification loses its significance in out-of-sample predictions, the evidence of out-of-sample predictability for Taylor rule fundamentals is still significant following the implementation of the IT regime and instrument independence.

This paper contributes to two strands of literature. First, it can be treated as an application of Y. S. Kim & Seol (2016)'s approach to the USD/GBP nominal exchange rate. In their paper, both the modelling outcomes and empirical evidence on EUR/USD nominal exchange rate indicate that excessive monetary policy interventions contribute to a violation of the UIP condition. This paper shows that the UIP condition fails when there exists frequent intervention by monetary authorities and holds when the monetary reaction is relatively passive. As a model based on the UIP condition, Taylor rule fundamentals present similar changes in predictability according to different monetary regimes.

Second, to the best of our knowledge, this is the first study suggesting that institutional changes in CBI can rebuild the link between exchange rate and macroeconomic fundamentals. The identified CBI increases are consistent with the monetary policy regime shifts considered by previous studies. Following CBI increases, significant evidence of predictability for UIP specification and Taylor rule fundamentals are found based on various in-sample and out-of-sample tests. These results imply that CBI revolutions affect the relationship between exchange rate and macroeconomic variables via shifts in monetary policy regime.

The remainder of the paper is organized as follows: Section 3.2 reviews previous literature of this issue. Section 3.3 dicusses the historical development of the UK CBI and monetary regimes; section 3.4 discusses exchange rate forecasting performance before and after the CBI level increases; section 3.5 provides a plausible explanation for the empirical results; section 3.6 concludes this paper;

3.2 Literature review

The influence of CBI has been widely studied in previous literature. For example, Bodea & Hicks (2015) studies whether CBI affects a central bank's control of inflation. Spyromitros & Tuysuz (2008) examines the relationship between central bank transparency and costs of disinflation. Weber (2019) studies how central bnak transparency affects exchange rate volatility. Although most studies focus on the influence of CBI over the macroeconomic variables, few works have considered the CBI's indirect effects on the exchange rate predictability through macroeconomic fundamentals.

This paper aims to build a connection between exchange rate movements and macroeconomic variables though monetary policy behaviours. On the one hand, several works studied the influence of central bank revolutions in the BoE towards the moentary policy behaviour. For example, Baxa et al. (2014) and Kuttner & Posen (1999) study the influence of IT adoption over the monetary policy decisions. Cobham (2003) discusses UK monetary policy interventions under different level of CBI measured by Cukierman et al. (1992)'s index. On the other hand, Y. S. Kim & Seol (2016) investigate whether UIP condition holds for euro/usd nominal exchange rate under different levels of monetary policy interventions. They find that UIP condition holds when there exists less monetary policy interventions. Combining both aspects, it is reasonable to investigate whether CBI have significant influences over the exchange rate predictability using UIP specification. Furthermore, Taylor rule fundamentals model is builded based on the UIP condition and appreciated by preivous researchers when solving advanced economy's exchange rate disconnect puzzle (see e.g. Molodtsova & Papell (2008) Rossi (2013)). Therefore, this paper will investigate the exchange rate predictabiity of these two macro fundamentals under different levels of CBI.

To verify the efficacy of CBI in improving GBP/USD nominal exchange rate predictability, I firstly identify the historical changes of UK CBI level and associated behaviours of monetary policy. As following, both UIP and Taylor rule fundamentals models' exchange rate predictability are investigated under different levels of CBI. The results are not only expected to make contribution to the literature of CBI, but also provides a new dimension to solve the exchange rate disconnect puzzle.

3.3 Central Bank Independence and Monetary Policy Regime Shifts

3.3.1 Central bank independence

In this section, I present historical development of relationship between the BoE and government from October 1986 to September 2008 using Cukierman et al. (1992)'s index of CBI in Table 5 [13]. The first rise of index comes from the provisions of the UK Protocol to the Maastricht Treaty in February 1992, which leads to greater limitations on lending from the Bank of England (BoE) to the government (rows(9),(10) and (16)). It contributes 0.24 increase in Cukierman's overall unweighted index (LVAU) and 0.22 increase in weighted index(LVAW).

Since October 1992, there is a slight increase in LVAU and LVAW entirely from a greater autonomy of the BoE in policy formulation(rows(5) and (6)). Although there is only 0.02 increase in overall index, it could be more influential to the monetary policy making due to the enhancement of credibility for the IT adoption[14]. As a

[13] Table 7.1 in Cobham (2003) 's book presents a similar table for Cukierman's index from 1971 to 2001 in yearly frequency.

[14] Although some institutional changes are executed in 1993 and early 1994, the decision of the changes was announced in October 1992.(See King (1994))

Table 5: Cukierman's (1992) index of CBI for the UK from October 1986 to September 2008

Criterion	Oct86-Jan92	Feb92-Sep92	Oct92-Apr97	May97-Sep08
Chief executive officer				
1 Term of office	0.5	0.5	0.5	0.5
2 Who appoints Governor?	0	0	0	0
3 Provisions for dismissal	0.83	0.83	0.83	0.83
4 Is the Governor allowed to hold another office?	1	1	1	1
Policy formulation				
5 Who formulates monetary policy?	0	0	0.33	0.67
6 Government directives and resolution of conflicts	0	0	0.2	0.4
7 Is CB given active role in formulation of Government budget?	0	0	0	0
CB objectives				
8 Price stability?	0	0	0	0.8
Limitations on lending				
9 Limitations on advances	0	0.67	0.67	0.67
10 Limitations on securitised lending	0	1	1	1
11 Who decides control of terms of lending ?	0.33	0.33	0.33	0.33
12 How wide is the circle of potential borrowers from CB?	1	1	1	1
13 Type of limit when such limit exists	1	1	1	1
14 Maturity of loans	1	1	1	1
15 Restrictions on interest rates	0.25	0.25	0.25	0.25
16 Prohibition on lending in primary market	0	1	1	1
Indices of legal independence				
17 LVAU (unweighted)	0.31	0.55	0.57	0.70
18 LVAW (weighted)	0.26	0.48	0.51	0.67

new framework following the exit of ERM, inflation target is only one part of the evolution, second part is the 'institutional changes designed to bolster the credibility of the commitment to low inflation' (King, 1994: 123). With these institutional changes, public may be convinced that any inflation fluctuations will be transitory and therefore cause stability of inflation expectations. As argued by Cobham (2003), the new framework could have been provided without conceding autonomy in policy formulation to the BoE. The institutional separation of responsibilities is mainly due to the severe loss of credibility by the government in the crisis of Black Wednesday, 16 September 1992. In order to restore credibility, the government turned its attention to the BoE whose reputation was less adversely affected by the event. The measures including the BoE's independent publication of the inflation report, published minutes of the monthly monetary meetings thus become important steps to foster the credibility of anti-inflation strategy.

Another substantial increase in the level of CBI resulted from the legal independence in May 1997. While the inflation target is continuously set by the Chancellor of the Exchequer, the BoE is now given operational responsibility for setting the instrument rate in order to achieve the target. Interest rate decisions are made by a new Monetary Policy Committee (MPC) comprising the Governor and two Deputy Governors appointed by the government, two members appointed by the Bank and four external members appointed by the Chancellor. These measures lead to greater autonomy for policy formulation (rows (5) and (6)) and about 20% increase for both overall indexes. Another institutional change relevant to Bank's independent policy decision is the change of inflation target from '2.5% or less' to a target of 2.5%. The Treasury commented that previous target may cause ambiguity because it could be interpreted as setting a ceiling, but without a floor on the target (Rodgers (1997)). To encourage the bank to fulfill the inflation target, the Governor, on behalf of the MPC, is required to write an open letter to Chancellor if the actual inflation is 1% higher or lower than the 2.5% target.

The letter should explain the situation and specify how and when the inflation could return to the target. No matter for the further separation of responsibility between the BoE and government as instrument independence, or the more strict institutions to fulfill the target, we expect the credibility is enhanced for a monetary policy where domestic inflation plays a central role.

Overall, the history of U.K. CBI development (1986:M10 -2008:M9) is divided into four subperiods based on Cukierman et al. (1992)'s index. They are: 1986:M10-1992:M1, 1992:M2-1992:M9, 1992:M10-1997:M4, 1997:M5 - 2008:M9. Substantial improvements of CBI took place in February 1992 and May 1997, while we also believe the slight increase of the index in October 1992 could bring significant change for monetary policy regime. Table 6 presents summary statistics for the U.K. and the U.S. over each subperiod. Details of data are shown in appendix. As the CBI level improves, the mean value of actual or expected inflation for the U.K. decreases. It can be seen that the U.K. short-term interest rate moves in same direction as the actual or expected inflation. This may not be true for the U.S. as the mean Fed funds rate increases while mean actual inflation decreases after September 1992.

3.3.2 Monetary responses

Next, we will investigate whether estimation results using our forecasts data are consistent with the previous literature. According to Svensson (2003), if actual outcomes for inflation and output in simple Taylor (1993)'s rule are helpful to predict inflation and output,

Table 6: Summary statistics

U.K.

	Oct 1986- Jan 1992				Feb 1992- Sep 1992			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Actual inflation	5.69	1.77	3.3	9.5	4.83	0.76	3.8	5.7
Expected inflation	5.18	1.18	3.93	9.08	3.75	0.19	3.5	4.09
Output gap outcome	2.38	3.76	-4.15	6.63	-5.07	0.57	-5.62	-4.15
Output gap forecast	4.25	5.65	-6.45	10.42	-5.22	1.15	-6.45	-3.19
Interest rate	11.37	2.14	7.15	14.62	9.19	1.05	6.76	10.21

	Oct 1992- Apr 1997				May 1997- Sep 2008			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Actual inflation	2.83	0.38	2	3.8	2.34	0.61	1.1	5.2
Expected inflation	3.16	0.44	2.68	4.26	2.24	0.31	1.6	3.09
Output gap outcome	-1.36	1.91	-5.07	1.54	0.75	0.67	-1.32	1.93
Output gap forecast	0.93	2.89	-5.82	4.89	3.09	1.26	-0.14	5.39
Interest rate	5.72	0.57	4.71	6.76	5.01	1	3.33	7.36

U.S.

	Oct 1986- Jan 1992				Feb 1992- Sep 1992			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Actual inflation	4.54	0.47	3.7	5.64	3.67	0.2	3.27	3.89
OECD Forecasts	4.33	0.93	2.04	6.28	3.11	0.04	3.07	3.17
SPF Forecasts	3.89	0.43	3.11	4.58	2.93	0.21	2.71	3.25
Output gap outcome	1.91	1.76	-1.36	4.05	-1.3	0.12	-1.45	-1.16
Interest rate	7.49	1.76	4.07	14.35	3.79	0.5	3.04	4.53

	Oct 1992- Apr 1997				May 1997- Sep 2008			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Actual inflation	2.95	0.29	2.43	3.57	2.22	0.39	1.04	2.98
OECD Forecasts	2.77	0.28	2.23	3.23	2.66	0.96	-0.18	5.25
SPF Forecasts	2.72	0.23	2.35	3.1	2.06	0.23	1.54	2.46
Output gap outcome	0.74	1.33	-1.56	2.66	3.35	1.61	0.84	7.41
Interest rate	4.95	1.24	2.66	7.07	3.83	1.88	0.22	7.06

Notes: The statistics summarized for each variable are: mean, the mean, SD, the standard deviation, min, and max, the minimum and maximum values. The data is for macroeconomic variables for the U.K and U.S over each CBI subperiod from October 1986 to September 2008.

other variable should also be helpful if it contains information about future inflation and output. This leads to an optimal policy rule with forecasts for inflation and the output gap following his forward-looking model of the transmission mechanism. Recent studies show that such policy rule provides a more reasonable description of the monetary policy for IT countries than a traditional Taylor rule(See Gorter et al. (2008); Neuenkirch & Tillmann (2014)). Regarding the mismeasurement of the potential output in late 1980s and 1990s (see Nelson et al. (2002)) and the non-existence of expected output in the database, I instead construct the expected output level using the real GDP and expected GDP growth. By subtracting the potential output level estimated by quadratic detrending, the expected output gap is constructed in the monetary policy rules [18].Therefore, a forward-looking Taylor rule based on forecasts can be written as:

$$i_t^* = c + \lambda E_t \pi_{t+i} + \gamma E_t y_{t+j}, \tag{19}$$

where i_t^* is the target interest rate, c combines long-run equilibrium real interest rate and the inflation target, $E_t \pi_{t+i}$ is i-month-ahead forecasts for inflation, and $E_t y_{t+j}$ is j-month-ahead forecast of the output gap based on the information set released through period t. To be consistent with the BoE's view of the transmission mechanism, I use weighted average between 12 and 24 months ahead forecasted inflation and 12-month ahead forecast for output growth [19]. As-

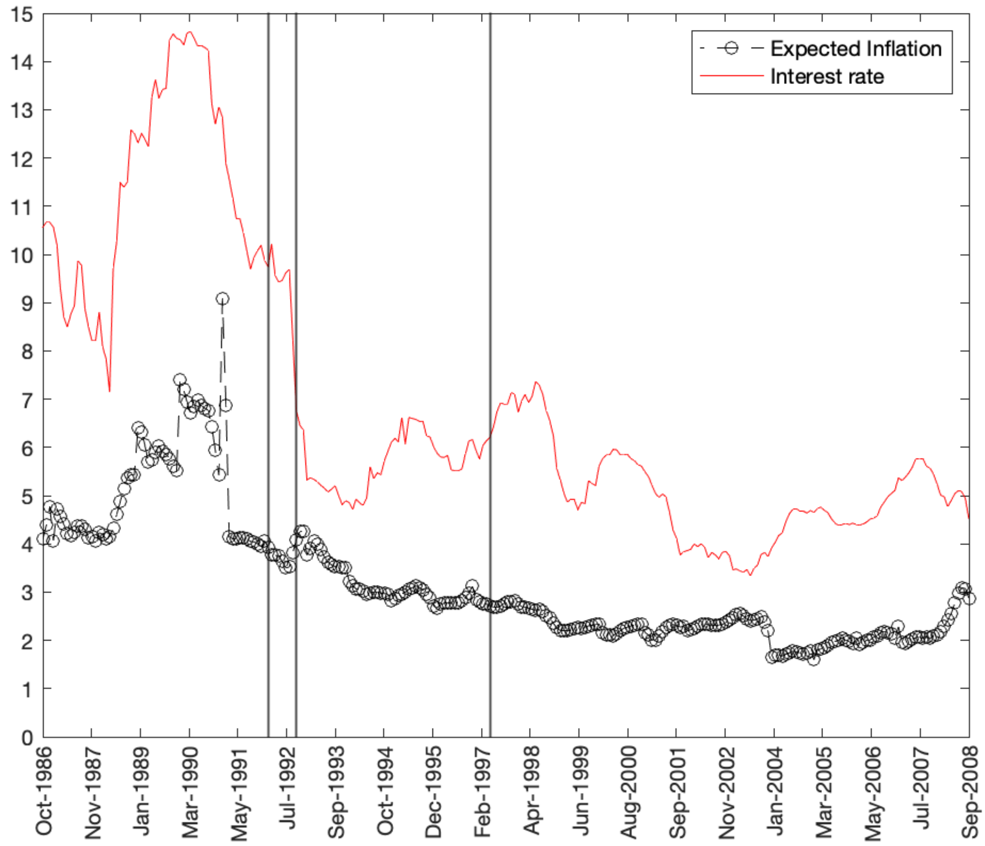
[18] 12-month ahead expected output level equals to 12-month ahead expected GDP growth times the real GDP at time t. Potential output level is constructed by real GDP using quadratic detrending method.

[19] See Appendix for details of data. See also Cobham & Kang (2013) for the time horizon of the forward-looking variables.

suming the target for the short-term nominal interest rate is to be achieved within the period, there is no distinction between the target and actual nominal interest rate under the Taylor rule. As I use interest rate at the end of month and the real-time forecasts are made up with information before the end of period t, the issue of endogeneity is largely alleviated.

When estimating the Taylor rule, it is usual practice to include the lagged interest rate and estimate the variables using nonlinear least squares. There are two reasons not to do so. First, the claim of interest rate smoothing has been rejected by some former members of the Monetary Policy Committee (Goodhart (2005)). As empirical evidence, Goodhart finds that the coefficient on lagged interest rate is insignificantly different from unity and the lagged terms in the first difference rule are never significant. Cobham & Kang (2013) also doubts the high level of 'gradulism' as the adjustment of the interest rate is too slow to offset the destablising effect from an inflation shock. Second, Murray & Urquiza (2017) argues that parameters of interest in forward looking Taylor rules with interest rate smoothing estimated by nonlinear least squares are subject to the Zero Information limit Condition stated by C. R. Nelson & Startz (2007). When observed sample observation is smaller than 100, the coverage probability of confidence interval using standard methods for the estimated coefficients is too small especially when interest rate smoothing exceeds 0.7.

Figure 9: Short-term interest rate and expected inflation



The figure 2.1 reports UK 3-month treasury bill rate(red line) and expected inflation(point-dashed line). Each vertical line represents a change of the Cukierman's CBI index. These dates include Feb-1992, Oct-1992 and May-1997.

To maintain price stability, the BoE adjusts its bank policy rates and responds to changes in inflation (illustrated in figure 9)[15]. Table 7 reports estimated break dates using Bai & Perron (2003)'s test and estimated monetary responses to expected inflation and expected output gap based on equation 19 under each sub-period. The 95 % confidence interval of estimated break dates indicates that there are no significant differences between the break times and the dates when CBI improves. Furthermore, it can be found that monetary response to inflation is only above the unity before the IT adoption. Although German monetary policy has heavy influence over the BoE's interest rate decisions in this period, the behavior of the BoE in controlling inflation is still characterized as "conservatism" especially before the entry of ERM (See Clarida et al. (1998); Kuttner & Posen (1999)). This kind of conservatism i.e. more aggressive policy response to inflation can be due to the policy maker 's uncertainty about the monetary policy transmission, especially like the late 1980s when inflation is much higher than targeted levels (Tillmann (2011)).

After the IT adoption, the estimated response to inflation become below unity. Since the introduction of IT framework in October 1992, with a better anchoring of inflation expectation, short-term interest rate is also adjusted in a less extent. Kuttner & Posen (1999) described the new framework as a change of policymaker's preference from "conservatism" to "trust building" of inflation targeting. Instead of over sacrificing output for inflation stability as a conservative central bank, the BoE respond to the supply disturbances while

[15] I use 3-month treasury bill rate here to approximate different policy rates over different periods, which is a conventional way in this type of exercise (see E. Nelson (2000)).

Table 7: Response of interest rate to expected inflation and output gap

Sub-sample period	$\hat{\lambda}$			$\hat{\gamma}$			95% Confidence Intervals
1986:M10 - 1992:M9	1.62	***	(0.19)	-0.06	**	(0.03)	
1992:M10 - 1997:M3	0.78	***	(0.26)	0.19	***	(0.05)	1992:M8 - 1993:M2
1997:M4 - 2001:M3	0.86	**	(0.38)	0.28	***	(0.04)	1996:M10 - 1998:M10
2001:M4 - 2004:M11	0.06		(0.31)	0.38	***	(0.09)	2001:M3 - 2001:M6
2004:M12 - 2008:M9	0.52	*	(0.31)	0.30	***	(0.09)	2004:M10 - 2005:M1

*Notes: $\lambda(\gamma)$ is monetary response to expected inflation(output gap) and robust standard errors are in parentheses. *** indicate λ is statistically different from the null of zero at the 1% significance level. The last column reports 95% confidence interval for the estimated break dates using White standard errors .*

committing to reach the inflation target on average (following King (1997)'s "optimal state contingent rule"(OSCR)). This means that the inflation is not required to meet the target over each period, but should be consistent with an optimal distribution which has mean equals to the target. This new framework needs a high level of credibility for the BoE. The BoE Inflation Report is the new institutional change which suits this demand. It provides consistent information for private agents to understand not only the reaction mechanism of the BoE towards the supply disturbances, but also the Bank's forecasts and analysis used to make policies. This makes the publication of inflation report become one important step to build credibility for the BoE. Under the trust-building framework of IT, public are convinced that central bank will achieve the target inflation on average and any inflation fluctuations will be transitory[16], which leads to smaller fluctuations in private-sector inflation expectations as in our study.

Despite the fact that expected inflation has become much more stable since the instrument independence in May 1997, there still exists upward and downward adjustments in interest rate decisions which cannot be neglected. This can be seen from the relatively increase of monetary response to inflation after the instrument independence (0.76 to 0.86). As the interest rate decisions for the Monetary policy has become the independent decision-making of the new MPC after May 1997, stricter responsibility to fulfill the inflation target also follows. After May 1997, inflation target was set specifically at 2.5% on

[16] As argued by Baxa et al. (2014), the very distinct fall of UK inflation persistence since the IT adoption also supports the belief of transitory inflation fluctuations.

the RPIX instead of 2.5% or less previously. A more strict institution is raised with open letter to explain when the inflation is below and above the target by more than 1%, and specify how and when the deviations would be eliminated. These institutional changes may force the BoE to take more active monetary policy reaction towards the changes of inflation, in order to reach the new criterion for the IT regime. The direct evidence is that most interest rate changes over 1997:M5-2001:M2 are explained by officials as measures to forestall or prevent inflation (see Table 8.1 in Cobham (2003)), while there is no deviation of RPIX inflation larger than 1% from the 2.5% target in this period. The stricter settlements above may force the policy makers to be more sensitive to inflationary pressures when making interest rate decisions.

Furthermore, the insignificant monetary repsonse to inflation during the early era of 2000s is mainly caused by infrequent change of interest rate decisions. Over the pre-financial crisis period(2004:M12 - 2008:M9), the BoE responded more positively to the output gap. This is reflected as more signfiicant coefficients for expected output gap relative to the inflation. To study influences from the U.K. CBI changes to usd/gbp exchange rate return, it is necessary to investigate over a sample period where the influences of U.S. monetary regime shift can mostly be excluded. Using real-time data for the U.S., Nikolsko-Rzhevskyy et al. (2014a) estimate structural change points on Taylor rule deviations calculated as the absolute value of the difference between the federal funds rate and the rate implied by the original Taylor (1993)'s rule (see Figure 32 in Appendix). They produce rule-based era for 1985-2000 and discretionary era for 2001-2013. This is close to the results from a broad historical approach used by Meltzer (2012) and Taylor (2012), which shows that 1985-2003 in the U.S. was a rule-like period while the times before and after the era were discretionary. Furthermore, Cochrane et al. (2019) evaluated deviations of the actual rate from the rate prescribed by five different rules in the Monetary Policy Reports[20]. Their results support that 1985-2002 can be characterized as a period with less discretion. Based on above views, we assume 1986:10-2001:02 as a period with no significant shifts of U.S. monetary regime. By focusing on the exchange rate forecasts over this period, we can mainly investigate the role of U.K. monetary policy formulation in influencing the usd/gbp exchange rate predictability.

3.4 CBI Revolutions and Exchange Rate Reconnect

To study the predictability of USD/GBP nominal exchange rate before and after the CBI revolutions, I examine the connection between the exchange rate and macroeconomic fundamentals including interest rate differential and Taylor rules.

Except using forward-looking Taylor rule (in equation 19) to describe the BoE's interest rate decisions, I assume the Fed followed Taylor (1993)'s contemporaneous rule to set monetary policy. The simple monetary policy rule can be specified as:

$$i_t^* = \pi_t + \phi(\pi_t - \pi_t^*) + \gamma y_t + r^*, \tag{20}$$

[20] These rules include original Taylor rule, Balanced-approach rule, First-difference rule, Taylor adjusted rule and Price-level rule named in their paper

where i_t^* is referred to as the target for the short-term nominal interest rate, r^* is the equilibrium real interest rate, $(\pi_t - \pi_t^*)$ is the deviation of actual inflation (π_t) from its target (π_t^*), y_t is the output gap, or percent deviation of actual output from an estimate of its potential level using quadratic interpolation. As the target for the short-term nominal interest rate is assumed to be achieved within the period, there is no distinction between the target and actual nominal interest rate under the simple rule.

I use the contemporaneous Taylor rule rather than the forecast-based rule or other specifications for the U.S. for three reasons. First, it is consistent with the very specification of the monetary policy rule in the FRB-US (Brayton & Tinsley (1996)) and SIGMA (Erceg et al. (2006)) models used at the Federal Reserve Board. Second, contemporaneous Taylor rule is more influential on Fed policymaking than other specifications. Although forward-looking rules are often used to characterize Fed's monetary policy, the contemporaneous Taylor rules have been shown to the Federal Open Market Committee since 2004 and have been involved in the Federal Reserve Board's semi-annual Monetary Policy Report since 2017[12]. Third, Taylor (1999) argues that forecast-based rules are not more forward-looking than contemporaneous rules since the forecasts of macroeconomic variables are made upon current and lagged data. By analysing performance of forecast-based rules using five different macroeconomic models for the U.S., Levin et al. (2003b) find no superiority

[12]The rules shown in the Monetary Policy Report include Taylor (1993) rule, "balanced-approach" rule, difference rule, adjusted Taylor rule and price level rule, which are all based on contemporaneous rather than forecasted variables.

of forecast-based rules compared with the contemporaneous Taylor rules. Orphanides (2010) also doubts the stability of performance for U.S. forecast-based rules regarding its sensitivity towards the sources and horizons of inflation forecasts data. For these reasons, the contemporaneous rule is mostly used as the benchmark when studying deviations of Fed funds rate from the Taylor rule (see e.g. Nikolsko-Rzhevskyy et al. (2019b, 2021), Cochrane et al. (2019), Ince et al. (2016) and Teryoshin (2014)).

If parameters r^* and π_t^* in equation (20) are combined into one constant term $c = r^* - \phi\pi_t^*$, equation (20) can transform into the following form:

$$i_t^* = c + \lambda\pi_t + \gamma y_t, \tag{21}$$

where $\lambda = 1 + \phi$.

To derive the exchange rate forecasting equation for Taylor rule fundamentals, we subtract the monetary policy reaction function for the U.K.(equation 19) from that for the U.S.(equation 21), which leads to interest rate differential as following:

$$i_t - \tilde{i}_t = \alpha + \lambda_u\pi_t - \lambda_k E_t\tilde{\pi}_{t+i} + \gamma_u y_t - \gamma_k E_t\tilde{y}_{t+j}, \tag{22}$$

where ˜ denotes the U.K. variables, k and u denote coefficients for the U.K. and the U.S respectively, α is a constant. As there is no evidence that monetary responses for both countries are similar over each period, we do not restrict the U.S. and U.K. variables to share same coefficients.

Under rational expectation hypothesis, the UIP relation for the forecasting equation of exchange rate s_{t+h} made at time t can be described as:

$$s_{t+h} - s_t = \alpha + \beta(i_t - \tilde{i}_t) + \epsilon_t. \tag{23}$$

Given that the UIP condition holds, $\beta = 1$. This suggests when the interest rate differential is positive, the US dollar is expected to depreciate over time.

Assuming UIP holds in the short run, the interest rate differential on the right-hand-side of (23) can be replaced by Taylor rules differential in equation (22) to derive an exchange rate forecasting equation, which is shown as:

$$s_{t+h} - s_t = \alpha + \alpha_{u\pi}\pi_t - \alpha_{k\pi}E_t\tilde{\pi}_{t+i} + \alpha_{uy}y_t - \alpha_{ky}E_t\tilde{y}_{t+j} + \eta_t. \tag{24}$$

Although the signs of parameters in (24) is consistent with UIP condition, more extensive research suggests that the signs of the parameters can be reversed, which presumes that any variables that cause the Fed and/or the BoE to raise the U.S. interest rate relative to the U.K. rate will lead to the U.S. dollar appreciation(i.e. $s_{t+h} - s_t < 0$). For example, this can be caused by a systematic under-estimation of the persistence of interest rate shocks (See Gourinchas & Tornell (2004)) or infrequent portfolio decisions(See Bacchetta & van Wincoop (2010)). In this paper, we will also argue that the signs can be reversed due to the change of monetary policy stance. For these reasons, we do not put restrictions that coefficients in (23) and (24) must share same magnitudes or signs.

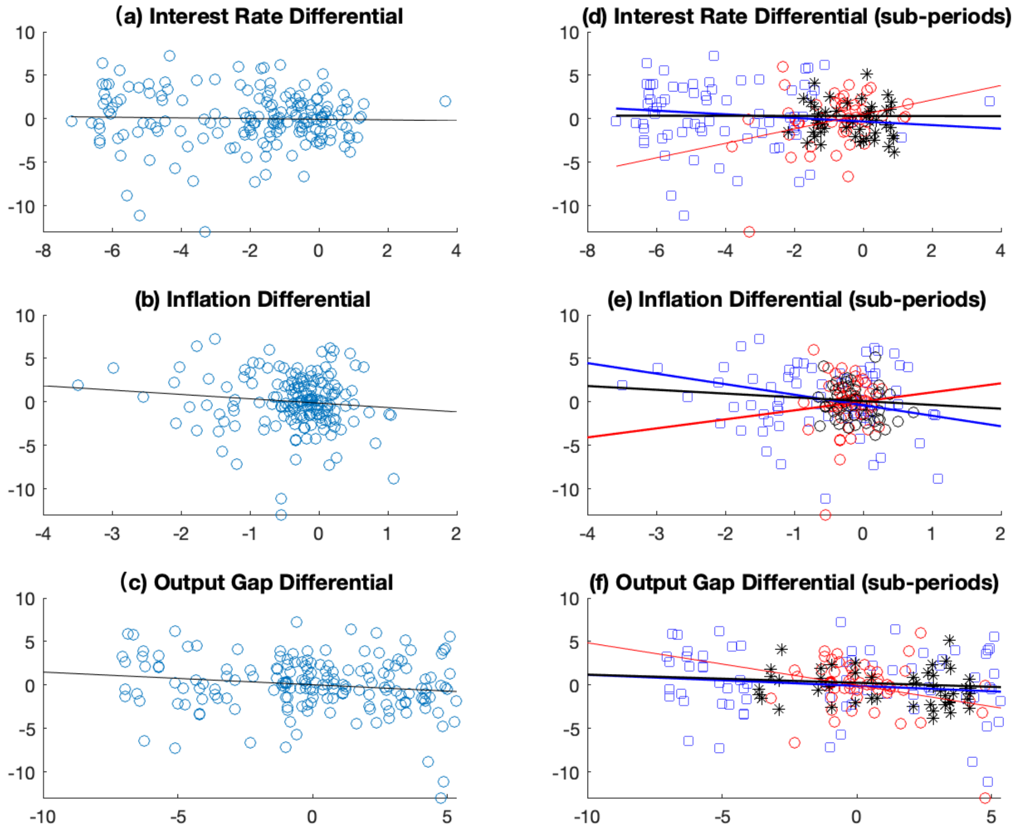
3.4.1 Preliminary Analysis

The increase of CBI level in February 1992 is associated with limitations on lending while two other CBI level increases are caused by monetary policy formulations. Following previous empirical studies, we focus on the periods before and after the monetary policy revolutions including IT adoption(October 1992) and Instrument Independence(May 1997). For each of the three sub-periods, Pre-IT period (1986:M10 - 1992:M9), Post-IT period(1992:M10 - 1997:M4) and Post-independence period(1997:M5 - 2001:M2), we test the in-sample explanatory power and out-of-sample predictability for UIP/Taylor rule exchange rate models.

Figures 10(a),10(b) and 10(c) reproduce the well-known disconnection between the USD/GBP exchange rate and macroeconomic variables between U.S. and U.K from October 1986 to February 2001. For instance, Figure 10(a) relates regression of *ex ante* one-month USD/GBP nominal exchange rate return, $s_{t+1} - s_t$, on the current interest rate spread $i_t - \tilde{i}_t$. UIP supposes to imply a positive and significant relationship between the dependent and independent variables. However, the linear regression analysis with these data indicates a small and insignificant estimate of the relationship. Figure 10(b) and (c) report similar outcomes when relating changes in inflation(output gap) differentials with the exchange rate.

To have a preliminary sub-sample analysis about the influences of monetary policy regime shifts to the dynamic behavior of exchange rate, Figures 10(d) (e) and (f) relate exchange rate movements to the

Figure 10: Exchange Rate Return and Macro Fundamentals: Pre-IT, Post-IT and Post-Independence periods



Notes: This figure plots the relationship between the monthly changes in the USD/GBP and macroeconomic variables from October 1986- February 2001. Changes in the *ex ante* one-month USD/GBP exchange rate return are reported on the y-axis and the relevant macroeconomic variables are reported on the x-axis. An increase in the USD/GBP exchange rate indicates dollar depreciation, and a leftward move in the x-axis relates to a lower level for the U.S. minus the U.K. Panel (a) tests the UIP relation. Panel (b) uses the inflation rate of the U.S. relative to the U.K. Panel (c) uses the output gap of the U.S. relative to expected output gap of the U.K.. Panel (d) looks at UIP relation over each subperiod. the dots and regression line in blue color are for Pre-IT period (1986:10 - 1992:09), red color dots and line are for Post-IT period (1992:10 - 1997:04), black dots and regression line are for Post-independence period (1997:05 - 2001:02). Panel (e) looks at the relative difference of inflation rate between U.S. and U.K over each subperiod. Panel (f) looks at the relative difference of output gap under each subperiod.

macroeconomic fundamentals over each subperiod. The plots and regression line for Pre-IT period are denoted in blue, while Post-IT and Post-independence periods are denoted in red and black color. As illustrated in Figure 10(d), the relationship between change of exchange rate and interest rate differential is remarkably different during the Post-IT period, whereas the spread in other two periods still indicate no significant evidence of predictability based on visual inspection. During the Post-IT period when the BoE turns to passive monetary stance, 1992:M10- 1997:M4, the interest rate differential tends to predict exchange rate movement with a sign consistent with the UIP relation. Figure 10(e) relates changes in the exchange rate to the inflation differential over each subperiod. During the Post-IT period, we see positive relationship between exchange rate return and the inflation differential, but negative relationship over post-independence period. For output gap differential, there exists a slightly negative relationship over post-IT period.

To confirm the visually inspected relationship between return on exchange rate and macroeconomic variables, Table 8 reports regression estimates for the current interest rate differential, inflation and output gap differential on the one-month exchange rate movements for each sub-sample period. First, as in Figures 10(a),(b) and (c), the point estimates are not statistically different from zero for any fundamentals during the full sample period. The ability of macro fundamentals to explain exchange rate movement is slight since R^2s are close to zero for all cases. This poor performance issue for three fundamentals remain during the Pre-IT period. Next, when the BoE's

Table 8: USD/GBP Exchange Rate Return and Macro Fundamentals

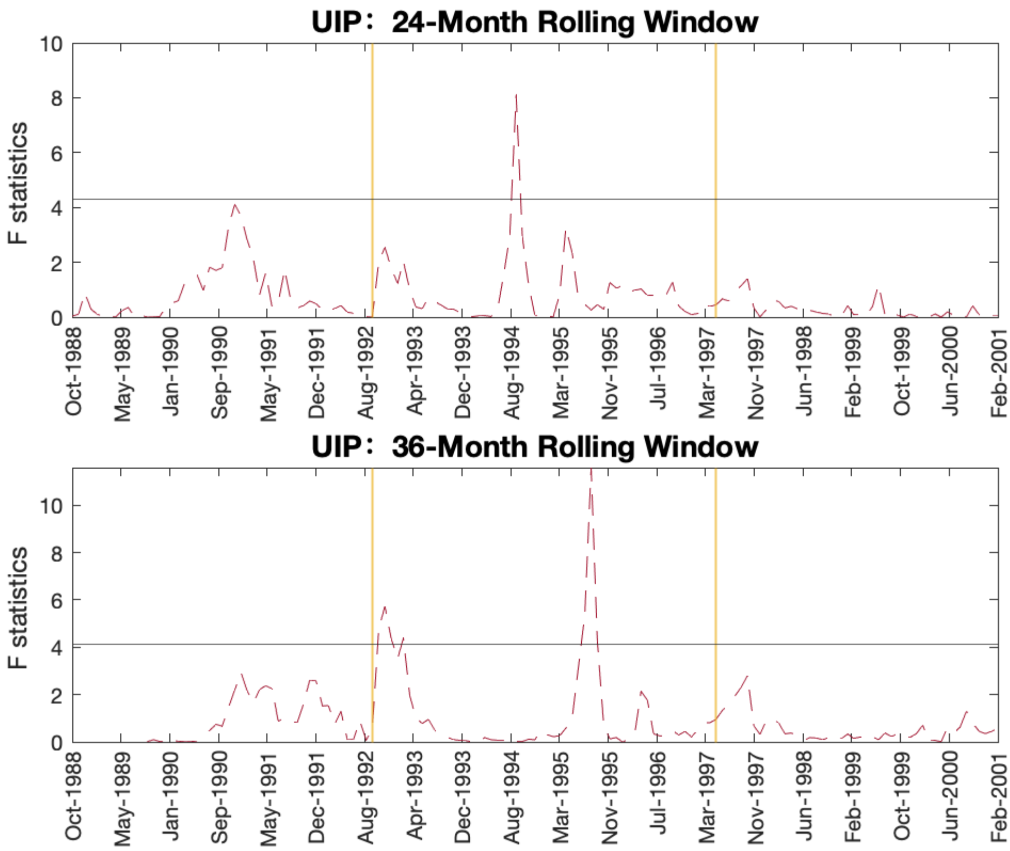
Fundamentals	(Full sample) Oct1986- Feb2001 $\hat{\beta}$	R^2	(Pre-IT) Oct1986- Sep1992 $\hat{\beta}$	R^2	(Post-IT) Oct1992- Apr1997 $\hat{\beta}$	R^2	(Post-independence) May1997- Feb2001 $\hat{\beta}$	R^2
Interest rate differential	-0.04	0.01	-0.005	0.01	0.83**	0.09	-0.21	0.01
	(0.11)		(0.19)		(0.48)		(0.33)	
Inflation differential	-0.50	0.01	-0.44	0.01	1.04	0.01	-1.21*	0.04
	(0.35)		(0.43)		(2.09)		(0.61)	
Output gap differential	-0.15	0.02	-0.09	0.01	-0.49	0.08	-0.13	0.03
	(0.09)		(0.11)		(0.33)		(0.08)	

Notes: This table presents regressions estimate (β) of the form $s_{t+1} - s_t = \alpha + \beta X_t + \epsilon_t$, where $s_{t+1} - s_t$ is one-month-ahead exchange rate movement and X_t represents different macroeconomic variables. HAC standard errors are in parentheses. For UIP regression, X_t is U.S. interest minus U.K. interest rate or $i_t - \tilde{i}_t$ in our case. For inflation differential, X_t is U.S. actual inflation minus U.K. expected inflation or $\pi_t - E_t\tilde{\pi}_{t+i}$ in our case. For output gap differential, X_t is U.S. actual output gap minus U.K. expected output gap or $y_t - E_t\tilde{y}_{t+j}$ in our case. First column reports regression results from full sample October 1986 - February 2001. Second column reports regression results for the Pre-IT period (October 1986- September 1992). Third column reports regression results for the Post-IT period(October 1992 - April 1997). Fourth column reports regression results for the Post-independence period (May 1997 - February 2001). For UIP specification, ** indicates that $\beta = 1$ falls in the 95% confidence interval of estimated β. For inflation differential, * indicates that β is statistically different from the null of zero at the 10% significance level.

monetary policy response to inflation becomes milder or relatively passive in the Post-IT period, the estimated slope coefficient ($\hat{\beta}$) drastically changes. The null hypothesis for $\beta = 1$ cannot be rejected at the 5% significance level for the interest rate differential, which suggests that the UIP condition holds. In addition, R^2 has an increase to 9 percent implying that interest rate differential contains effective component to predict exchange rate. Both evidence suggest an exchange rate reconnection through UIP channel after IT adoption. At the same period, we find the estimated coefficient for inflation differential increases, but statistically insignificant from zero. The R^2 remains low. The last column suggests that slope coefficient for interest rate differential again becomes negative and insignificant. R^2 is nearer to zero, which also suggests a resurgence of UIP puzzle. On the other hand, the estimated coefficient for inflation differential changes from positive to negative after the independence and the R^2 has a slight increase simultaneously. While the statistical result shows that the estimated coefficient for inflation differential is significant at 10 %, it is worthy to investigate whether the inflation differential contains useful information to predict exchange rate after May 1997. The full-sample and sub-sample analysis for output gap differentials did not find significant outcomes.

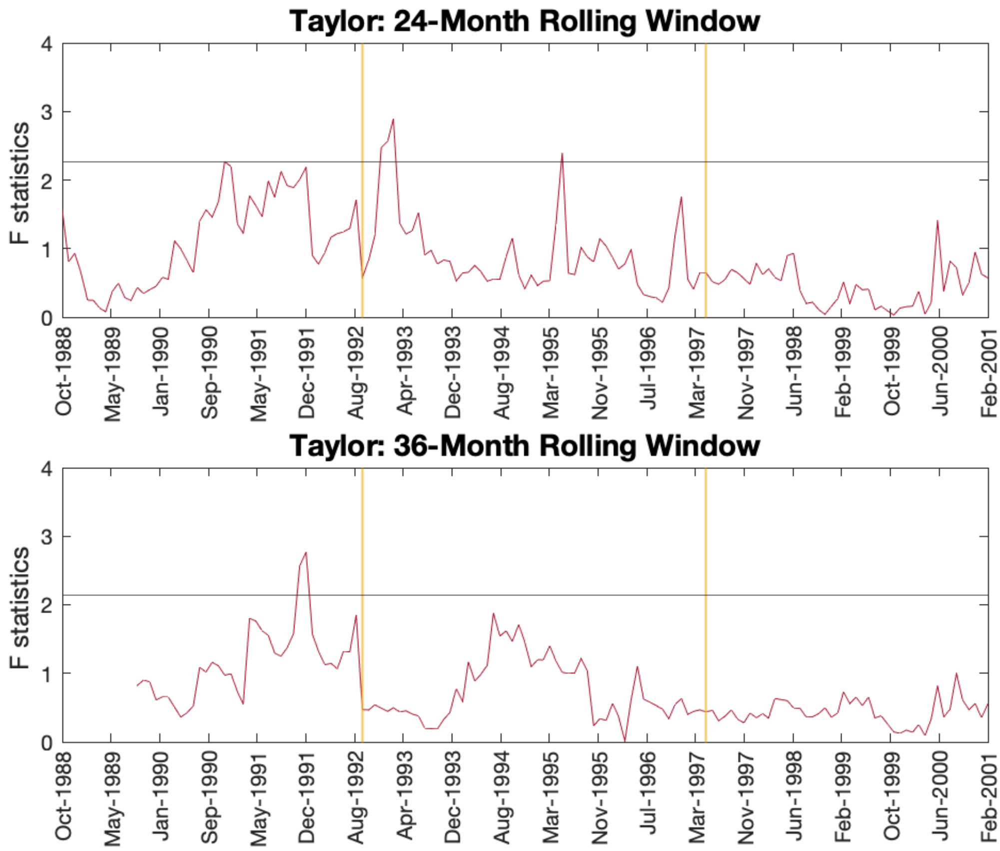
3.4.2 Exchange rate reconnect after CBI revolutions

Figure 11: Reconnect of The USD/GBP Exchange Rate and Interest Rate Differential: overall F test statistics



Notes: These figures show overall F test statistics for the 24- and 36- month rolling regressions of the log change in the USD/GBP exchange rate against various macroeconomic fundamentals. The regression specification is $s_t - s_{t-1} = \alpha + \beta X_t + \epsilon_t$, where $s_t - s_{t-1}$ is monthly change of nominal exchange rate and X_t represents different contemporaneous macroeconomic variables. For UIP regression, X_t is U.S. interest minus U.K. interest rate or $i_t - \tilde{i}_t$ in our case. Yellow lines denote the times of CBI revolutions. Horizontal line associates with critical value of F test with 5% significance level

Figure 12: Reconnect of The USD/GBP Exchange Rate and Taylor rule fundamentals: overall F test statistics



Notes: These figures show overall F test statistics for the 24- and 36- month rolling regressions of the log change in the USD/GBP exchange rate against various macroeconomic fundamentals. The regression specification is $s_t - s_{t-1} = \alpha + \beta X_t + \epsilon_t$, where $s_t - s_{t-1}$ is monthly change of nominal exchange rate and X_t represents different contemporaneous macroeconomic variables. For Taylor rule fundamentals, X_t includes U.S. actual inflation and output gap, U.K. expected inflation and expected output gap or $(\lambda_u \pi_t - \lambda_k E_t \tilde{\pi}_{t+i} + \gamma_u y_t - \gamma_k E_t \tilde{y}_{t+j})$in our case. Yellow lines denote the times of CBI revolutions. Horizontal line associates with critical value of F test with 10% significance level.

To investigate the in-sample explanatory power of macro fundamentals for exchange rate return. Figure 11 and 12 plots the test statistics for overall F test of rolling regressions run in monthly data of the *ex ante* one-month USD/GBP exchange rate return on a constant and the contemporaneous macroeconomic fundamentals. These fundamentals include interest rate differential (UIP)(equation 23) in Figure 11 and Taylor rule fundamentals (equation 24) in Figure 12. Regressions are estimated on 24-month and 36-month rolling windows, starting in October 1986 and ending in February 2001.

Before the IT adoption in 1992, the overall F test statistics (in Figure 11) indicate no rejection of null hypothesis for no in-sample explanatory power of UIP specification regarding both 24 and 36 months rolling window[13]. The overall F test statistics show that the null hypothesis of no explanatory power of UIP specification can be rejected at 5% level only after the IT adoption in October 1992. It can be seen no matter using 24- or 36-month rolling window for estimation. This implies an increase of in-sample explanatory power during the post-IT period. However, evidence of explanatory power for the UIP specification becomes insignificant after the instrument independence in May 1997.

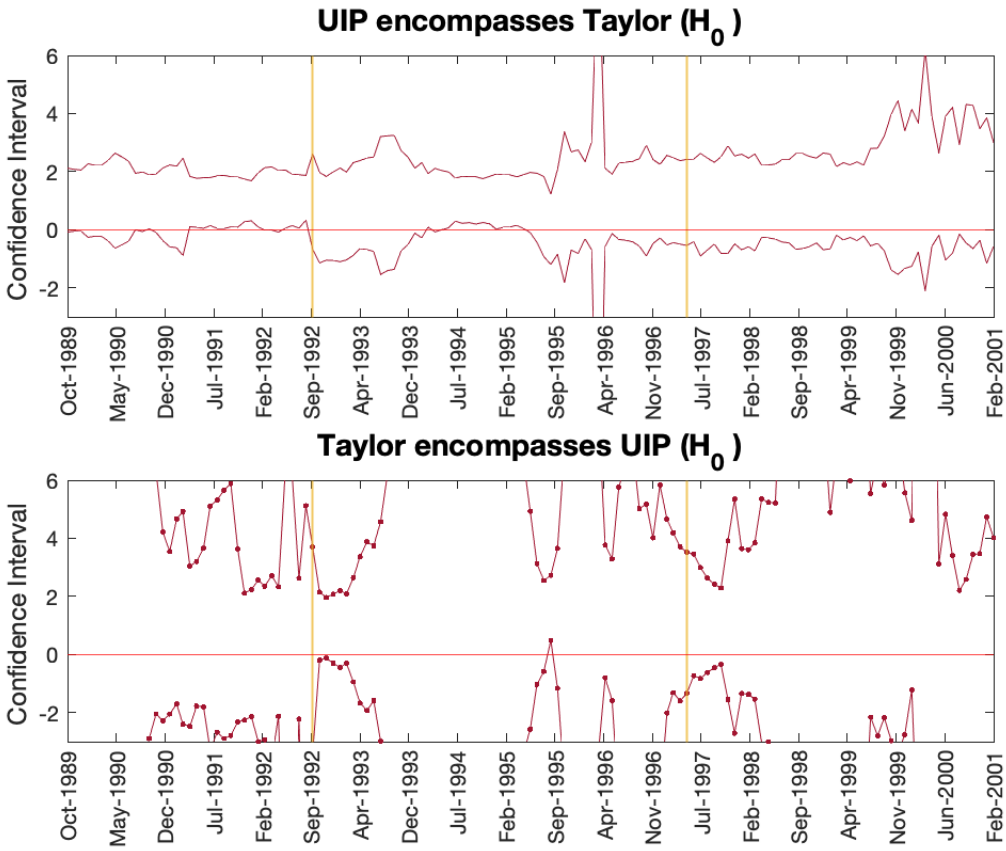
The results of overall F test (in Figure 12) for Taylor rule fundamentals are more volatile than the UIP specification. Although there exists several peaks along the time periods, we only observe significant results at 10% significance level over the Pre- and Post-IT period. This makes it hard to conclude the changes of in-sample

[13] Although there exists a peak of F-statistic after entry of ERM in October 1990, it has not reached the critical value of 4.3 for 5 % significance level

explanatory power before and after the IT adoption. After the independence in 1997, it shows that the in-sample explanatory power become relatively weaker than previous sub-periods.

Next, I employ non-nested encompassing test (Davidson & MacKinnon (1981)'s J test) on the two model specifications. As test results for 24-month rolling regressions are similar to those of the 36 month rolling regressions, we put the former ones into Appendix (see Figure 29). On the one hand, test on 36-month rolling regression (upper panel of Figure 13) shows that zero value of estimated coefficient may not be covered by the 95% confidence interval when testing the null hypothesis for UIP encompasses Taylor rule model, which suggest rejection results for null hypothesis over both pre- and post-IT periods. On the other hand, the 95% confidence interval (lower panel of Figure 13) for the null hypothesis of Taylor rule model encompasses UIP indicate no rejection outcomes over almost all periods. Overall, the encompassing tests suggest that Taylor rule fundamentals dominates UIP specification during pre- and post-IT periods.

Figure 13: Compare UIP and Taylor rule fundamentals: 95% confidence interval for encompassing test



Notes: These figures show the 95% confidence interval for Davidson & MacKinnon (1981) 's J test using 36-month rolling regressions of the log change in the USD/GBP exchange rate against various macroeconomic fundamentals. The regression specification is $s_t - s_{t-1} = \alpha + \beta X_t + \epsilon_t$, where $s_t - s_{t-1}$ is monthly change of nominal exchange rate and X_t represents different contemporaneous macroeconomic variables. For UIP regression, X_t is U.S. interest minus U.K. interest rate or $i_t - \tilde{i}_t$ in our case.. For Taylor rule fundamentals, X_t includes U.S. actual inflation and output gap, U.K. expected inflation and expected output gap or $(\lambda_u \pi_t - \lambda_k E_t \tilde{\pi}_{t+i} + \gamma_u y_t - \gamma_k E_t \tilde{y}_{t+j})$ in our case. Yellow lines denote the times of CBI revolutions. Horizontal line indicates zero value coefficient on UIP (Taylor) associated with the true model is Taylor (UIP) under null.

3.4.3 Out-of-sample Exchange Rate Predictability

Next, we evaluate the out-of-sample predictability of macro fundamentals model over different sub-periods. Two models are considered in this section, which include the UIP and the Taylor rule fundamentals model. I use two metrics to compare the out-of-sample predictability of a macroeconomic fundamentals model to that of a driftless random walk. First, the Root Mean Squared Error (RMSE) of one model's forecasts is divided by the RMSE of the random walk. This is denoted as "RMSE Ratio", in which a value less than unity implies the forecasts using this model outperform the random walk. Second, I use the Clark & West (2006) test statistic to formalize the test of the out-of-sample predictability for one specific model. This is same as testing whether the coefficients on the economic fundamentals model are jointly significantly different from zero. If the null hypothesis cannot be rejected, the model is treated as having equal predictability as random walk. I plot the two metrics for each 24-month out-of-sample forecast evaluation period using 24-month rolling window in one figure, and for each 36-month out-of-sample forecast evaluation period using 36-month rolling window in other figure. The evaluation periods are chosen to start at the beginning of each calendar year, with the first evaluation period spanning 1990:01-1992:12 and the next period starting and ending a year later, and so each forecast period overlaps [14]. The "x" markers denote evaluation periods that start before October 1992, the hollow dots present re-

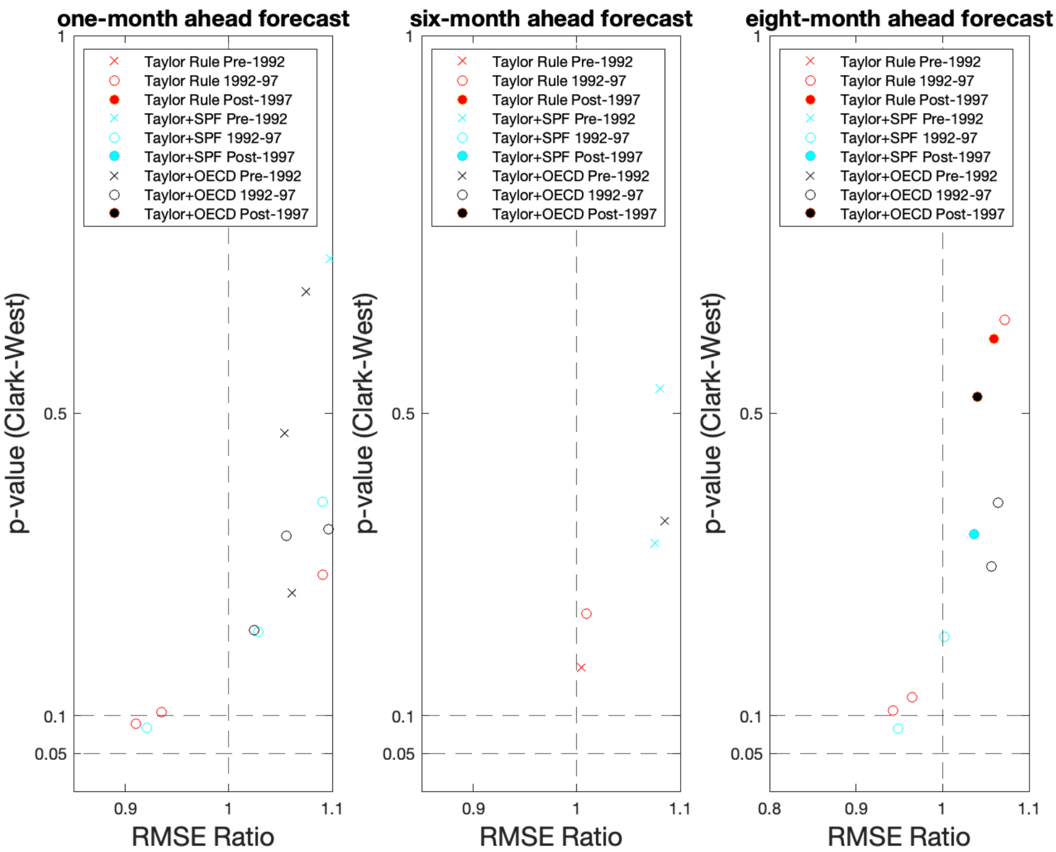
[14]When evaluating each 36-month forecast period, the first evaluation period spanning 1991:01-1993:12.

sults of evaluation periods that start after October 1992 but before May 1997, and the solid dots denote outcomes of evaluation periods that start after May 1997.

We firstly investigate results for out-of-sample predictability of UIP specification (in Figures 30 and 31 of Appendix)). For the UIP specification, null hypothesis of no predictability cannot rejected at 10 % level during the post-IT and post-independence periods. At the same time, their RMSE ratios are above the unity. This is inconsistent with the overall F-test outcomes for explanatory power in Figure 11, which indicates significant outcomes after the IT adoption. From out-of-sample performance for UIP specification, there no longer exists an USD/GBP exchange rate reconnection with the interest rate differential over the post-IT period.

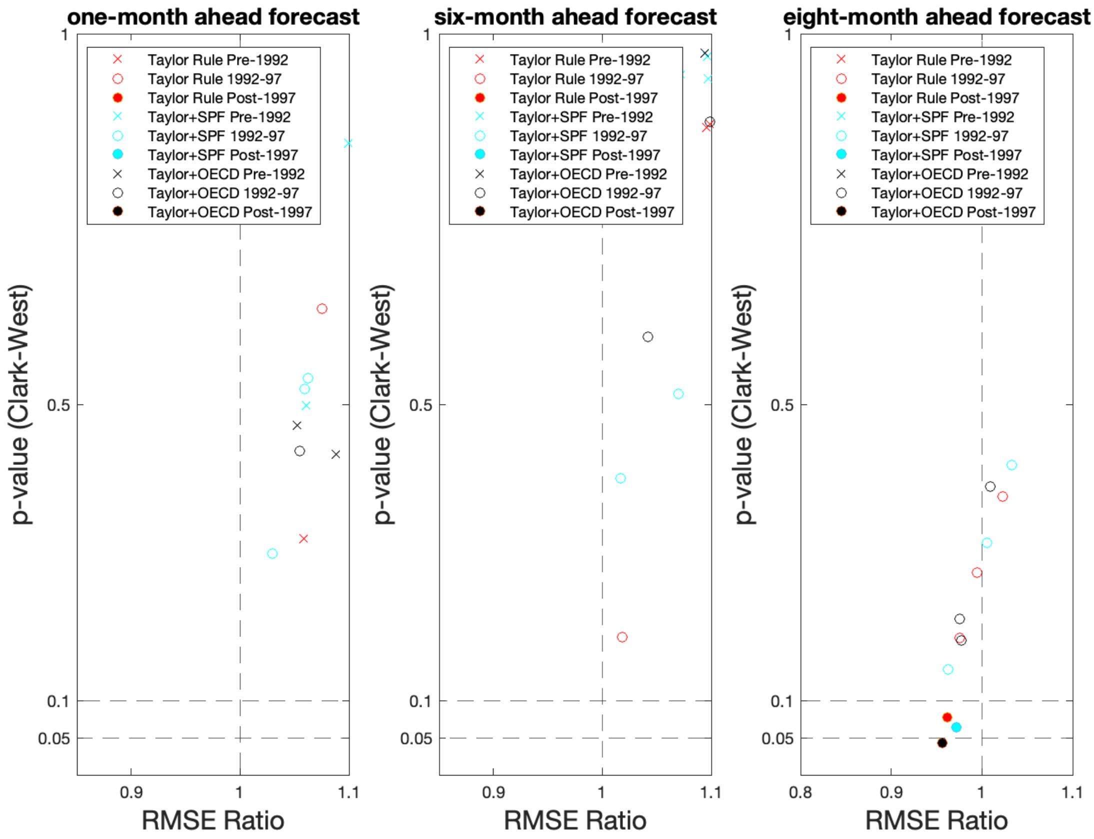
Although UIP specification losses its significance in out-of-sample forecasts, we find significant evidence for out-of-sample performance of Taylor rule fundamentals model during both post-IT and post-independence periods. When investigating 24-month evaluation periods after the IT adoption(in figure 14), the null hypothesis of no predictability is rejected at 10 percent level while RMSE ratio is below unity for both one-month and eight-month forecasts. These results hold up even when U.S. actual inflation is replaced by SPF's one year ahead inflation forecasts(INFPGDP1YR) in U.S. Taylor rule. This is consistent with the stronger in-sample explanatory power for Taylor rule model over the post-IT period. We therefore conclude there exists a short-term exchange rate connection with Taylor rule fundamentals after the IT adoption.

Figure 14: Reconnect with Taylor rule fundamentals (24-month Evaluation Periods): One, Six, Eight-Month Ahead Out-Of-Sample Predictability



Notes: This figures reports the 1, 6, 8-month-ahead out-of-sample predictability of exchange rate forecasts using Taylor rule fundamentals relative to a random walk over different sample periods. Each marker reports the ratio of the model's root mean squared prediction error relative to a random walk (x-axis) and the p-value of Clark-West test for the out-of-sample predictability of the model relative to a random walk (y-axis). Each observation shows a 24-month model evaluation period, using a 24-month rolling estimation windows. The "x" markers represent periods where the forecasts start prior to Oct 1992, the hollow dots relate to periods where the forecasts start after Oct 1992 but before May 1997, and the solid dots show periods where all forecasts occur after May 1997

Figure 15: Reconnect with Taylor rule fundamentals (36-month Evaluation Periods): One, Six, Eight-Month Ahead Out-Of-Sample Predictability



Notes: This figures reports the 1, 6, 8-month-ahead out-of-sample predictability of exchange rate forecasts using Taylor rule fundamentals relative to a random walk over different sample periods. Each marker reports the ratio of the model's root mean squared prediction error relative to a random walk (x-axis) and the p-value of Clark-West test for the out-of-sample predictability of the model relative to a random walk (y-axis). Each observation shows a 36-month model evaluation period, using a 36-month rolling estimation windows. The "x" markers represent periods where the forecasts start prior to Oct 1992, the hollow dots relate to periods where the forecasts start after Oct 1992 but before May 1997, and the solid dots show periods where all forecasts occur after May 1997

For the out-of-sample predictability after the instrument independence, we find significant evidence for Taylor rule fundamentals when concerning eight-month ahead forecast (in Figure 15). The null hypothesis of no predictability is rejected at 10 percent level while RMSE ratio is below unity for Taylor rule fundamentals. These results hold up even when U.S. actual inflation in the model is replaced by SPF's one year ahead inflation forecasts(INFPGDP1YR) or OECD forecasts(CPIFORECAST). This supports that Taylor rule fundamentals model offers predictability during post-independence period, although not over the short-run horizon.

3.5 Why the exchange rate is connected with economic fundamentals?

From previous analysis, we find that the exchange rate is reconnected with interest rate differential, or UIP holds, only during the post-IT period. We find the estimated coefficient of UIP is close to unity and the in-sample explanatory power is only significant during that period. However, we did not find obvious evidence for the UIP relation over Pre-IT period. One possible explanation for this concerns the role of monetary policy regime over each sub-period. Based on the dynamic behavior of interest rate and expected inflation, empirical evidence supports that U.K. monetary policy turns from active to passive after the IT adoption. The performance of exchange rate forecasts then becomes explainable by Y. S. Kim & Seol (2016)'s study outcomes about the international capital market equilibrium condition when introducing occasional shifts of monetary policy regime. In their study, both the simulation results and empirical evidence on Euro-US Dollar nominal exchange rate support the claim that relatively active monetary response to inflation contribute to the violation of the UIP condition. My study for USD/GBP nominal exchange rate also support this argument.

After instrument independence, no evidence supports the condition of UIP. This may be caused by the more active monetary response to inflation over the period, or higher risk premium after the CBI revolution. At the same period, we find some evidence of out-of-sample predictability for Taylor rule fundamentals model. Regarding the U.K. forecasted variables used in the Taylor rule fundamentals, the predictability maybe because expectations of inflation and output gap contain information about risk premium when UIP fails.

Previous literature indicates that the CBI institutional changes can explain the structural change of monetary policy regime over each period. With the adoption of IT framework, the credibility enhanced by IT framework ascertains that the inflation expectations is anchored to the inflation target without pursuing active monetary responses to inflation. This facilitates a transformation of U.K. monetary framework from 'inflation conservatism' to 'credibility-enhanced'. Accompanying with the instrument independence in 1997, a stricter accountability to fulfill the target - such as the settlement of inflation letter- was imposed on the BoE. The Bank was forced to take more active reaction towards the changes of inflation, in order to fulfill the target on time. This leads to a more significant role for the expected inflation and output gap in monetary policy decisions. Combining the empirical evidence of exchange rate predictability under different CBI levels, what we can see is how CBI revolutions influence the exchange rate connection with macroeconomic variables through shifts of monetary regime.

3.6 Conclusion

The institutional context in which central bank independence has been reformed in the U.K. has undergone great changes since the mid-1980s. To scrutinize how these changes have influenced exchange rate forecasts using macroeconomic fundamentals, I review the historical development of U.K. CBI and associated monetary policy-making, and then investigate the exchange rate connection with macroeconomic variables before and after the CBI revolutions. My investigation yields important results for exchange rate disconnect puzzle. First, using UIP specification, I find significant evidence that UIP holds for usd/gbp nominal exchange rate after the IT adoption. However, these evidence are not significant before the IT adoption and after instrument independence.

Second, after the instrument independence, the UIP puzzle reemerges but there exists evidence of out-of-sample predictability using Taylor rule fundamentals model. The evidence for out-of-sample performance are obvious over eight-month ahead forecasts, but not for shorter-horizons.

Concerning the transformation of monetary regime to credibility-enhanced framework after the IT adoption, the empirical evidence on the UIP condition may be caused by the less intervention from the central bank afterwards. Since the instrument independence, the BoE was under stricter responsibility to fulfil the inflation target. This amplifies the role of expected inflation and output gap in making monetary policy decisions, and therefore the predictability of Taylor rule fundamentals model under this period. Overall, we conclude that CBI revolutions really make a difference in connection between exchange rate and macroeconomic variables through shifts of monetary policy regime.

4 Chapter 4

Inflation targeting and exchange rate predictability in emerging and low income economies

4.1 Introduction

Since the proposition of Meese & Rogoff (1983a) puzzle, predicting exchange rate especially in out-of-sample has become a critical issue in international economics. Specifically, previous studies use various macroeconomic fundamentals for short-run out-of-sample forecasts and seek for evidence of superior performance relative to the random walk model (see review by Rossi (2013)). Among them, Taylor rule fundamentals present significant evidence in out-of-sample predictability at short horizons (e.g. Molodtsova et al. (2008); Rossi (2013); Alba et al. (2015); Byrne et al. (2016); Salisu et al. (2022)). Although these studies displayed evidence of out-of-sample predictability using various tests, the estimated coefficients are usually unsatisfactory especially for study in EMEs [1]. In a later research, Eichenbaum et al. (2021) argue that real exchange rate (RER) must adjust through changes in the nominal exchange rate (NER) as long as the home and foreign central banks adopt inflation-targeting(IT) regimes and consumers have home bias in consumption [2]. In their work, the current RER provides out-of-sample predictabil-

[1] Studies like Salisu et al. (2022) plot the estimated parameters without confidence interval. Dynamic coefficients in Alba et al. (2015) are insignificant more than half the sample period. Other studies did not present dynamic coefficients.

[2] Regarding a negative shock to the domestic endowment, the domestic good becomes more expansive. For consumers with home bias and having both domestic and foreign good in their

ity for six advanced IT countries in horizons greater than one year. On the other hand, the RER is usually incorporated into the Taylor rule specification when presenting evidence of predictability by previous studies. This makes us to conjecture that previous evidence of predictability for Taylor rule fundamentals mainly comes from the use of RER. It is even possible that RER alone is sufficient to provide superior out-of-sample predictability for NERs of countries that adopted inflation targeting. In addition, regarding the small sample size for EMEs, Galimberti & Moura (2013) used panel error correction regression in these countries to produce more efficient estimates, but their tests of homogenous coefficients indicated rejection of poolability. Also for IT EMEs, country-by-country study is performed by Alba et al. (2015) and significant evidence of predictability are found with Taylor rule fundamentals. Therefore, it is still undecided whether pooled estimation is helpful to improve exchange rate predictability in EMEs.

I mainly use three types of evidence to tackle these issues. They are historical inflation behaviour, dynamic coefficients estimation during the exchange rate forecasts and various test results and Theil's U ratio for out-of-sample forecasts. To verify the hypothesis that predictability of Taylor rule fundamentals mainly come from the RER term, I plot dynamic parameters for different specifications of Taylor rule fundamentals and for RER model. Statistical results of out-of-sample performance using Taylor rule fundamentals with and with-

consumption basket, the price of the foreign consumption basket becomes cheaper relative to the domestic consumption basket-i.e. the RER declines. If maintaining inflation stability is the target for domestic and foreign country, the RER can only adjust to shocks through movements in the NER.

out RER term, and also the RER model are presented. To investigate whether different EMEs' exchange rates respond heterogeneously to the macroeconomic fundamentals, I replicate the out-of-sample forecasts exercises made by Galimberti & Moura (2013) using panel error correction regressions[3] and compare with the forecasts results using country-by-country study through individual specifications.

In addition, Morozumi et al. (2020) found that CBI and democracy have interaction effect with IT to help reducing inflation in LICs and EMEs[4]. In other words, IT with high level of CBI/democracy is more effective in reducing inflation. Recall the mechanism generated by Eichenbaum et al. (2021), if the inflation becomes more stable under high level of CBI/democracy, RER is expected to adjust through movements in the NER in a more efficient way. This drives me to investigate whether more significant evidence of predictability with RER exists under high level of CBI/democracy after IT adoption. To study whether CBI and democracy are helpful for IT to reduce the inflation and enhance the RER-NER comovement, I firstly compare the historical inflation during the highest level of CBI/ democracy and the post-IT periods[5]. At last, I compare evidence of predictability under these two periods for currencies in EMEs and LICs.

[3]Forward Taylor rule specifications in their work have not been studied due to the lack of forecasts data in EMEs.

[4]The categorization of countries into different income levels is made by Morozumi et al. (2020) using per capita real GDP in PPP terms (in 2011 international dollars, from IMF's World Economic Outlook) over the 1980-2016 period, which overlaps most times in our study (1989-2021)

[5]Following Morozumi et al. (2020), we use lending restrictions component from Cukierman et al. (1992) index for CBI. As a democracy measurement, we use "xconst" from Polity V which represents institutional constraints on the decision-making powers of chief executives. These variables were shown to have interactive effect with IT in reducing inflation.

For both EMEs and LICs, I find that estimated coefficients on inflation, output gap and lagged interest rate are mostly insignificant after the IT adoption, whereas RER coefficients are significantly negative in most times. Inflation becomes less volatile after the IT adoption. Few evidence of predictability are found when RER is excluded in Taylor rule fundamentals while other specifications with the RER term (including the RER model) present significant evidence in most EMEs and LICs. One implication is that all variables except the RER in Taylor rule fundamentals are not persistently effective in improving forecasting performance. After the IT adoption, the empirical evidence on the RER combining with the stabilized inflation indicate that RER adjusts to shocks overwhelmingly through movements in the NER for IT countries. When comparing the results from individual specification with the outcomes from pooled panel regression, the formal methodology offers superior exchange rate predictability for the EMEs relative to the later one. I think the more efficient estimates of panel regression produced by Galimberti & Moura (2013) come from two aspects. One is the selection of drift random walk as benchmark model, which shows less forecastability than driftless random walk over short-term horizons. Another is the use of forecasts data for inflation and output, which might produce superior forecasting performance but are unavailable in our study. Regarding the superior forecasting ability of individual specifications relative to pooled panel regression in my study, I believe that RER adjusts through movements in NER heterogeneously in EMEs. Following the argument by Morozumi et al. (2020) that lending restriction from central bank to the government helps reducing inflation, I find NER predictability with the RER improved in some extent with stricter lending restrictions under IT framework. For the aspect of democracy, although inflation becomes more stabilized during the max democracy period, I have not found stronger evidence of exchange rate predictability at the same time. The max democracy sample period maybe too short to provide stable estimates of test statistics.

The remainder of paper is organized as follows: Section 4.2 reviews the literature and raises the issues that needs to be emphasized in my research. Section 4.3 discusses estimation equations, forecasting methodology, and the data. Section 4.4 presents our main empirical findings. Section 4.5 concludes this paper.

4.2 Literature review

Guided by the extensive review of exchange rate predictability by Rossi (2013), I firstly highlight some issues in the review that are crucial to motivate my study and include more recent studies on the topic. First, especially in the short horizons exchange rate forecasts, Taylor rule fundamental models offer more significant evidence of predictability relative to the random walk model as well as the other fundamentals such as the uncovered interest rate parity(UIRP), purchasing power parity(PPP) and monetary models. Second, most countries studied in the review are advanced economies, the currencies in EMEs and LICs have not been formally investigated. Since then, a series of works have changed focus to exchange rate predictability in EMEs and used Taylor rule fundamentals as the main predictor following the conclusion inferred from Rossi (2013). Galimberti & Moura (2013) use panel data regression to forecast currencies in EMEs since IT adoption and find strong evidence of predictability with a present-value forward-looking specification. Alba et al. (2015) investigates EMEs with IT regimes using standard OLS rolling regression with country-by-country study and find evidence of out-of-sample predictability in half of the countries. Salisu et al. (2022) focus on BRICS exchange rates and find that fixed effect panel regression provides more significant evidence of predictability than time varying approaches in monthly frequency. Some salient issues still exist in these studies. First, it has not been clear whether panel data regression has superiority in forecasting EME's exchange rates relative to the standard linear regression. Second, from the plots of coefficients in these out-of-sample forecasts, it has not been clear which variable in Taylor rule fundamentals is persistently significant during the forecasts. Third, all these works focus on EMEs but same subject on LICs has not been studied.

As a later research, a new dimension is offered by Eichenbaum et al. (2021) for the macroeconomic fundamentals used as predictor of the NER. Assuming home bias in consumption and IT adoption for both home and foreign countries, their economic model and empirical evidence indicate that RER adjusts to shocks completely through movements in NER. The intuition of mechanism is as follows. Suppose a negative shock to the domestic endowment, the domestic good becomes more expansive. For consumers with home bias and having both domestic and foreign good in their consumption basket, the price of the foreign consumption basket becomes cheaper relative to the domestic consumption basket-i.e. the RER declines. If maintaining inflation stability is the target for both domestic and foreign country, the RER can only adjust to shocks through movements in the NER. Using the RER term, they present significant evidence of medium and long-term out-of-sample predictability of the NER in six advanced economies. For EMEs, although Eichenbaum et al. (2021) showed coefficient estimates for the NER regression with horizons greater than one year, formal out-of-sample tests and RMSE ratio have not been studied.

With respect to the efficiency of IT in reducing inflation, Morozumi et al. (2020) find that both higher level of CBI and democracy can help reducing the inflation under IT framework. Based on the new dimensions offered in this study, we further consider the role of CBI and democracy in exchange rate predictability for EMEs and LICs. Overall, our study incorporates salient features of earlier and later studies on exchange rate predictability, in addition to providing LICs with evidence that has been relatively understudied in this area to date.

4.3 Methodology

Regarding the hypothesis that Taylor rule fundamentals including interest rate, inflation, and output can be predictors of exchange rate movements, we formulate several specifications in the analysis of EMEs and LICs exchange rates. In consistent with the traditional

Taylor (1993) rule, the central bank increases the short-term nominal interest rate when facing higher inflation above its target level and/or output above its potential level. In addition to the simple Taylor rule, which only contains inflation and the output gap, an augmented specification is estimated which adds the interest rate smoothing regarding the possibility that the interest rate adjusts gradually to achieve the rate advised by the rule (see e.g. Clarida et al. (1998))). Furthermore, it is common practice, following Clarida et al. (1998), to include RER in Taylor rule fundamental for foreign countries (assuming US home country). The rationale is that the central bank sets the target level of the exchange rate to be consistent with the long-run PPP. It increases (decreases) the nominal interest rate if the exchange rate depreciates (appreciates) from its PPP value. Thus, combining these extensions together leads to a Taylor rule for foreign country (denoted by *) as following:

$$i_t^* = c + \beta^* \pi_t^* + \gamma^* \bar{y}_t^* + \lambda^* e_t^* + \rho^* i_{t-1}^* + \nu_t. \quad (25)$$

where i_t is the short-term nominal interest rate set by the central bank, π_t is actual inflation, $\bar{y}_t$ is output gap, e_t is the (logarithm) real exchange rate obtained as $e_t = s_t + p_t^* - p_t$, and s_t is the log of nominal spot exchange rate (USD per foreign currency unit), p_t is the log of the price level and ν_t is regression error following Gaussian distribution.

From the view of policy making for exchange rates (see Molodtsova et al. (2008); Galimberti & Moura (2013); and Salisu et al. (2022)), both the home and the foreign central banks make interest rate decisions through Taylor rule, and therefore focus on inflation and output deviations from their target level. An equation for interest rate differential is therefore constructed by subtracting the Taylor rule for the foreign country from that for the U.S.:

$$i_t - i_t^* = \alpha + \beta\pi_t - \beta^*\pi_t^* + \gamma\bar{y}_t - \gamma^*\bar{y}_t^* + \lambda^* e_t^* + \rho i_{t-1} - \rho^* i_{t-1}^* + \eta_t \quad (26)$$

Following Engel & West (2005), this equation holds even if U.S. sets the exchange rates target. Suppose UIRP holds without expected values, we have

$$s_{t+1} = s_t - (i_t - i_t^*). \quad (27)$$

By substituting equation (26) into (27), if we also assume that home and foreign countries share same coefficients in their Taylor rules, then a homogeneous specification of Taylor rule fundamentals with real exchange rate is shown as:

$$s_t = s_{t-1} + \alpha + \gamma_\pi(\pi_{t-1} - \pi_{t-1}^*) + \gamma_y(\bar{y}_{t-1} - \bar{y}_{t-1}^*) + \gamma_e e_t^* + \gamma_i(i_{t-2} - i_{t-2}^*) + \epsilon_t \quad (28)$$

We will call Equation (28) the homogeneous/asymmetric Taylor model (TAsy-hom.). When real exchange rate e_t^* is not included in the Taylor rule, this becomes same as the homogeneous finite-difference Taylor (FDT-hom.) model used by Galimberti & Moura (2013). If we instead assume that home and foreign Taylor rules do not share same coefficients, then the equation becomes

$$s_t = s_{t-1} + \alpha + \gamma_\pi\pi_{t-1} - \gamma_\pi^* \pi_{t-1}^* + \gamma_y\bar{y}_{t-1} - \gamma_y^*\bar{y}_{t-1}^* + \gamma_e e_t^* + \gamma_i i_{t-2} - \gamma_i^* i_{t-2}^* + \epsilon_t. \quad (29)$$

Equation (29) is called the heterogeneous/asymmetric Taylor model (TAsy-het.). The specification when excluding real exchange rate in this model is same as the heterogeneous finite-difference Taylor(FDT-het.) model used by Galimberti and Moura.

Before introducing second type of macroeconomic fundamental used for exchange rate forecast, RER for any foreign country relative to the home country can be expressed as

$$RER_t = \frac{NER_t P_t^*}{P_t}, \tag{30}$$

From Eichenbaum et al. (2021)'s hypothesis, RER would not adjust to shocks through changes in relative prices since both home and foreign central banks maintain their inflation target through Taylor rules. Further assuming that consumers have home bias in consumption, the RER would adjust back to its mean-reverting level overwhelmingly through movements in NER. Consequently, Eichenbaum et al. (2021) use the following regression (with constant) to forecast the NER:

$$s_t = s_{t-1} + \alpha^{NER} + \beta^{NER} e_{t-1} + \epsilon_t^{NER} \tag{31}$$

where same symbols as in Taylor rule fundamentals are used to represent logarithm of RER (denoted as e_t) and NER (denoted as s_t). Equation (31) is called RER (RealE.) model.

As previously noted, we intend to replicate the EMEs exchange rate forecasts made by Galimberti & Moura (2013), who use a fixed-effect panel error correction model (ECM). The ECM methodology composes two steps. First, estimating the coefficients and therefore obtaining the fitted values for (long-run) empirical specifications discussed above. Second, using the fitted values from the previous step to form an ECM. Through estimation of each ECM, forecasts from the fundamentals are calculated[6].

In the first step, a panel data specification is used for all exchange rate models discussed above (Tasy, FDT, RealE). All of the models presented above (i.e., Equations (28), (29) and (31)) can be nested into a fixed effect panel model as follows:

$$s_{it} = \mu_i + X_{it}'\beta + \nu_{it} \quad i = 1, 2, ...N_t \quad t = 1, 2, .., T. \tag{32}$$

where $N_t \leq N = 14$ is the number of countries observed at time t and N is total number of EMEs in our study. X_{it} is the vector of macro fundamentals , and β are associated coefficients, μ_i is country i specific fixed effect, the disturbance error ν_{it} follows Gaussian distribution.

Using pooled panel-data estimation with Equation (32) for each macro fundamental model, we obtain the implied fundamental value of the exchange rate for each country. This is the fitted value for s_{it} shown as:

$$\hat{s}_{it} = \hat{\mu}_i + X_{it}'\hat{\beta} \quad i = 1, 2, ...N \quad t = 1, 2, .., T. \tag{33}$$

[6] We use a panel data toolbox for MATLAB developed by Álvarez et al. (2017) for fixed-effect panel regression estimations in both steps.

In the second step, a pooled panel-data ECM is estimated using the following regression:

$$s_{i,t+k} - s_{it} = \alpha_{ik} + \phi_k(\hat{s}_{it} - s_{it}) + \nu_{it}. \tag{34}$$

For each country, estimated coefficients of Equation (34) are used to forecast future values of NER ($s_{i,t+k}$) for $k = 1, 6, 12$ months ahead. A precise estimation of ϕ_k ascertains the NER converges back to its fundamental value. In Galimberti and Moura's study, they also use ECM on a country-by-country basis (i.e. ϕ_{ik}) for the second step. In this paper, we aims to draw an conclusion about whether the EMEs exchange rates behave homogeneously or heterogeneously to the macroeconomic fundamentals. Assuming homogeneity, pooled panel-data regression should also be used in the second step. Suppose heterogeneity across EMEs, exchange rates are forecasted using a linear regression of individual country for comparative purpose. In that case, we use OLS rolling window estimation of equations (28), (29) and (31) and forecast the future NERs. As we forecast not only 1 month but also 6 and 12 months ahead, the left-hand side of equations are therefore changed from s_{it} to $s_{i,t-1+k}$ with $k = 1, 6, 12$.

4.3.1 Forecast implementation and evaluation

We employ monthly data on exchange rates, inflation, price level, output, interest rate for the EMEs, LICs and the United States (US). The data coverage for the whole sample periods of various macroeconomic fundamentals model and dates for IT are summarized in Tables 12 from Appendix E. In Table 12, IT adoption dates are based on the year of loose-IT from Morozumi et al. (2020). We then find the specific month of IT adoption and transform them into monthly frequency. We use loose-IT rather than strict-IT dates because more EMEs and LICs experienced stabilized inflation immediately after the former dates in our study. Beginning and end dates for Taylor rule and RER model are based on the longest available data for each macroeconomic variable. In most EMEs and LICs, the time period when RER and NER coexist is much longer than the period when all variables for Taylor rule fundamentals exist. This leads to a much larger sample size when forecasting NER using RER model. As the output data for Armenia and Moldova are only available in yearly frequency, we have to exclude them during the exchange rate forecasts with Taylor rule fundamentals.

To fully replicate the work by Galimberti & Moura (2013), an unbalanced panel of monthly data for all EMEs is used from January 1995 to December 2021 no matter forecasting NER with Taylor rule or RER model. Similarly, we initiate the estimation with 60-month rolling window (i.e. from January 1995 to Dec 1999) for Equation (32) and obtain the fitted values as in Equation (33). We then obtain the estimated coefficients in the pooled panel-data ECM(Equation (34)) with the error correction over last period, to produce the forecast of one, six and twelve months ahead NER. Based on rolling regressions method, we then drop the first observation (January 1995) and include one more observation at the end (January 2000) i.e. keeping the 60-month rolling window constant, and repeat the above procedure until the end of whole sample. In Galimberti &

Moura (2013)'s work, they mainly compare the forecasting accuracy of macroeconomic fundamentals model with the drift random walk shown as:

$$s^{rw}_{i,t+k} = \alpha_i + s_{it}, \quad i = 1, 2, .., N_t \quad t = 1, 2, ..., T. \tag{35}$$

where α_i can be treated as fixed effect for country i. We also compare the forecasting precision of macro fundamentals model with driftless RW; driftless RW v.s. drift RW. These comparisons help us to explain in what circumstances there exists evidence of NER predictability for Taylor rule models. For single-country linear regression, we use both 60- and 36-month rolling window estimation during the forecasts. The use of another shorter window is not just for robustness but also for plots of parameter shifts. Model parameters estimated by a shorter length of window can better reflect the changes of NER responses in presence of parameter instabilities. We use three measures for forecast evaluation including Theil's U ratio, CW statistics and DMW statistics. Theil's U ratio is calculated as the ratio of root mean squared forecast error of one model relative to the other one. If the ratio is below the unity, the former model is considered to be more precise than the later one. CW statistic is used to test whether variables in the larger or full model are jointly significant relative to the benchmark model (drift or driftless random walk). DMW statistic is used to test whether one model has significantly better forecasts accuracy than the other one. Over the three measurements, DMW statistic is the most strict test to have null rejections. Furthermore, we based our test results on a 1 %

level of significance which is a much tougher standard than previous studies[8].

4.3.2 Data sources

We use monthly data spanning 1980:01–2021:12. Exchange rates are end-of-month values of the national currencies relative to the U.S. dollar for the following EMEs: Brazil, Chile, Colombia, Dominican Rep, Hungary, Mexico, Poland, Romania, Russian Federation, Serbia, Slovak Republic, South Africa, Thailand and Turkey, and for the following LICs: Albania, Armenia, Georgia, Ghana, Guatemala, Indonesia, Moldova, Paraguay, Peru, Philippiness and Uganda. Most data are accessed from the International Financial Statistics (IFS) database by IMF and Federal Reserve Economic Data (FRED) by St. Louis Fed. All data are measured in monthly frequency. In the IFS database, twelve month percentage change of consumer price index(CPI) is used as proxy for actual inflation. The level of CPI index is used to calculate real exchange rate. To have the longest data availability, manufacturing industrial production index(IPM) is used as proxy of output level for Chile, Colombia, Dominican Rep, South Africa, Guatemala, Indonesia, Peru, Philippines and Uganda. Monthly data for output level are not available for Thailand, Albania, Georgia. We use quarterly IPM into the monthly frequency instead. Composite index nominal growth accessed from central bank is used in Ghana. For the rest EMEs, Paraguay and the U.S., total industrial production index(IPT) is used. Output data for Armenia

[8] Galimberti & Moura (2013) and Salisu et al. (2022) use 10% level of significance for the decision of tests. Alba et al. (2015) use 5% level of significance.

and Moldova are unavailable for monthly/quarterly frequency. CPI level and IPM/IPT are seasonally adjusted by taking the equally weighted average over current and previous eleven months. Output gap is obtained using quadratically detrending method. Except Slovak Republic, we use so called monetary policy-related interest rate in IFS for most EMEs, LICs and the U.S.. Regarding the zero lower bound after the GFC, Wu & Xia (2016)'s shadow rates are used for the US from Jan 2009 to Sep 2015. For the Slovak Rep, 3-month interbank rate (from FRED) and Euro dollar/USD exchange rate (after Jan 2009) are used regarding the entry of Eurosystem.

4.4 Results

4.4.1 Individual v.s. panel regression

Here, we display the results of the EMEs exchange rate forecast performance from the single-country linear and the Fixed Effect Pooled Panel regressions, conditioned on four different Taylor rule specifications and the RER model; The first and second forms have homogeneous/heterogeneous coefficients and no RER (i.e. FDT-hom/ FDT-het), which are also the constructs studied by Galimberti & Moura (2013). The third and fourth Taylor rules are defined as having homogeneous/heterogeneous coefficients and RER term (TAsy-hom/TAsy-het). The forecasts performance of the single-country linear and fixed effect pooled panel regression models are studied in comparison with the driftless RW model, where we treat a model better than the driftless RW if more than half of the countries show outperformance. More specifically, superior predictability is based on the Theil's U ratio less than unity and rejection of CW test at 1% level in at least half of the currencies. Superior forecastability is based on the Theil's U ratio less than unity and rejection of DMW test at 1% level in at least half of the currencies [10]. We consider three out-of-sample forecast horizons - 1, 6 and 12, where the 1 month is considered as short out-of-sample horizon, while the other two (6 and 12) are considered as longer out-of-sample horizons. The DMW test results are presented in figure 16 (Table 13 in Appendix E presents also Theil's U and CW test outcomes),

Figure 16 displays the evidence of out-of-sample exchange rate forecasts for the four earlier defined Taylor rule fundamentals and the RER estimated using the single regression and the fixed effect panel regression, in comparison with the driftless random walk model. The first word of label indicates the regression method used (single v.s. panel regression). Second word indicates sample period studied (full sample v..s. post-IT period). Third word indicates out-of-sample horizons studied (1, 6 or 12 months ahead). For example, the bars labeled "Single-Post-12" indiates number of countries having significant evidece of forecastability using single regression for 12-month ahead out-of-sample forecasts after the IT. Dark blue, Orange bars associate with Taylor rule models without the RER term (FDI-hom, FDT-het). Grey and yellow bars represents Taylor rule models with the RER term(Tasy-hom, Tasy-het). Light blue bar indicates the

[10] Predictability test such as CW test is to investigate whether the coefficients in a model are jointly significantly different from zero in explaining future exchange rate return. Forecastability test such as DMW test is to test wether one model produces more precise forecast than the benchmark model.(see discussion of Rogoff & Stavrakeva (2008))

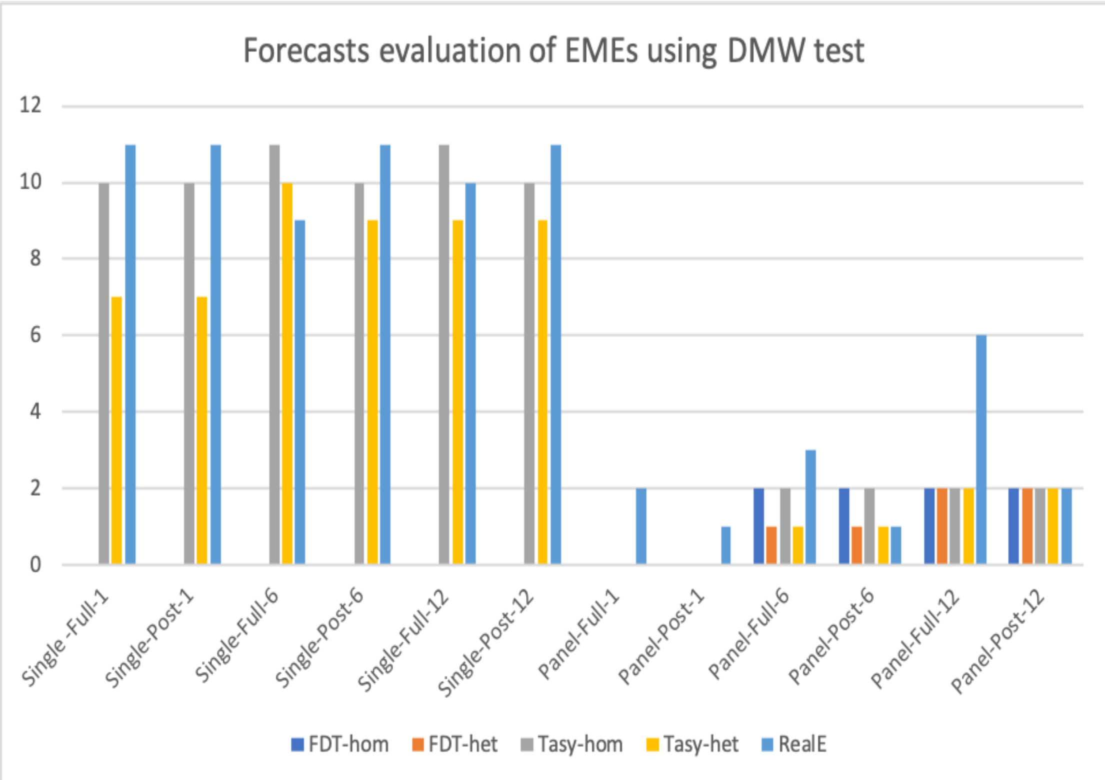


Figure 16: This figure presents number of countries having DMW test rejection results significant at 1 percent level. The first word of name indicates the regression method used (single v.s. panel regression). Second word indicates sample period studied (full sample v..s. post-IT period). Third word indicates out-of-sample horizons studied (1, 6 or 12 months ahead). For example, the bars labeled "Single-Post-12" indiates number of countries having significant evidece of forecastability using individual regression for 12-month ahead out-of-sample forecasts. The forecastability for EMEs with four different Taylor rule constrcuts (FDT-hom, FDT-het, Tasy-hom, Tasy-het) and real exchange rate (RealE) model are reported. Each bar represents one type of macro fundamental model.

RER model (RealE). We report the number of countries with outperformance under each model, horizon and sample. Test statistics for the individual countries are available upon request. Following the single regression results under the full sample period, we find the regression conditioned on Taylor rule models with RER (TAsy_hom and TAsy_het) outperform the driftless RW over 1, 6 and 12 months forecast horizons, with DMW test rejected results significant at 1% level in more than half the EMEs currencies. However, evidence of outperformance becomes insignificant once the RER is excluded in the Taylor rule models (FDT_hom and FDT_het) with none of forecast performances is significant in any countries across any forecast horizons. The most robust evidence of short-horizon out-of-sample forecastability is found in RER model (RealE.) with single regression (see light blue bars labeled single-full-1, 6, 12), where 11 out of 14 countries present null hypothesis rejected results for one-month-ahead forecast based on DMW test in 1% significance level.

The outperformance of the individual regression condition on the Taylor rule with RER or the RER alone, is consistent across full and post-IT periods, with outperformance in forecastability over the driftless RW in all forecast horizons for both periods. For RER model, there appears a relative increase of number of countries with rejection results significant at 1% level based on the DMW tests after IT adoption (e.g. Single-full-12 v.s. Single-post-12 in figure 16). This implies an improvement of forecasting performance using RER model in some extent over the post-IT sub-sample. Following Galimberti & Moura (2013)'s pooled-panel estimation , post-IT period starts from January 1995 which is a date much earlier than the beginning of sample for any EMEs in Taylor models. This leads to same sample for Taylor rule models (FDT-hom; FDT-het; Tasy-hom; Tasy-het) regardless the full or post-IT period when estimated by panel regression. The results from the fixed effect panel regression are not as good as those of the single regression. No matter for Taylor rule or RER model, fewer countries have outperformance in forecastabiity relative to single regression. Among the cases of out-of-sample forecastability over the driftless RW, single regression is statistically preferred over the fixed effect panel regression. This can be seen from the length of bars labeled with 'Single-' relative to the ones labeld with 'Panel-'.

The relatively worse forecasts performance of fixed effect panel regression raises a question about why significant evidence of outperformance is found in this type of regression over previous studies such as Galimberti and Moura(2013). We further investigate the forecasts outcomes using fixed effect panel regression by comparing the results with drift RW (as in Galiberti and Moura) and also comparing the drift with driftless random walk (see Figure 17 and Table 14 in Appendix). In Figure 17, the first word of label indicates the evalution method(Theil's U or CW test). Second word indicates the out-of-sample horizon studied (1, 6 ,12). For example, 'U-12' indicates number of countries having Theil's U ratio <1 for 12-month ahead forecasts. We find that significant evidence of 12-month ahead out-of-sample predictability for the panel regression conditioned on Taylor rule models, with Theil's U ratio less than unity, CW test rejected

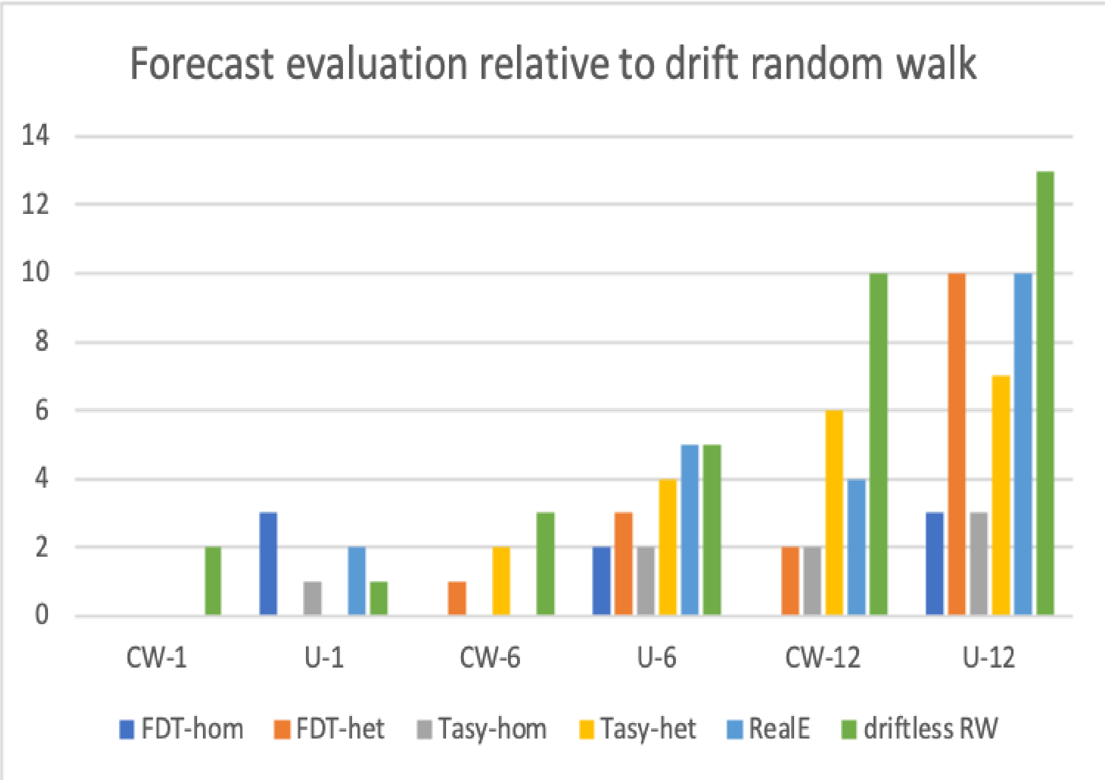


Figure 17: This figure presents number of EMEs having significant evidence of out-of-sample performance relative to drift random walk(RW) using fixed effect panel regression method after the inflation targeting. Theil's U ratio <1 and CW test rejected results significant at 1 percent level are used. The first word of name indicates the evalution method(U or CW). Second word indicates the out-of-sample horizon studied (1, 6 ,12). For exmaple, 'U-12' indicates number of countries having U ratio <1 for 12-month ahead forecasts. Each of the four different Taylor rule constrcuts, real exchange rate model, driftless RW is compared with the drift RW. Each bar represents evaluation outcomes for one type of macro fundamental model

results significant at 1% level in more than half the EMEs currencies. Comparing drift with driftless RW, the drift RW also outperform the driftless RW in exchange rate predictability over 12 months forecast horizon. These evidence support that drift RW model seems harder to beat as a benchmark model over longer out-of-sample horizon. This helps explain worse predictability over longer-term forecasts horizons when Galimberti and Moura use drift RW as benchmark. What's more, the other Taylor rule constructs (e.g. PVT; FDFT) in their study use forecasted inflation and output gaps, which might provide more valuable forecasts information but unavailable in our study.

4.4.2 IT and real exchange rate model results

Given the observed out-of-sample predictability and forecastability for EMEs using individual regression, we proceed to expand our study to include currencies in both EMEs and LICs (see Figure 18 and Table 15 in Appendix). There are two general findings across the two income groups. First, only when RER is included in the Taylor rule(TAsy.model) or RER model (RealE.) is used, outperformance in out-of-sample forecastability is found in both periods, with the DMW test results significant at 1% level in more than half the EMEs/LICs currencies. Second, the out-of-sample forecastability is found for LICs only when the RER model is used and IT regime is adopted. This is evidenced by the number of LICs in which the DMW statistics indicate significance at 1% level (see blue bars labeled LIC-Post-1, 6, 12). It makes us to conclude that the RER

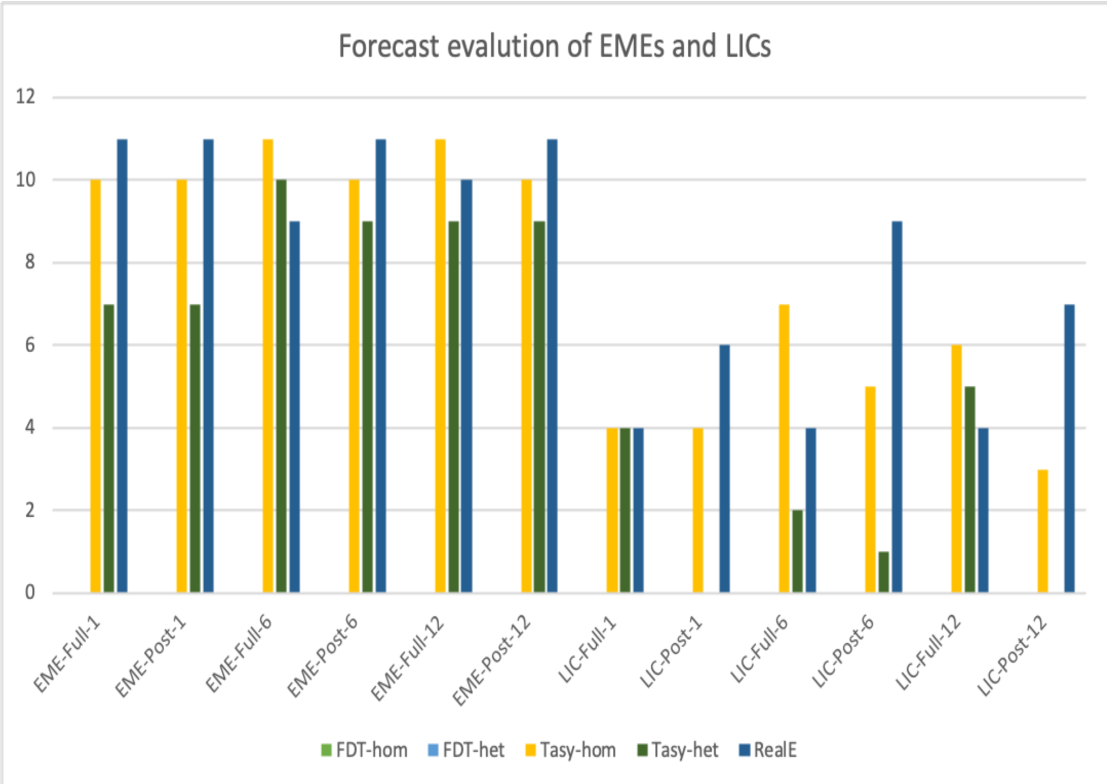


Figure 18: This figure reports number of EMEs and LICs having DMW test rejection results significant at 1 percent level using individual regression. The first word of name indicates the country group studied (EME or LIC). Second word indicates the period studied (full or post-IT). Third word indicates the out-of-sample horizons studied. Four different Taylor rule constructs and real exchange rate model are studied. Each bar represents number of countries having test significant results using one type of macro fundamental model.

model contributes to an increase in forecasts performance for both EMEs and LICs after the IT adoption.

To further verify Eichenbaum et al. (2021)'s hypothesis that RER adjusts to shocks overwhelmingly through movements in NER, all EMEs and LICs' inflation behaviour and dynamic responses of exchange rates toward macroeconomic variables will be presented in the following. Figures 19 and 20 display annual inflation measured by 12-months growth of CPI index in EMEs and LICs , with the red vertical lines indicating dates of IT-adoption. Note that for Brazil, Chile, Colombia, Dominican Rep, Hungary Mexico, Poland, Romania, Serbia, Thailand and Turkey, there is a very large spike in inflation before the IT adoption, and then becomes more stabilized after the IT. Similar pattern can also be seen in LICs including Ghana, Indonesia, Moldova, Paraguay, Peru and Uganda. The assumption of RER-NER comovement that inflation are relatively stable in IT countries are evidenced by above figures, with at least half of the EMEs and LICs have more stable inflation after the IT.

Given the superior out-of-sample forecasting performance of the individual regression model over the RW in most EMEs and LICs, we consequently report the estimation of dynamic coefficients on macroeconomic variables from the Taylor rule and RER models corresponding to each of the EMEs and LICs. The model parameters estimated include inflation differential, output gap differential and interest rate differential from the FDT_hom model; US inflation, foreign inflation, U.S. output gap, foreign output gap, U.S. interest rate and foreign interest rate from the FDT_het model; RER from the

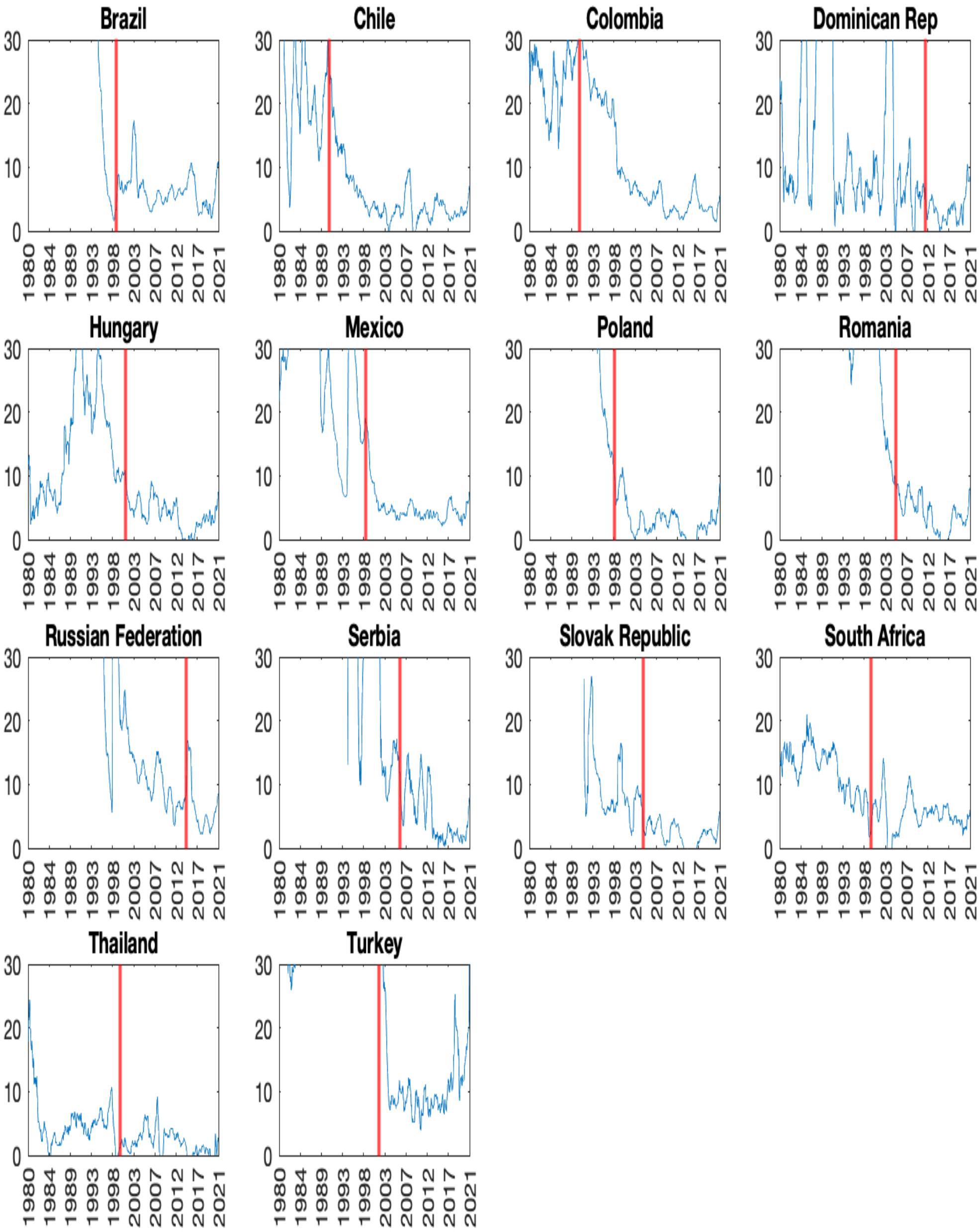


Figure 19: inflation and IT adoption (red line) in EMEs

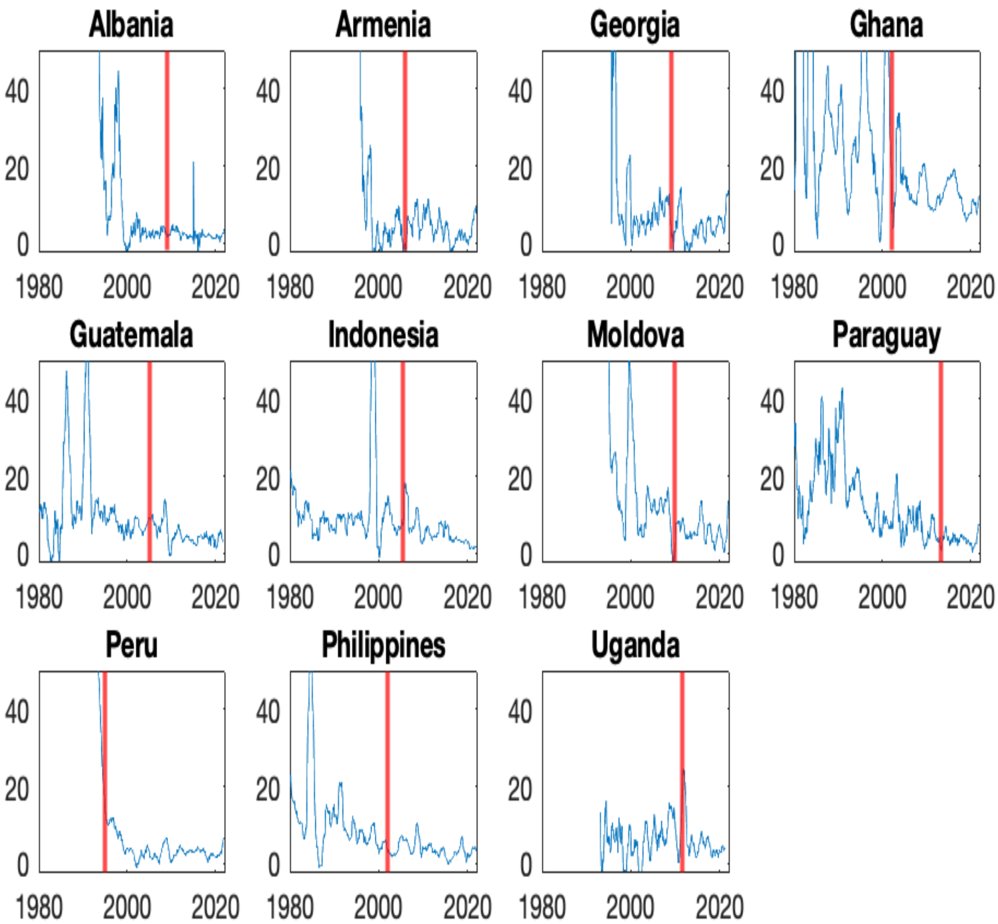


Figure 20: Inflation and IT adoption date (red line) in LICs

RealE model. The parameters are estimated with 36-month rolling window at each time period when a new observation is included in the sample. Since the beginning of data is different for each EME or LIC, dynamic estimation starts at different times (see Table 12 in Appendix E). In the plots of parameters from FDT_hom model (Figures 33 to 38 in Appendix E), although some parameters are significant in several countries over a short period of time(e.g. inflation differential(Philippines), output gap differential(Slovak), interest rate differential(Russia)), we cannot find any parameters in FDT_hom model which are significant or having a clear trend over most of the sample period. For the parameters from FDT_het model (Figures 39 to 46 in Appendix E), estimated parameters in some individual countries are significant over a short period(e.g. interest rate (Russia), US interest rate (Dominica), US interest rate(Paraguay)). Regardless of the country, no parameters are persistently significant or having clear sign over the sample. Things become change when focusing on the estimated coefficients on RER in RealE model (Figures 21 and 22.). In all 14 EMEs and 11 LICs, RER parameters are significant and negative over most of the period. Before the IT adoption(vertical line), there exists time periods when parameters are insignificantly different from zero in more than half number of EMEs and LICs. After the IT, only Colombia, Dominica, Slovak, Ghana, Armenia still have several time points with insignificant parameters. In other words, 11 out of 14 EMEs and 9 out of 11 LICs present significantly negative coefficients on RER over whole post-IT period. On the one hand, the significance of results indicates that RER takes vital role in forecasting NER relative to other macroeconomic variables. On the other hand, the persistently negative sign of parameter(i.e. β^{NER} in Equation 31) indicates that NER moves in an opposite direction to the changes in RER in order to reestablish long run PPP. The persistently significant and negative parameters of RER in most countries hold over 6 and 12 months forecast horizons(Figures 23 to 26). This implies that the NER takes effect to restore the RER back to its mean reverting level over one-year horizon at least.

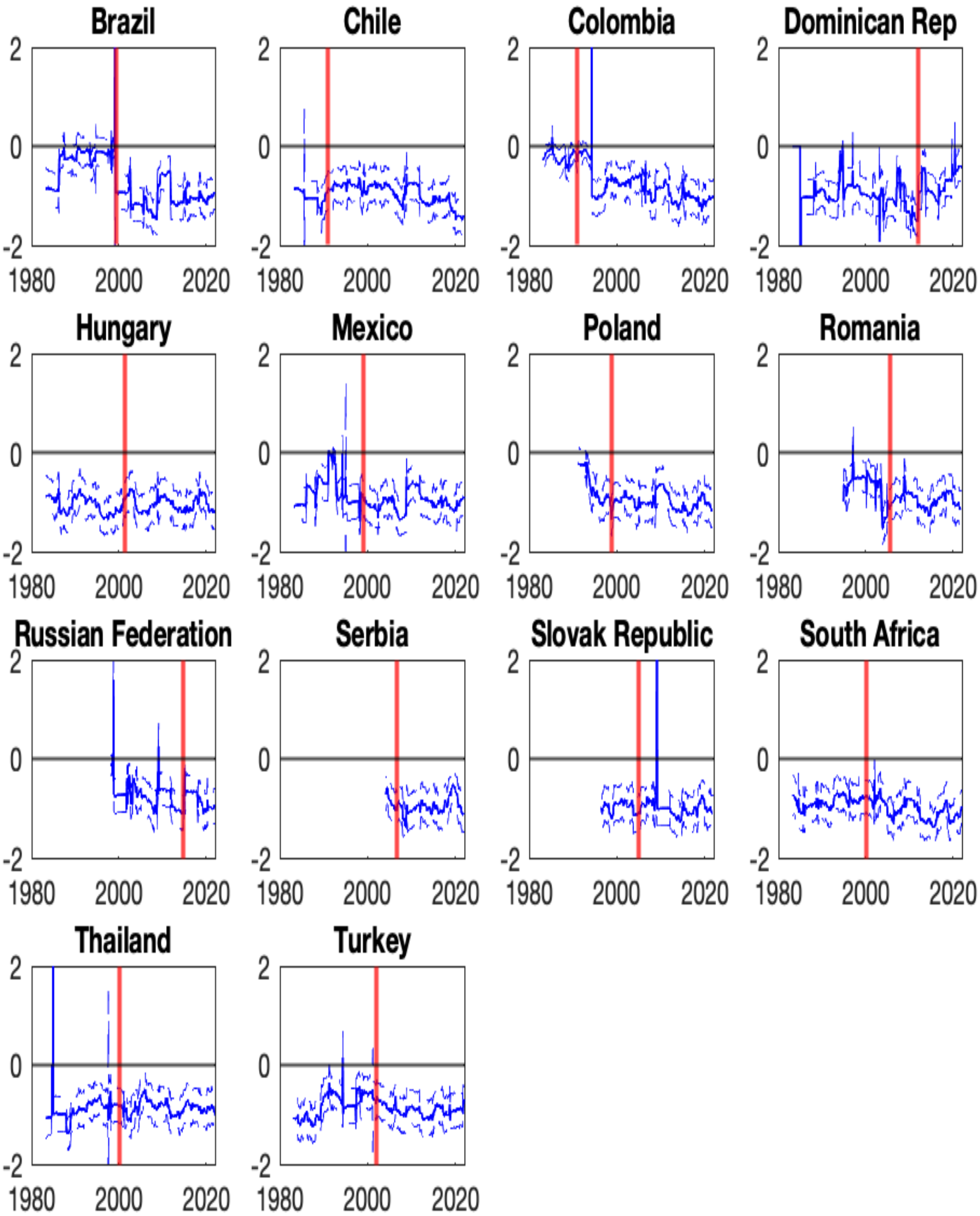


Figure 21: RER (EME) 1-month ahead

Notes:This figure presents dynamic coefficient estimation for real exchange rate in RER based model from 1980 to 2021 in 14 EMEs during 1-month ahead forecasts. Since the beginning of data is different for each EME, dynamic estimation starts at different times (see Table 12 in Appendix E). Solid line is the estimated coefficient along the time. Red vertical line is IT adoption dates. X-axis shows time points. Y-axis represents value of estimated coefficients.. Dashed lines are upper and lower bounds for 95% confidence interval of the estimated coefficient. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. In this figure, most EMEs have persistently negative and significant coefficient for RER.

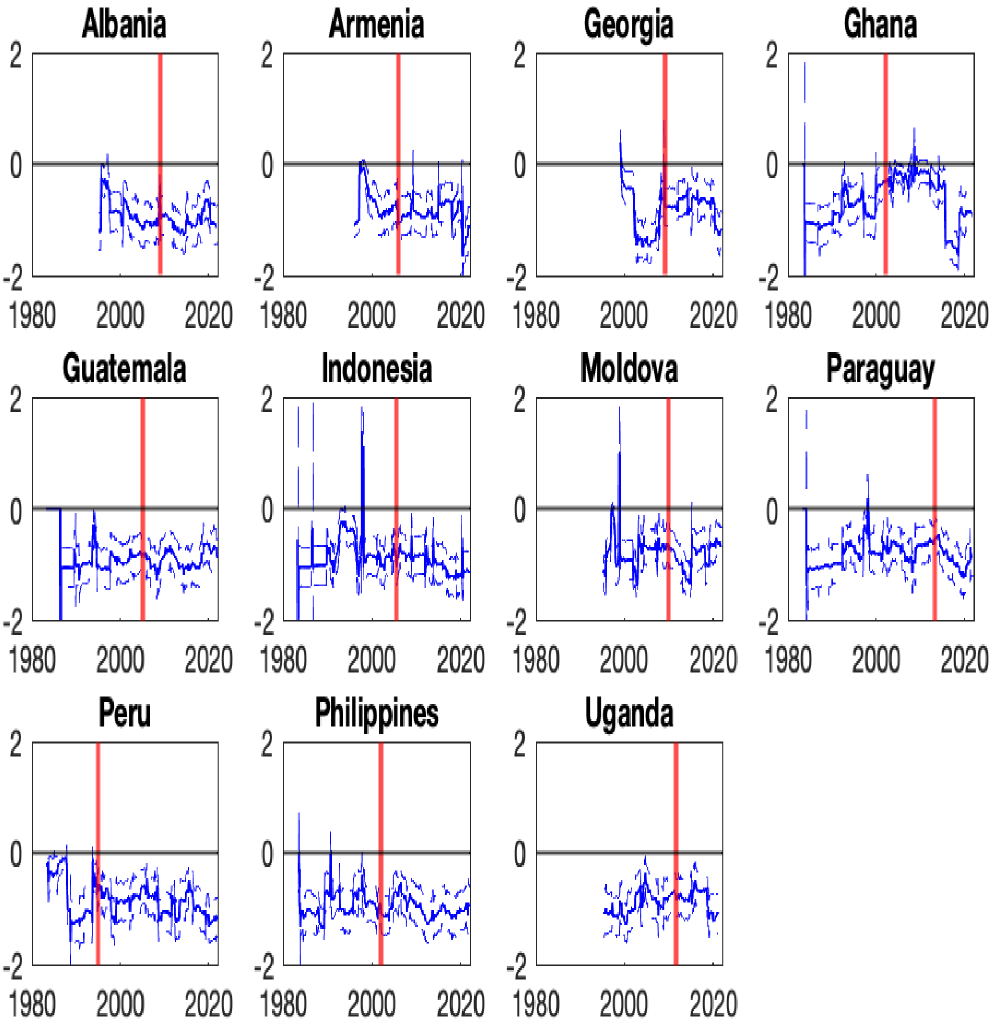


Figure 22: RER (LIC) 1-month ahead

Notes:This figure presents dynamic coefficient estimation for real exchange rate in RER based model from 1980 to 2021 in 11 LICs during one month ahead forecasts. Since the beginning of data is different for each LIC, dynamic estimation starts at different times (see Table 12 in Appendix E). Also see notes in figure 21.

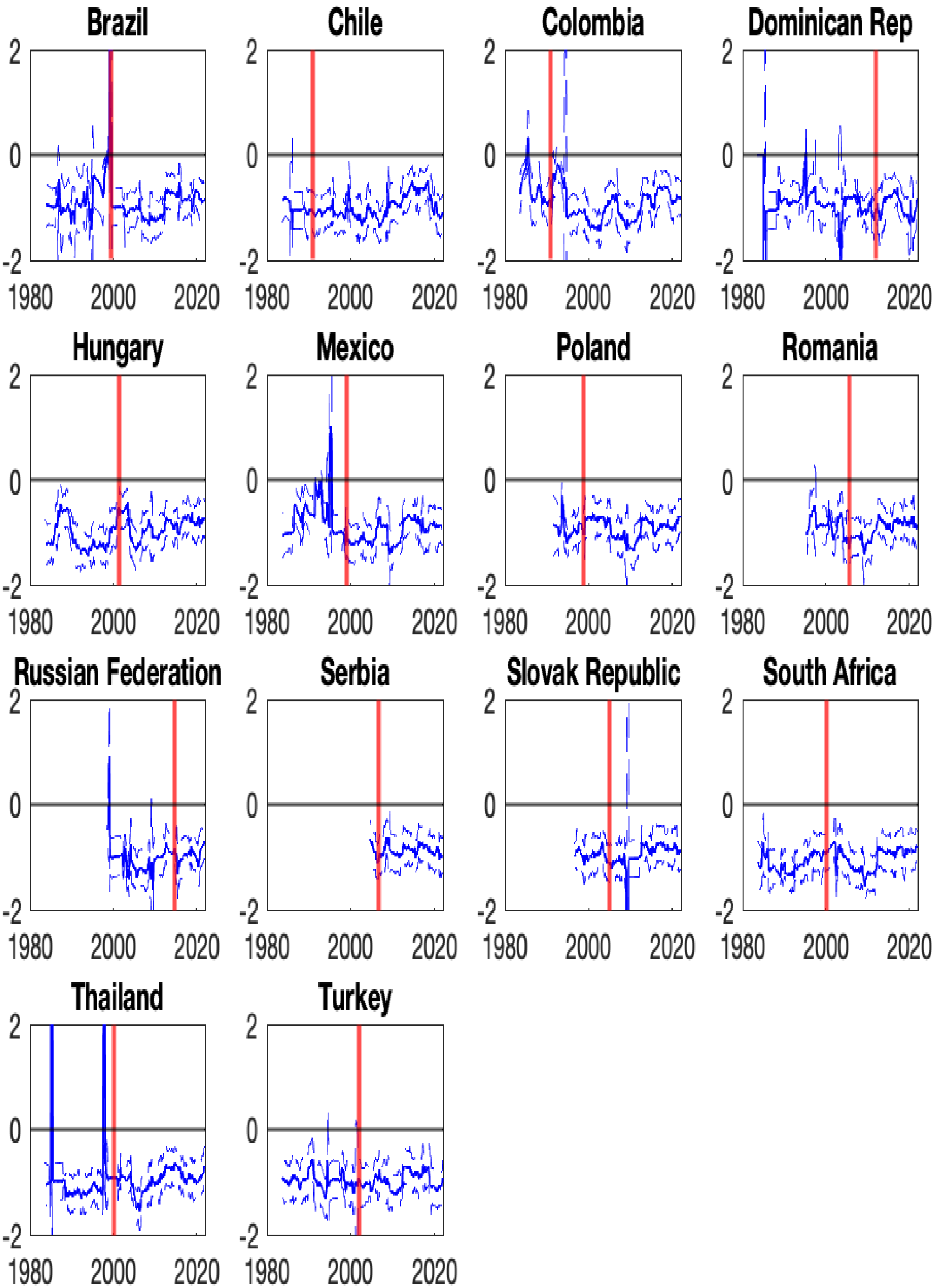


Figure 23: RER (EME) 6-month ahead

Notes:This figure presents dynamic coefficient estimation for real exchange rate in RER based model from 1980 to 2021 in 14 EMEs during six month ahead forecasts. Also see notes in figure 21.

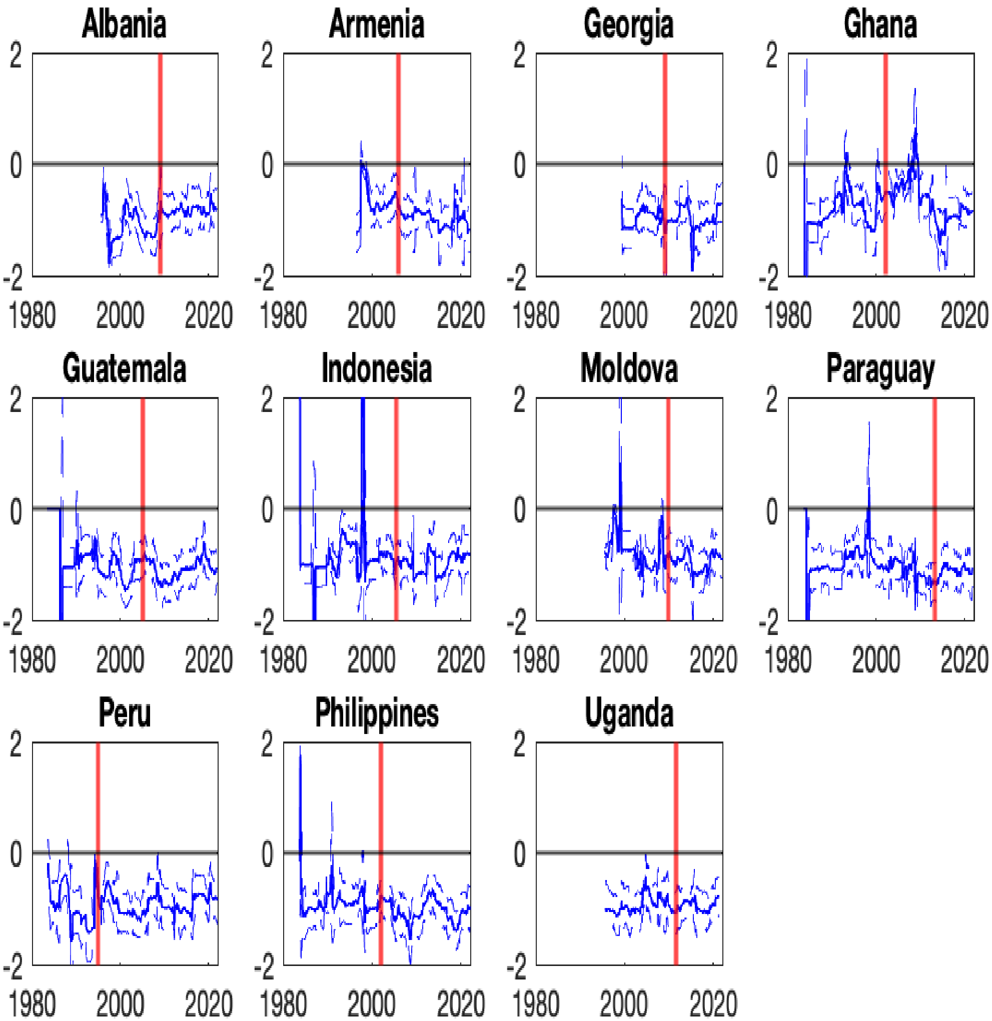


Figure 24: RER (LIC) 6-month ahead

Notes:This figure presents dynamic coefficient estimation for real exchange rate in RER based model from 1980 to 2021 in 11 LICs during six month ahead forecasts. Also see notes in figure 21.

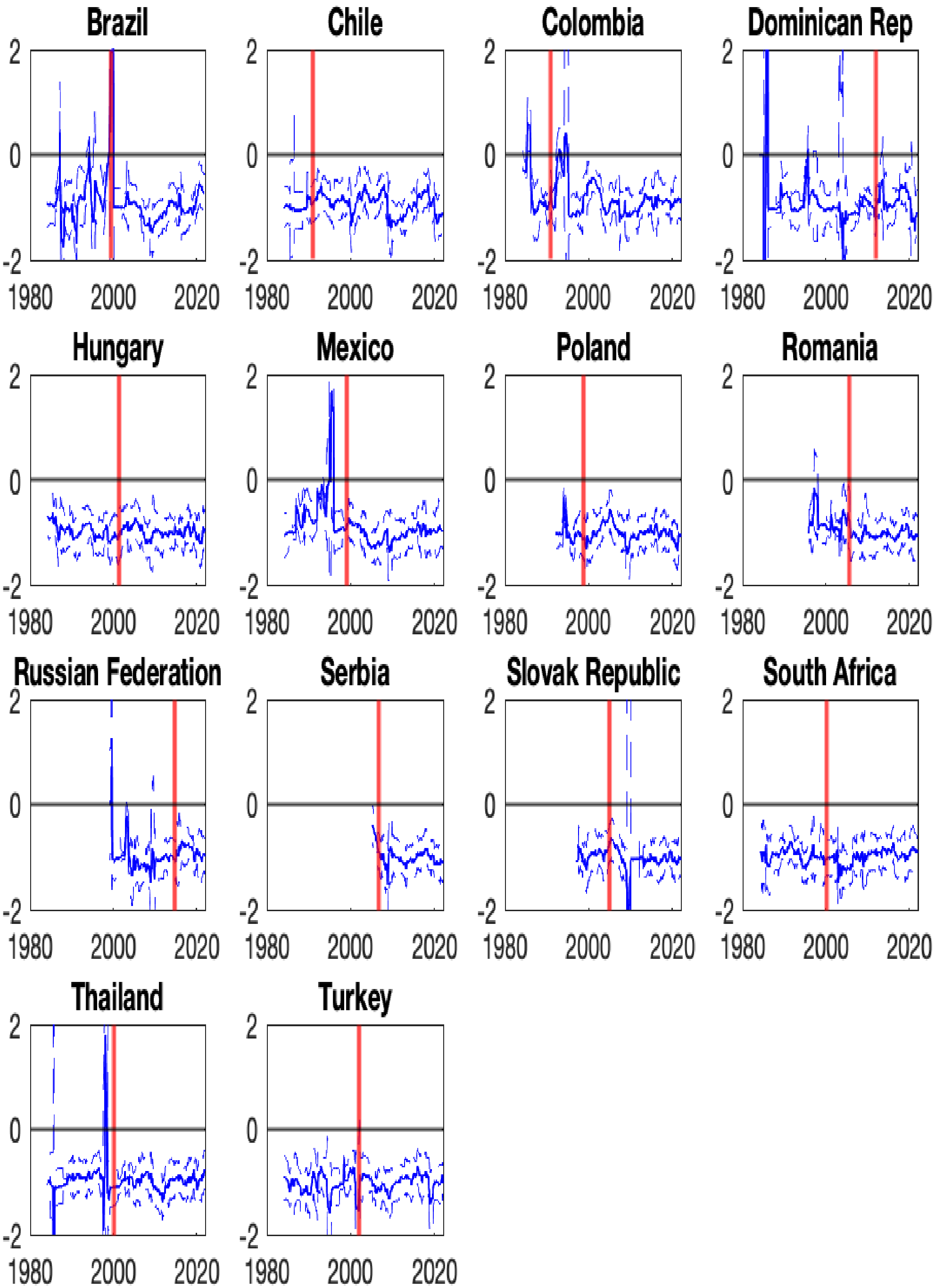


Figure 25: RER (EME) 12-month ahead

Notes:This figure presents dynamic coefficient estimation for real exchange rate in RER based model from 1980 to 2021 in 14 EMEs during twelve month ahead forecasts. Also see notes in figure 21.

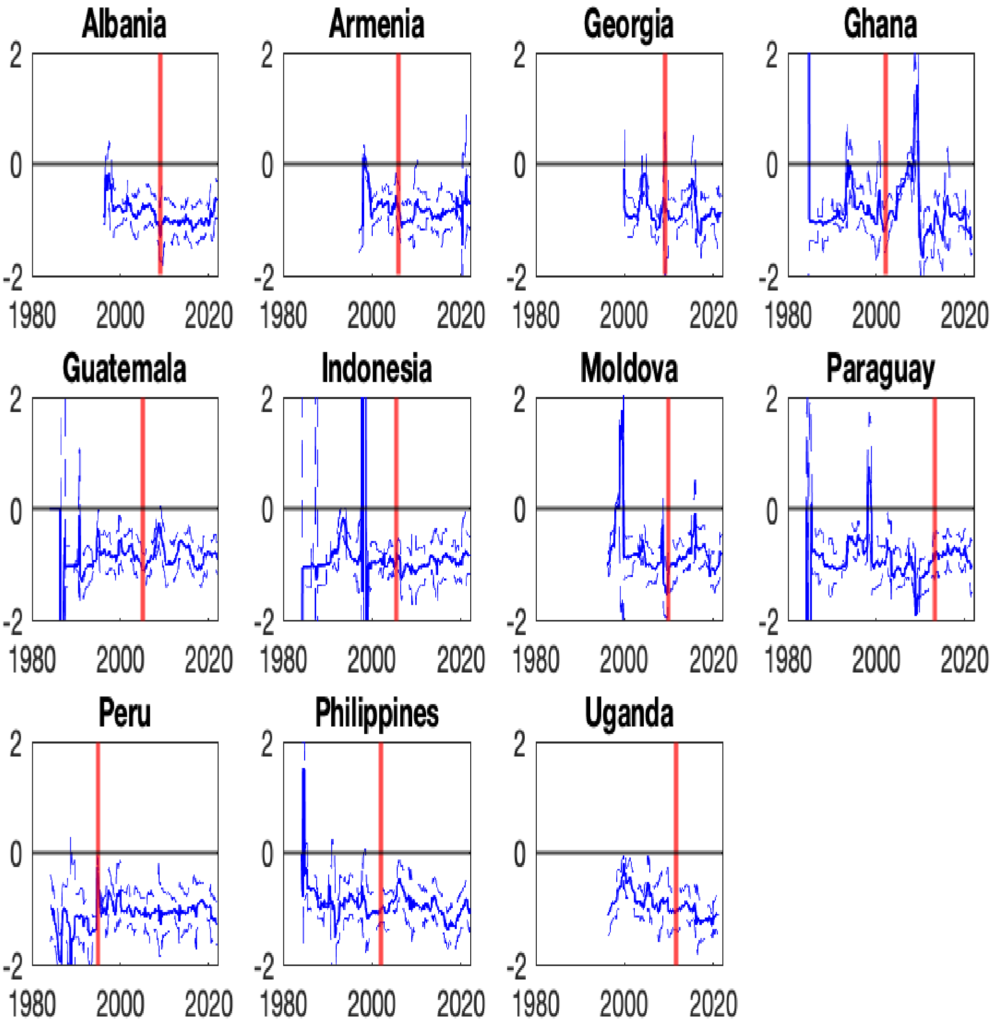


Figure 26: RER (LIC) 12-month ahead

Notes:This figure presents dynamic coefficient estimation for real exchange rate in RER based model from 1980 to 2021 in 11 LICs during twelve month ahead forecasts. Also see notes in figure 21.

4.4.3 The role of CBI

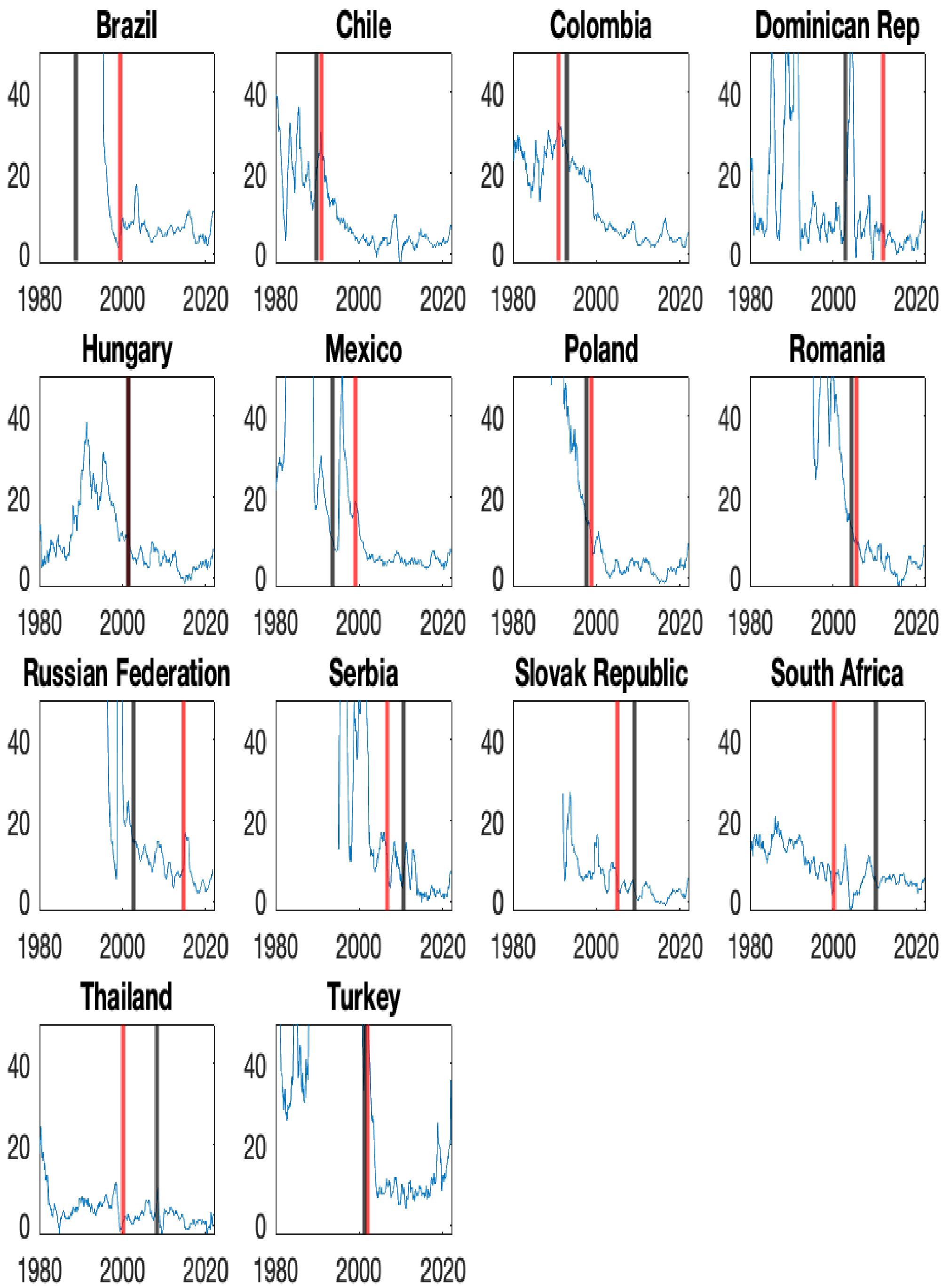


Figure 27: Inflation, IT adoption date(red line) and CBI date (black line) in EMEs

When investigating IT efficiency in reducing inflation in LICs and EMEs, Morozumi et al. (2020) shows that high level of CBI is helpful for IT in reducing inflation especially during stricter restrictions on lending from central bank to the government. Regarding the hypothesis of NER-RER comovements, if there exists a higher efficiency of IT in reducing inflation, the effects of NER in offsetting initial movements in RER should be more obvious [11]. Following this hypothesis, we now study whether higher level of CBI contributes to stronger evidence of out-of-sample predictability of NER using RER. Table 16 summarizes the time period when individual country has maximum level of CBI (measured by lending restriction from central bank to government based on Cukierman et al. (1992)'s index) and the period when each country has highest level of democracy (measured by constraints on decision making power of chief executive based on Polity V). The former index is calculated by Garriga (2016) while later one is calculated by Marshall (2020), both of which are measured in yearly frequency. According to Morozumi et al. (2020), these components have significant effect in interacting with IT in reducing inflation in LICs and EMEs. We further look up the events and associated months causing the shifts of the components[12] and therefore ascertains the month and year with maximum index level. To study whether high level of CBI has such an effect over NER forecasts, we focus on the NER forecasts with RER model under both high level of CBI and IT regime. Using the component of lending restriction from

[11] See detailed explanation of this hypothesis in Eichenbaum et al. (2021)

[12] In most LICs and EMEs, the periods with maximum level of the components are also the times with highest CBI/democracy overall index.

Cukierman et al. (1992)'s CBI index, the data period with max CBI level in each EME/LIC has been listed in Table 16. Figure 27 plots inflation with IT adoption (red vertical line) and max CBI starting dates (black vertical line) in 14 EMEs. Countries including Colombia, Serbia, Slovak, South Africa and Thailand have max CBI dates after the IT, which makes it possible to compare the forecast after IT with the ones after IT and maximum CBI level. For all 11 LICs, the IT adoption dates happen at the same time or later than the start of max CBI level, which makes the comparison impossible for LICs. Table 9 reports exchange rate forecasts performance for RER model under 36 and 60 months rolling window estimation. From post-IT period (IT=1) to the period also with max CBI level(IT=1 $\times$ CBI=1), there exists an improvement of out-of-sample forecastability using RER model, with at least one unit increase of the number of countries with U ratio < 1 and DMW test rejected results significant at 1% level. The decrease (increase) of mean value of EMEs U ratio(DMW statistics) over 1- and 6-month ahead forecast also support this argument. The main improvement of out-of-sample forecastability comes from the Slovak Republic after joining in the Euro-system. As Slovak began to use euro dollar after the CBI, the outperformance actually indicates superior out-of-sample forecastability of euro currency with RER model. During the post-IT period, few evidence of exchange rate outperformance is found in Slovak koruna as a single country currency. After the CBI improvement in Slovak caused by joining in the EU, significant evidence of exchange rate forecasts performance is found in the euro currency[12].

Table 9: Impact of CBI in EMEs exchange rate forecasts using RER model.

Model	Statistics	60-month			36-month		
		h=1	h=6	h=12	h=1	h=6	h=12
IT=1							
RealE	No of U <1	4	4	4	4	4	5
	No of CW***	5	5	5	4	4	4
	No of DMW***	4	4	4	3	4	4
	Mean U	0.816	0.859	0.807	1.568	0.894	0.701
	Mean CW	6.139	5.362	5.655	4.815	5.232	5.268
	Mean DMW	3.569	2.795	3.318	2.726	3.441	3.918
(IT=1) X (CBI=1)							
RealE	No of U <1	5	5	5	5	5	5
	No of CW***	5	5	5	5	5	5
	No of DMW***	5	5	5	5	5	5
	Mean U	0.742	0.76	0.716	0.744	0.776	0.746
	Mean CW	5.332	5.172	4.944	5.804	5.308	5.219
	Mean DMW	3.636	3.653	3.711	3.945	3.741	3.728

This table compares forecasts performance of RER model before and after CBI increases in IT EMEs. We use 36 and 60-month rolling window individual regressions to estimate and forecast 5 EMEs currencies and the benchmark is driftless RW. For each regression, macro fundamental, data periods and forecast horizon h, "No of U < 1" provides the number of countries which has better forecasting accuracy relative to the RW based on the ratio of root mean squared forecast error. "Mean U " is mean value of EMEs' U ratio. "No of CW*** " shows number of cases reject the null hypothesis for no predictability based on Clark & West (2006) test at 1% level of significance. "Mean CW" is mean value of EMEs' CW statistics. "No of DMW*** " shows number of cases reject the null hypothesis for no forecastability based on Diebold & Mariano (1995) and West (1996) test at 1% level of significance. "Mean DMW" is mean value of DMW statistics.

4.4.4 The role of democracy

Morozumi et al. (2020) also finds that high level of democracy is helpful for IT in reducing inflation especially through the component of tighter institutional constraints on executives. To study whether

[12]For Slovak, CW statistics changes from insignificant to significant at 1% level for both six and twelve months ahead forecasts after the max CBI level.

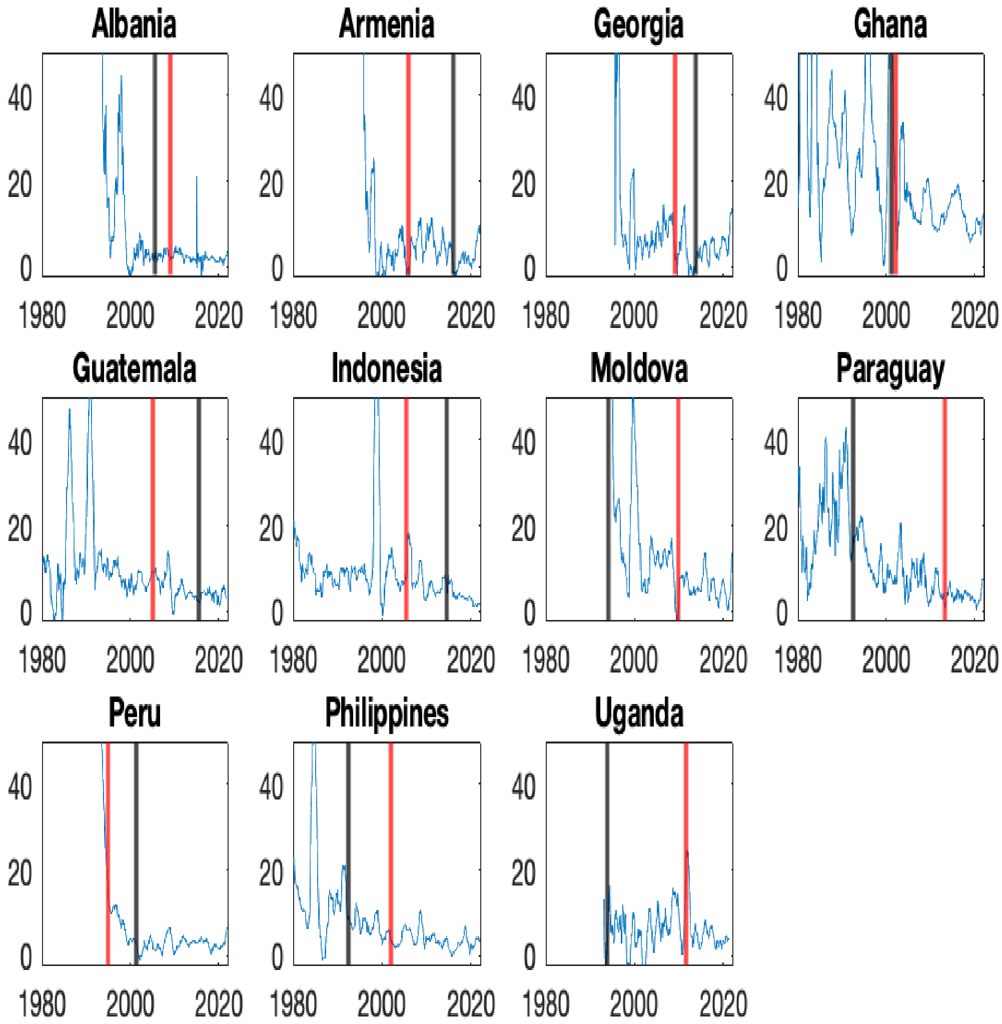


Figure 28: Inflation, IT adoption date(red line) and democracy date(black line) in Lower Income Economics

democracy has an effect over NER-RER comovement, we compare the RER model forecasts under IT framework with the ones under both IT and maximum level of democracy (proxied by constraints on executives). Using the component of constraints on executives from POLITY V, the data period with max democracy level in each EME/LIC has been listed in Table 16. For all 14 EMEs, the IT adoption dates happen almost the same time or later than the start of max democracy level, which makes the comparison impossible for EMEs. Figure 28 plots inflation with IT adoption (red vertical line) and max democracy starting dates (black vertical line) in 11 LICs. Countries including Armenia, Georgia, Guatemala, Indonesia and Peru have democracy improvements after the IT, which makes it possible to compare the forecast under IT with the ones under IT and max democracy level. We only report forecasts outcomes with 36-month rolling window estimation since the max democracy period for countries like Armenia, Guatemala and Indonesia are too short to use 60-month window. The inflation behaviour of the LICs clearly shows that inflation becomes less fluctuated after stricter constraints on executives. However, it is surprising that the out-of-sample performance for the five IT LICs become worse during the max democracy period (see Table 10), with decreasing number of countries having DMW and CW tests rejected at 1% significance level. After comparing the performance of the RER model for the individual LIC's exchange rates after IT and after IT/democracy, we find that the worse out-of-sample performance are mainly caused by Armenia, Guatemala and Indonesia. The beginning date of max democ-

Table 10: Impact of democracy in LICs exchange rate forecasts using RER model.

Model	Statistics		36-month	
		h=1	h=6	h=12
IT=1				
RealE	No of U <1	5	5	5
	No of CW***	4	5	4
	No of DMW***	3	3	4
	Mean U	0.764	0.707	0.727
	Mean CW	3.893	4.11	3.987
	Mean DMW	2.764	3.363	3.38
(IT=1) X (DEM=1)				
RealE	No of U <1	5	5	5
	No of CW***	2	4	3
	No of DMW***	1	2	2
	Mean U	0.775	0.754	0.76
	Mean CW	2.673	2.99	2.944
	Mean DMW	1.854	2.48	2.662

Notes: This table compares forecasts performance of RER model before and after democracy in IT LICs. We use 36 rolling window individual regressions to estimate and forecast 5 LICs currencies and the benchmark is driftless RW. For each regression, macro fundamental, data periods and forecast horizon h, "No of U < 1" provides the number of countries which has better forecasting accuracy relative to the RW based on the ratio of root mean squared forecast error. "Mean U " is mean value of EMEs' U ratio. "No of CW*** " shows number of cases reject the null hypothesis for no predictability based on Clark & West (2006) test at 1% level of significance. "Mean CW" is mean value of EMEs' CW statistics. "No of DMW*** " shows number of cases reject the null hypothesis for no forecastability based on Diebold & Mariano (1995) and West (1996) test at 1% level of significance. "Mean DMW" is mean value of DMW statistics.

racy period for these countries is around 2015. Although a short rolling window like 36-month is used, the size of out-of-sample may not be sufficient to achieve stable estimates for CW/DMW statistics in these countries. This may explain why forecasts performance of RER model in LICs becomes worse after democracy improvements, although it causes higher efficiency of IT in reducing inflation.

4.5 Conclusion

I evaluate the forecasts performance of the individual and fixed-effects panel regression models that incorporate four variants of the Taylor rule fundamentals- Finite difference Taylor rule with homogeneous coefficients (FDT-hom.); Finite difference Taylor rule with heterogeneous coefficients (FDT-het.); Asymmetric Taylor rule with homogeneous coefficients (TAsy-hom.); Asymmetric Taylor rule with heterogeneous coefficients(TAsy-het.); real exchange rate model (RealE.) to predict the EMEs exchange rates. The intuition here is to ascertain if poolability of data yield better forecasts of EMEs exchange rates than the benchmark random walk model. Following the non-poolability results and outperformance of the RER relative to Taylor models, I further consider forecasts performance of the RER model in EMEs and LICs during whole sample and post-IT subsample. This is to investigate if the forecasts results are consistent with the argument of NER-RER comovement for IT countries. Furthermore, we also compare the RER model performance in IT states before and after the maximum CBI or maximum democracy level. Through this way, we can see if high level of CBI/democracy can help reducing the inflation and facilitate the adjustment of RER through NER movements.

Our data spans January 1980 to December 2021, and comprises consumer price index and annual inflation, interest rate, industrial production index and exchange rates, on monthly frequency. I plot estimated dynamic parameters of macro fundamentals models when forecasting with individual regressions. I evaluate the out-of-sample forecast performance at h =1, 6 & 12 using Theil's U ratio, CW and DMW statistics. I find the individual regression models conditioned on the Asymmetric Taylor rule fundamentals (i.e. include RER term) and the RER model predict exchange rate better than the other models using fixed effect panel regression, since more than half of the EMEs beating the driftless RW model. When extending the study to more developing countries, I find that the RER term has vital role in forecasting exchange rates in both EMEs and LICs. Only the plots of this parameter present persistently significant and negative coefficients along the whole sample, while other parameters in Taylor rules are insignificant most of the time. Considering h =1 and h= 6 & 12 as short-run and long-run, respectively, there exists an improvement of forecasts performance using individual regression with RER model after the IT adoption, in both short-run and long-run horizons. A further increase of forecasts ability of RER model during the max CBI period is shown with one extra country beating the RW through DMW statistics. However, under high level of democracy, there seems no significant improvement of forecasts performance using RER model although inflation becomes more stable.

Overall, there are two implications of my findings. First, the RER in EMEs and LICs adjusts to shocks overwhelmingly through movements in the NER especially after the IT adoption. High level of CBI can increase the efficiency of IT and therefore encourage the comovement between RER and NER. Second, the non-poolability suggests the presence of heterogeneous behavior of the NER in responding to the RER in EMEs and LICs. This is not far-fetched as there exists difference in IT efficiency in reducing inflation across countries and one likely reason for the IT efficiency differences is the differences in CBI level.

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5 Appendix

Appendix A: US Taylor rules over May 1997- September 2008

See table 11

Appendix B: Definitions and Properties of Expectations data

Every month, major forecasting organisations give their forecasts of inflation and GDP growth for the current and the next year. The U.K. expected inflation and output growth series are formulated from these forecasts. The dataset only provides the average of the forecasters' expectations received in the three months prior. For example, the 2009 forecast for CPI inflation in May 2009 is the average of forecasts for CPI inflation between the months of March and May 2009. To fully utilise the forecast information in current month, the figures (of output growth and inflation) during month m are redefined as 3/6 times the forecast for month m plus 2/6 times the forecast for month $m+1$ and 1/6 times the forecast for month $m+2$. As the BoE recognises that the lag from changes of rates today to affect inflation is 18-24 months (see T.-H. Kim et al. (2008)), expectation of inflation for month m of a given year t is further processed as $(13-m)/12$ times the forecast for year t plus $(m-1)/12$ times the forecast for year $t+1$ following weighting scheme provided by Gorter et al. (2008). This makes the horizon of inflationary expectation closer to the lags recognised by the BoE. For output growth expectation, only forecast of output growth for the current year t is used since the lag of transmission process for output is twelve months.

The U.S. inflation forecasts are measured in terms of the annual growth rate for consumer price index (CPI), which are formulated by OECD in quarterly frequency. For our purpose, inflation forecasts

Table 11: **Estimates of monetary policy reaction function for the United States**

Inflation coefficient, β	1.90*** (0.39)	-0.07 (0.12)	-	-	-	-
Output gap coefficient, δ	0.60*** (0.09)	0.03 (0.03)	0.48*** (0.10)	0.03 (0.03)	-	-
Expected inflation coefficient, β'	-	-	0.002 (0.16)	0.06 (0.04)	0.04 (0.17)	0.05 (0.04)
Expected output gap growth coefficient, δ'	-	-	-	-	0.43*** (0.12)	0.06* (0.03)
Lagged interest rate, ϕ	-	0.97*** (0.03)	-	0.96*** (0.02)		0.96*** (0.002)
Long-run inflation coefficient	-	-	-	-	-	-
Long-run output gap coefficient	-	-	-	-	-	1.43
Adj R-squared	0.20	0.94	0.16	0.94	0.08	0.94

is defined as the monthly interpolation of the quarterly forecast. To convert these values into monthly inflation forecasts, we simply disaggregate the quarterly inflation forecasts corresponding with the relevant months. For example, the inflation forecasts made in January, February and March 1998 use inflation forecasts released in the first quarter of 1998. The inflation forecasts made in April, May and June 1998 use inflation forecasts released in the second quarter of 1998, and so on. Since the deadlines for surveys are set in the middle month of each quarter, which indicates an one-month lag in data releases after converting into monthly frequency, expectation of inflation for month m of a given year t is therefore used to measure data at month $m-1$. Output growth expectation is defined as the monthly interpolation of the one-quarter-ahead nominal GDP forecast(DNGDP2 respectively). The horizon of inflation and output growth expectations are consistent with the target horizons assumed by the Fed, which are one year for the inflation target and one quarter for the output (see Clarida et al. (2000)).

Appendix C: Data

Real-time monthly data is used from October 1986 to September 2008. The start of the period was dictated by the earliest time we can find for the U.K. forecasts data. As mentioned by Creel & Hubert (2015), one advantage using sample beginning in October 1986 is avoiding the suspicion that the low and stable inflation under IT is associated with the disinflation policies implemented in the early 1980s. Regarding the high inflation at the start of 1980s, beginning in October 1986 is helpful for us to study whether the CBI revolutions had an effect on the monetary policy regime over a relatively stable sample. The end of the period was chosen to correspond with the collapse of Lehman Brothers. As the BoE's inflation target has changed from 2.5% as measured by RPIX to 2% as measured by CPI after December 2003, RPIX and CPI are bonded together to measure actual inflation for the U.K.. Core CPI is used to measure inflation for the U.S.. Monthly vintages for quarterly real GDP are used to measure output for both the U.K. and the U.S.. Federal funds rate is used for the U.S. and three-month treasury bill rate is used for the U.K.. The U.K./U.S. interest rates and USD/GBP nominal exchange rate are for the last day in the month. Following Taylor (1993), the inflation rate is the rate of inflation over the previous twelve months.

As real-time datasets, real-time released core consumer price index (PCPIX) and real GNP/GDP for the United States are extracted from the Philadelphia Fed Real-Time Data set for Macroeconomists. Real-time core inflation is calculated as twelve months growth of core consumer price index. As real-time data for the index is only available since November 1998, real-time core inflation before that date is calculated based on revised data in November 1988. Real-time output growth for the U.K. is constructed by the real GDP available from the BoE website. As real time inflation data starting from October 1986 are unavailable for the U.K., RPIX/CPI inflation released in February 2022 are used instead. Nominal exchange rate are collected from the Federal Reserve Economic Data (FRED) website.

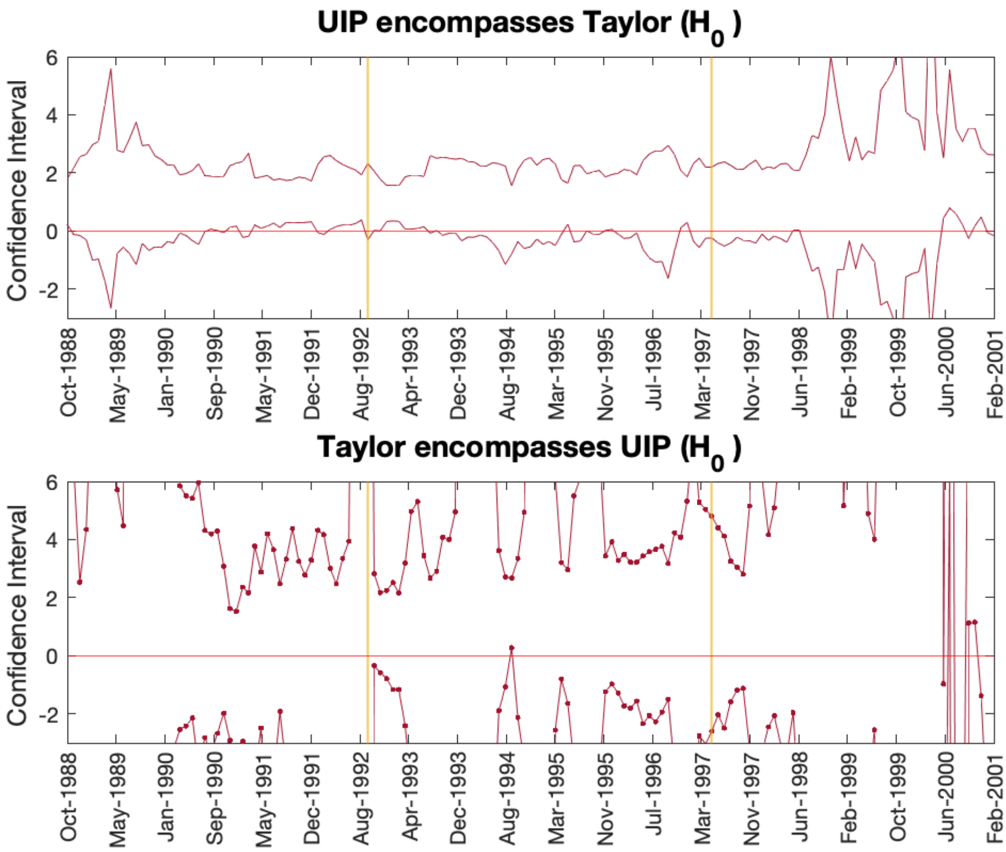
Real-time expected output growth and expected inflation time series for the U.K. have been constructed from a summary of private sector forecasts collected by the U.K. HM treasury. Every month, major forecasting organisations give their forecasts of inflation and GDP growth for the current and the next year. The U.K. expected inflation and output growth series are formulated from these forecasts. The dataset only provides the average of the forecasters' expectations received in the three months prior. For example, the 2009 forecast for CPI inflation in May 2009 is the average of forecasts for CPI inflation between the months of March and May 2009. To fully utilise the forecast information in current month, the figures (of output growth and inflation) during month m are redefined as 3/6 times the forecast for month m plus 2/6 times the forecast for month $m+1$ and 1/6 times the forecast for month $m+2$. As the BoE's statement implies that the lag from changes of rates today to affect inflation is 18-24 months (see T. H. Kim et al. (2010)), expectation of inflation for month m of a given year t is further processed as $(13-m)/12$ times the forecast for year t plus $(m-1)/12$ times the forecast for year $t+1$ following weighting scheme provided by Gorter et al. (2008). This makes the horizon of inflationary expectation closer to the lags recognised by the BoE. For output growth expectation, only forecast of output growth for the current year t is used since the lag of transmission process for output is twelve months. As the data are unique and not revised later on, the critique of ex-post data by Orphanides (2001) is not applied. I use OECD's inflation forecasts (CPIFORECAST) and Survey of Professional Forecasters(SPF)'s one year ahead inflation forecasts measured by GNP/GDP price index(INFPGDP1YR) to represent the inflation forecast for the U.S..

In the context of Taylor rules estimation and exchange rate forecasting, the U.K. potential output is constructed based on the real GDP with quadratic detrending. Expectation of output level is calculated as expected GDP growth minus the real GDP at time t. By subtracting the estimated potential output from the expectation of output level, we construct the forecasted rate of the output gap.

For exchange rate forecasting with Taylor rule fundamentals, the U.S. output gap is estimated in real-time in order to construct real-time forecasting. The U.S. potential output is constructed based on the real GNP/GDP with quadratic detrending. At each point in time, potential output is estimated using only information from October 1986 to the vintage date for which the information is available as it appeared at that point. By using this method, it can most closely mimic the information available to market participants at the moment the forecasts would have been made. Therefore, in each month the regression is re-estimated after including one additional observation to the sample.

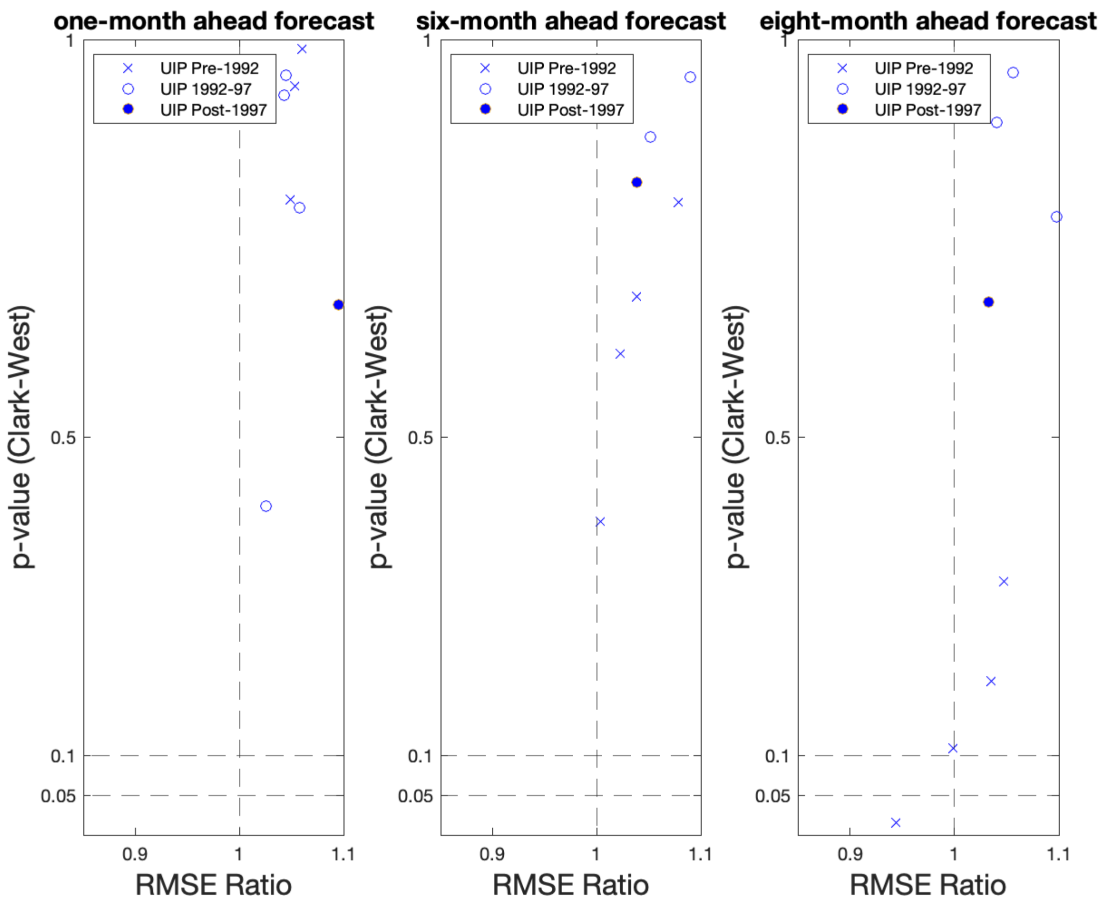
Appendix D: Robustness checks

Figure 29: Reconnect of The USD/GBP Exchange Rate and Taylor rule fundamentals: overall F test statistics



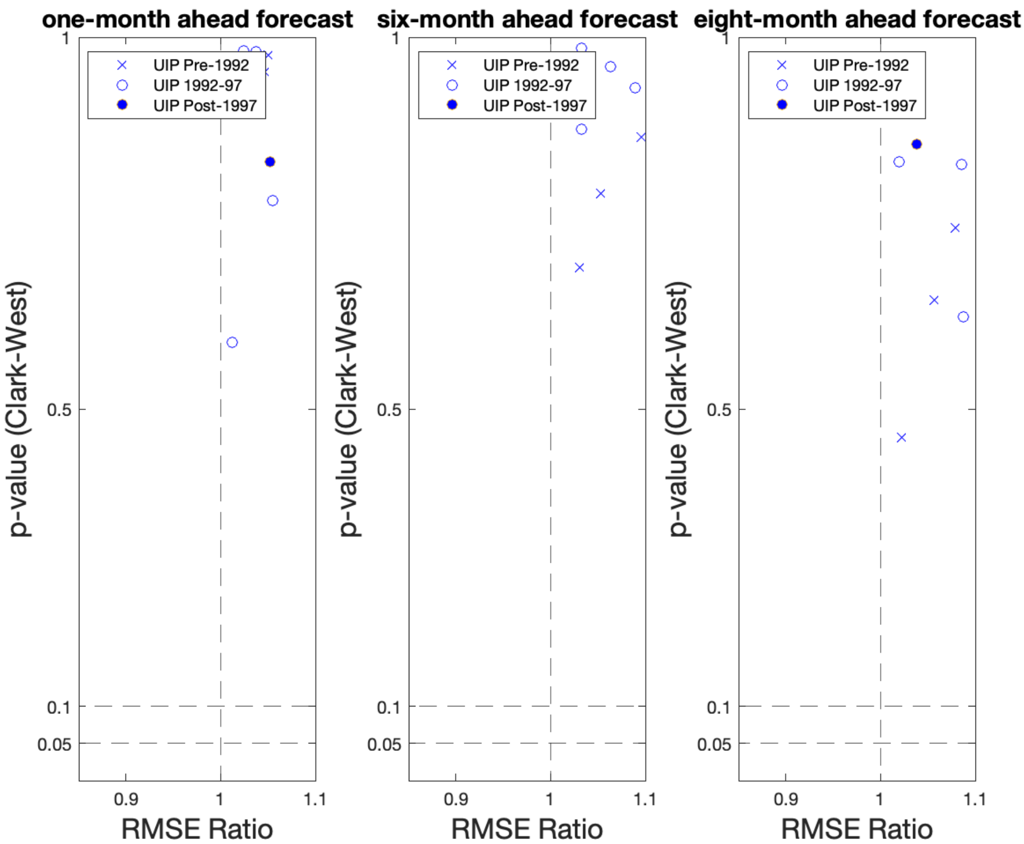
Notes: These figures show the 95% confidence interval for Davidson & MacKinnon (1981) 's J test using 24-month rolling regressions of the log change in the USD/GBP exchange rate against various macroeconomic fundamentals. The regression specification is $s_t - s_{t-1} = \alpha + \beta X_t + \epsilon_t$, where $s_t - s_{t-1}$ is monthly change of nominal exchange rate and X_t represents different contemporaneous macroeconomic variables. For UIP regression, X_t is U.S. interest minus U.K. interest rate in our case. For Taylor rule fundamentals, X_t includes U.S. actual inflation and output gap, U.K. expected inflation and expected output gap or $(\lambda_u \pi_t - \lambda_k E_t \tilde{\pi}_{t+i} + \gamma_u y_t - \gamma_k E_t \tilde{y}_{t+j})$ in our case. Yellow lines denote the times of CBI revolutions. Horizontal line indicates zero value coefficient on UIP (Taylor) associated with the true model is Taylor (UIP) under null.

Figure 30: Reconnect with Interest Rate Differential (24-month Evaluation Periods): One, Six, Eight-Month Ahead Out-Of-Sample Predictability



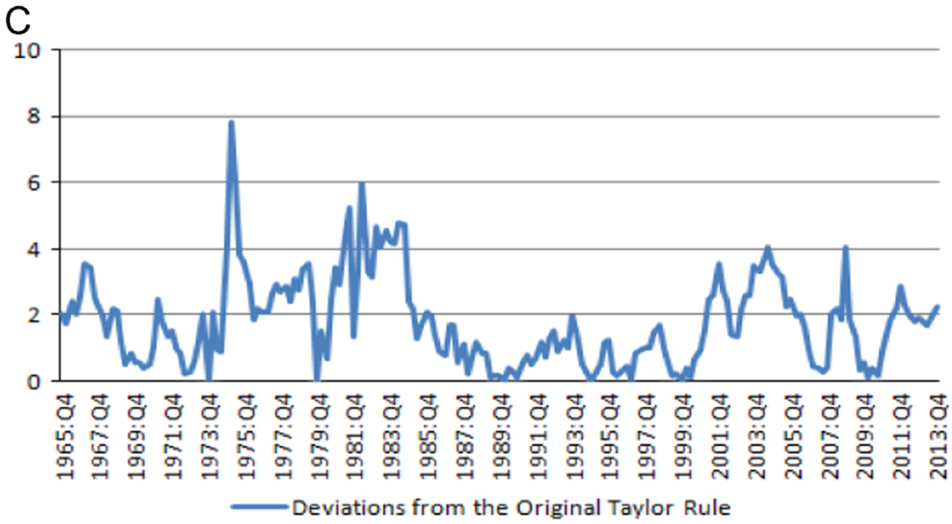
Notes: This figures reports the 1, 6, 8-month-ahead out-of-sample predictability of exchange rate forecasts using UIP relative to a random walk over different sample periods. Each marker reports the ratio of the model's root mean squared prediction error relative to a random walk (x-axis) and the p-value of Clark-West test for the out-of-sample predictability of the model relative to a random walk (y-axis). Each observation shows a 24-month model evaluation period, using a 24-month rolling estimation windows. The "x" markers represent windows where all forecasts are for periods start prior to Oct 1992, the hollow dots relate to windows where the forecasts start after Oct 1992 but before May 1997, and the solid dots show windows where all forecasts occur after May 1997

Figure 31: Reconnect with Interest Rate Differential (36-month Evaluation Periods): One, Six, Eight-Month Ahead Out-Of-Sample Predictability



Notes: This figures reports the 1, 6, 8-month-ahead out-of-sample predictability of exchange rate forecasts using UIP relative to a random walk over different sample periods. Each marker reports the ratio of the model's root mean squared prediction error relative to a random walk (x-axis) and the p-value of Clark-West test for the out-of-sample predictability of the model relative to a random walk (y-axis). Each observation shows a 36-month model evaluation period, using a 36-month rolling estimation windows. The "x" markers represent windows where all forecasts are for periods start prior to Oct 1992, the hollow dots relate to windows where the forecasts start after Oct 1992 but before May 1997, and the solid dots show windows where all forecasts occur after May 1997

Figure 32: Deviations from the original Taylor Rule by Nikolsko-Rzhevskyy et al. (2014a)



Notes: This figure copies panel C from Figure 2 in Nikolsko-Rzhevskyy et al. (2014a)which depicts the deviation of actual Fed funds rate from the rate implied by original Taylor rule from 1965:Q4-2013:Q4

Appendix E: data and results for EMEs and LICs

Table 12: IT adoption dates and data period description

EMEs	Date of the IT adoption	Sample begins (Taylor)	Sample ends (Taylor)	Sample begins (RealE)	Sample ends (RealE)
Brazil	1999-06	1999-04	2021-12	1980-01	2021-12
Chile	1991-01	1995-05	2019-09	1980-01	2021-12
Colombia	1991-01	2000-07	2019-09	1980-01	2021-12
Dominican Rep	2012-01	2007-12	2021-12	1980-01	2021-12
Hungary	2001-06	1995-01	2021-12	1980-01	2021-12
Mexico	1999-01	2001-12	2021-10	1980-01	2021-12
Poland	1998-10	1998-01	2021-12	1988-01	2021-12
Romania	2005-08	2003-01	2021-11	1991-09	2021-12
Russian Federation	2014-11	2001-12	2021-12	1994-12	2021-12
Serbia	2006-08	2001-12	2021-11	2000-12	2021-12
Slovak Republic	2005-01	1997-11	2021-09	1993-01	2021-12
South Africa	2000-02	2000-12	2018-08	1980-01	2021-12
Thailand	2000-04	2009-07	2019-06	1980-01	2021-12
Turkey	2002-01	2000-12	2021-12	1980-01	2021-12
LICs					
Albania	2009-01	2005-01	2021-12	1992-01	2021-12
Armenia	2006-01	N.A.	N.A.	1992-12	2021-12
Georgia	2009-01	2008-01	2016-12	1995-10	2021-12
Ghana	2002-01	2001-12	2021-12	1980-01	2021-12
Guatemala	2005-01	2005-01	2017-09	1980-01	2021-12
Indonesia	2005-07	2005-07	2019-04	1980-01	2021-12
Moldova	2009-12	N.A.	N.A.	1991-12	2021-12
Paraguay	2013-05	2011-01	2021-11	1980-01	2021-12
Peru	1994-12	2003-09	2018-04	1980-01	2021-12
Philippines	2001-12	2001-12	2021-12	1980-01	2021-12
Uganda	2011-07	2005-12	2016-02	1992-03	2021-03

Notes: This table reports IT adoption dates and dates of sample period for EMEs and LICs in each exchange rate model. Countries are classified as EMEs and LICs by Morozumi et al. (2020) using per capita real GDP in PPP terms. IT adoption dates are the specific month of loose-IT dates in Morozumi et al. (2020). In the rest columns, it reports beginning and end dates of the sample for each specification of macro fundamentals model. *Taylor* indicates Taylor rule models including TAsy-hom. TAsy-het. FDT-hom. FDT-het in Equations (28) (29). *RealE* indicates the macro fundamental model with only real exchange rate in Equation (31). The sample period of Taylor model for Armenia and Moldova are N.A. because output data in monthly/quarterly frequency are unavailable.

Table 13: Forecast evaluation of Taylor rules and RER model in EMEs

Model	Statistics	Individual Regression			Fixed Effect Panel Regression		
		h=1	h=6	h=12	h=1	h=6	h=12
Full Sample							
FDT-hom	No of U <1	0	0	0	1	2	8
	No of CW***	0	0	0	1	3	10
	No of DMW***	0	0	0	0	2	2
FDT-het	No of U <1	0	0	0	1	3	11
	No of CW ***	0	0	0	1	4	12
	No of DMW***	0	0	0	0	1	2
Tasy-hom	No of U <1	13	13	14	1	2	6
	No of CW***	12	12	12	1	4	12
	No of DMW***	10	11	11	0	2	2
Tasy-het	No of U <1	13	13	13	0	3	9
	No of CW***	12	12	12	1	4	12
	No of DMW***	7	10	9	0	1	2
RealE	No of U <1	13	12	13	6	10	14
	No of CW***	11	10	10	7	10	11
	No of DMW***	11	9	10	2	3	6
Post-IT							
FDT-hom	No of U <1	0	0	0	1	2	8
	No of CW***	0	0	0	1	3	10
	No of DMW***	0	0	0	0	2	2
FDT-het	No of U <1	0	0	0	1	3	11
	No of CW ***	0	0	0	1	4	12
	No of DMW***	0	0	0	0	1	2
Tasy-hom	No of U <1	13	13	13	1	2	6
	No of CW***	11	12	12	1	4	12
	No of DMW***	10	10	10	0	2	2
Tasy-het	No of U <1	13	12	13	0	3	9
	No of CW***	11	12	12	1	4	12
	No of DMW***	7	9	9	0	1	2
RealE	No of U <1	13	13	13	3	9	13
	No of CW***	12	12	12	2	7	10
	No of DMW***	11	11	11	1	1	2

The benchmark model for both forecasting regressions is the driftless RW. 60-month rolling window is used for estimation. For each regression, macro fundamental, data periods and forecast horizon h, "No of U $<$ 1" provides the number of countries which has better forecasting accuracy relative to the RW based on the ratio of root mean squared forecast error."No of CW*** " shows number of cases reject the null hypothesis for no predictability based on Clark & West (2006) test at 1% level of significance. "No of DMW*** " shows number of cases reject the null hypothesis for no forecastability based on Diebold & Mariano (1995) and West (1996) test at 1% level of significance.

Table 14: Forecast evaluation relative to drift random walk model.

Model	**Statistics**	**Fixed Effect Panel Regression**		
		h=1	h=6	h=12
Post-IT				
FDT-hom	No of U <1	3	2	3
	No of CW***	0	0	0
	No of DMW***	0	0	0
FDT-het	No of U<1	0	3	10
	No of CW ***	0	1	2
	No of DMW***	0	0	0
Tasy-hom	No of U <1	1	2	3
	No of CW***	0	0	2
	No of DMW***	0	0	0
Tasy-het	No of U <1	0	4	7
	No of CW***	0	2	6
	No of DMW***	0	0	0
RealE	No of U <1	2	5	10
	No of CW***	0	0	4
	No of DMW***	0	0	0
driftless RW	No of U <1	1	5	13
	No of CW***	2	3	10
	No of DMW***	1	2	2

The benchmark model for fixed effect panel regression is the drift RW. 60-month rolling window is used for estimation. For each regression, macro fundamental, data periods and forecast horizon h, "No of U < 1" provides the number of countries which has better forecasting accuracy relative to the RW based on the ratio of root mean squared forecast error."No of CW*** " shows number of cases reject the null hypothesis for no predictability based on Clark & West (2006) test at 1% level of significance. "No of DMW*** " shows number of cases reject the null hypothesis for no forecastability based on Diebold & Mariano (1995) and West (1996) test at 1% level of significance. The last three rows compare drift with driftless RW where the drift RW is full model in U ratio and tests.

Table 15: Forecast evaluation using individual regressions

Model	Statistics	EMEs			LICs		
		h=1	h=6	h=12	h=1	h=6	h=12
Full Sample							
FDT-hom	No of U <1	0	0	0	0	2	1
	No of CW***	0	0	0	0	0	0
	No of DMW***	0	0	0	0	0	0
FDT-het	No of U <1	0	0	0	0	1	1
	No of CW ***	0	0	0	0	0	0
	No of DMW***	0	0	0	0	0	0
TAsy-hom	No of U <1	13	13	14	9	9	9
	No of CW***	12	12	12	7	8	8
	No of DMW***	10	11	11	4	7	6
TAsy-het	No of U <1	13	13	13	9	8	9
	No of CW***	12	12	12	7	8	7
	No of DMW***	7	10	9	4	2	5
RealE	No of U <1	13	12	13	9	8	10
	No of CW***	11	10	10	6	6	5
	No of DMW***	11	9	10	4	4	4
Post-IT							
FDT-hom	No of U <1	0	0	0	0	1	0
	No of CW***	0	0	0	0	0	0
	No of DMW***	0	0	0	0	0	0
FDT-het	No of U <1	0	0	0	0	1	0
	No of CW ***	0	0	0	0	0	1
	No of DMW***	0	0	0	0	0	0
TAsy-hom	No of U <1	13	13	13	9	9	9
	No of CW***	11	12	12	7	7	7
	No of DMW***	10	10	10	4	5	3
TAsy-het	No of U <1	13	12	13	7	9	6
	No of CW***	11	12	12	7	7	4
	No of DMW***	7	9	9	0	1	0
RealE	No of U <1	13	13	13	11	11	11
	No of CW***	12	12	12	9	10	9
	No of DMW***	11	11	11	6	9	7

We use 60-month rolling window individual regressions to estimate and forecast 14 EMEs and 11 LICs currencies and the benchmark is driftless RW. For Taylor rule models, only 9 LICs are studied as two LICs do not have available monthly data. For RealE model, 11 LICs are studied. For each regression, macro fundamental, data periods and forecast horizon h, "No of U < 1" provides the number of countries which has better forecasting accuracy relative to the RW based on the ratio of root mean squared forecast error."No of CW*** " shows number of cases reject the null hypothesis for no predictability based on Clark & West (2006) test at 1% level of significance. "No of DMW*** " shows number of cases reject the null hypothesis for no forecastability based on Diebold & Mariano (1995) and West (1996) test at 1% level of significance.

Table 16: Periods with max CBI level and max democracy level for the EMEs and LICs

Country	Max CBI period	CBI events	Max Democracy period	Democracy events
EMEs				
Brazil	1988:10-2021:12	Article 164 of the Constitution	1988:10-2021:12	The seventh and current Constitution of Brazil
Chile	1989:10-2021:12	Basic Constitutional Act	1989:07-2021:12	1989 Chilean constitutional referendum
Colombia	1992:01-2021:12	Law No. 31 of 29th December 1992	1991:07-2021:12	reform the country's Constitution of 1886
Dominican Rep	2002:12-2021:12	Enforcement of the monetary and financial law	1996:05-2021:12	National and local elections become free and fair multiparty contests
Hungary	2001:05-2021:12	Act LVIII of 2001	1990:03-2021:12	1990 Hungarian parliamentary election
Mexico	1993:08-2021:12	changes to the constitution that granted monetary policy autonomy	1999:05-2021:12	The Municipal Reform of 1999
Poland	1997:08-2021:12	the Act on the National Bank of Poland of the Constitution	1995:11-2021:12	1995 Polish presidential election
Romania	2004:06-2021:12	National Bank of Romania Act (312/2004)	2004:11-2021:12	2004 Romanian general election
Russian Federation	2002:07-2021:12	Federal Law No. 86-FZ	2000:03-2021:12	2000 presidential election
Serbia	2010:07-2021:12	amendments to the Law on the National Bank of Serbia	2006:10-2021:12	Serbian constitutional referendum
Slovak Republic	2009:01-2021:12	Join in the Eurosystem	1998:09-2021:12	Slovak parliamentary elections
South Africa	2010:05-2021:12	South African Reserve Bank Amendment Bill	1994:04-2021:12	South African general election
Thailand	2008:03-2021:12	The Bank of Thailand Act 2008	1992:03-2005:09	Thai general election
Turkey	2001:04-2021:12	The law of CBRT passed on 25 April 2001	1989:10-2013:05	Turkish presidential election

Continued on next page

Table 16: (continued)

LICs				
Albania	1997:12-2021:12	the Law No. 8269 On the Bank of Albania	2005:07-2021:12	2005 Parliamentary Elections
Armenia	1996:06-2021:12	law of the republic of Armenia	2015:12-2021:12	March 1998 Armenian elections
Georgia	2009:09-2021:12	organic law of georgia No 1676 on the national bank of georgia	2013:10-2021:12	2013 Georgian presidential election
Ghana	2002:01-2021:12	the Bank of Ghana Act 2002 Act 612	2001:01-2021:12	Peaceful turnover after 2000 Ghanaian general election
Guatemala	2002:01-2021:12	a new banking law reformed prudential regulatory framework	2015:06-2021:12	2015 Guatemalan protests
Indonesia	1999:05-2021:12	Bank Indonesia gained CBI	2014:07-2021:12	2014 Indonesian presidential election
Moldova	1995:09-2021:12	Law on the National Bank of Moldova	1994:02-2021:12	1994 Moldovan parliamentary election
Paraguay	1995:06-2021:12	Law 489/95, Charter of the Central Bank of Paraguay	1992:06-2021:12	constitution adopted in 1992
Peru	1992:12-2021:12	Article 52 of the 1992 central bank law	2001:04-2021:12	2001 Peruvian general election
Philippines	1993:07-2021:12	central bank of the Republic of the Philippines established	1992:05-2021:12	1992 Philippine presidential election
Uganda	2011:07-2021:12	reformed central bank monetary policy framework	1993:11-2021:12	post-1993 decentralisation programme

Notes: This table presents sample period with maximum level of CBI and Democracy in EMEs and LICs. Countries are classified as EMEs and LICs by Morozumi et al. (2020) using per capita real GDP in PPP terms. CBI level is measured based on the level of lending restriction component of Cukierman et al. (1992) index calculated by Garriga (2016). Democracy level associates with the constraints on the decision-making powers of chief executives in Polity V available from Marshall (2020). In these datasets, changes of CBI and Democracy index are in yearly frequency. We then find the specific month and the events which cause the indexes increases, and transform the index into monthly frequency.

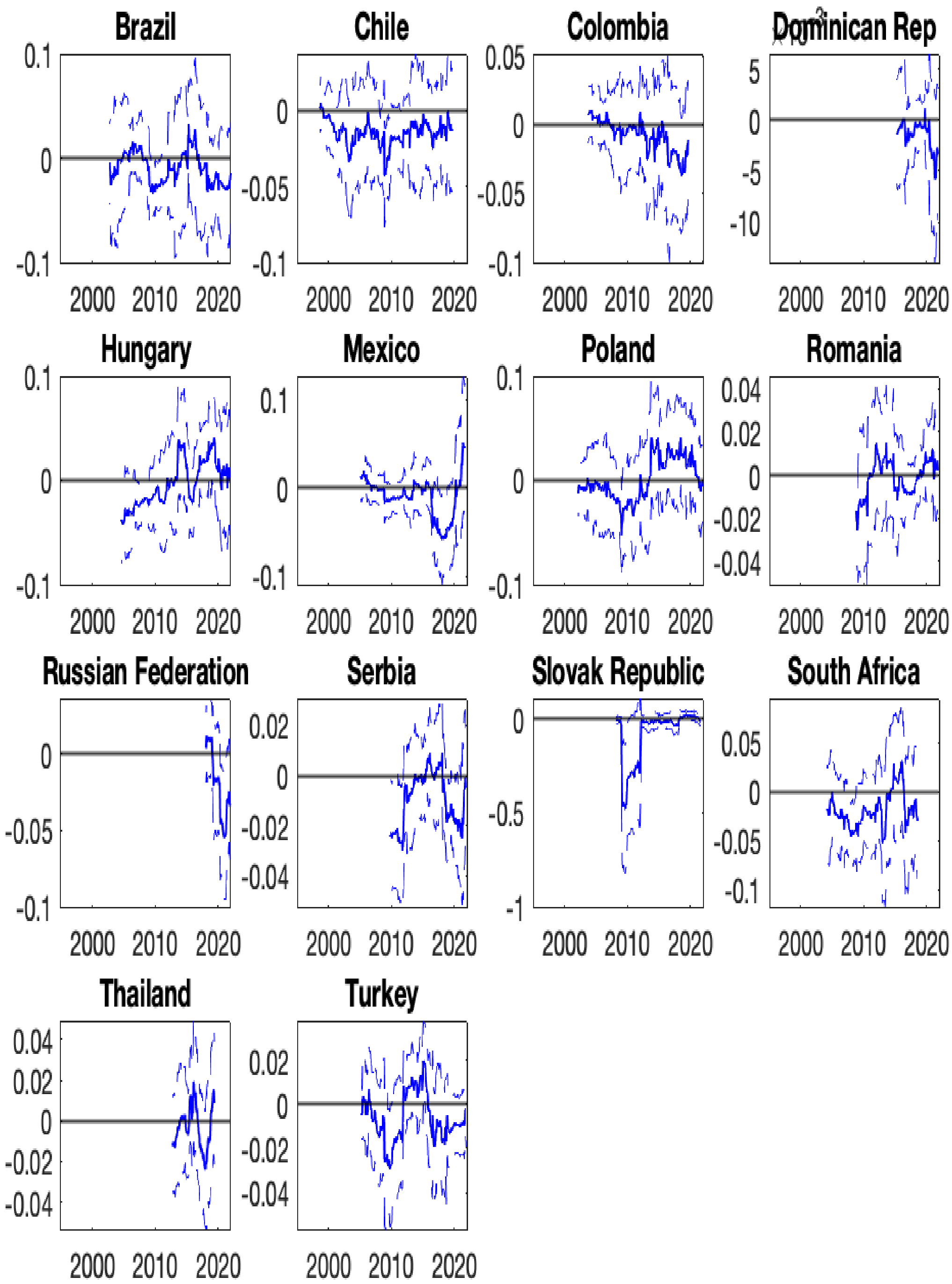


Figure 33: Inflation differential (EME)

Notes:This figure presents dynamic coefficient estimation for inflation differential in homogeneous finite-difference Taylor (FDT-hom.) model from 1995 to 2021 for 14 EMEs. Since the beginning of data is different for each EME, dynamic estimation starts at different times (see Table 12 in Appendix E). Solid line is the estimated coefficient along the time. X-axis shows time points. Y-axis represents value of estimated coefficients.. Dashed lines are upper and lower bounds for 95% confidence interval of the estimated coefficient. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point.

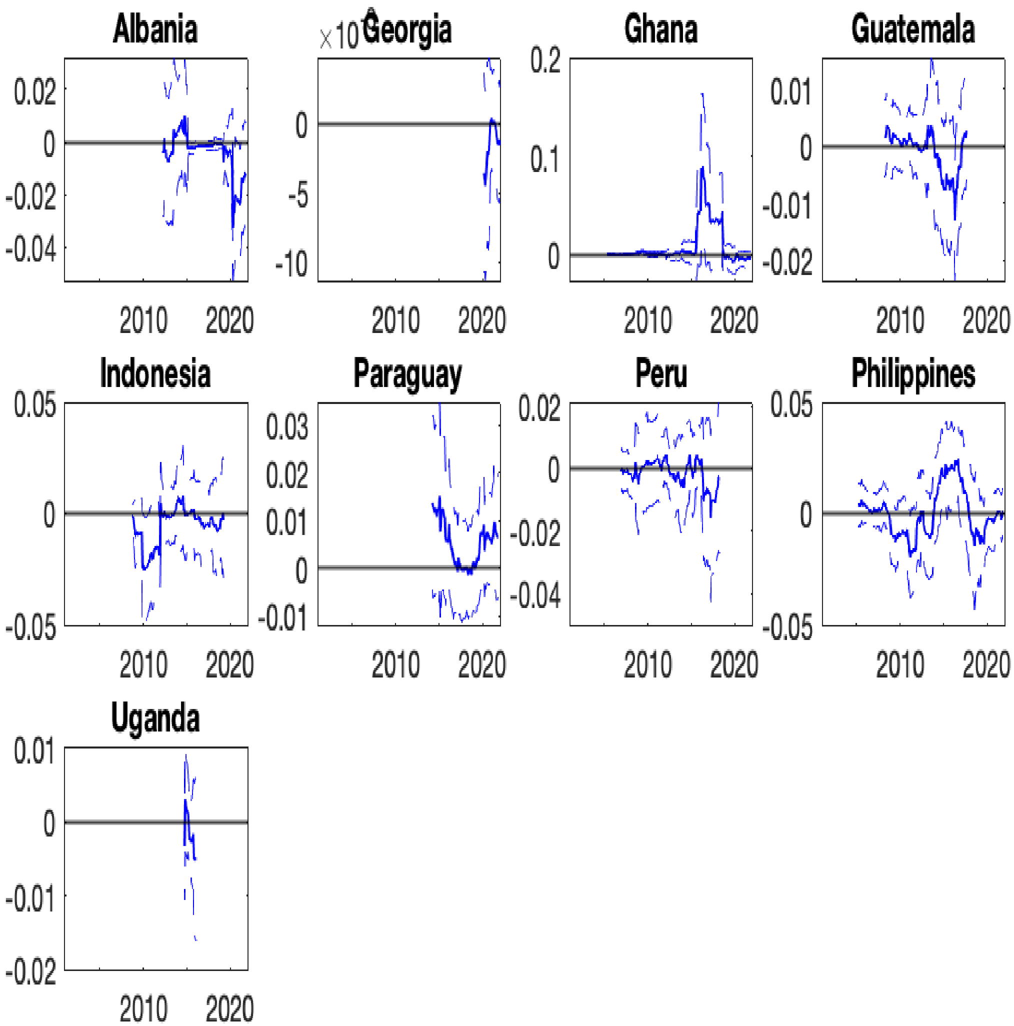


Figure 34: Inflation differential (LIC)

Notes:This figure presents dynamic coefficient estimation for inflation differential in homogeneous finite-difference Taylor (FDT-hom.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point.

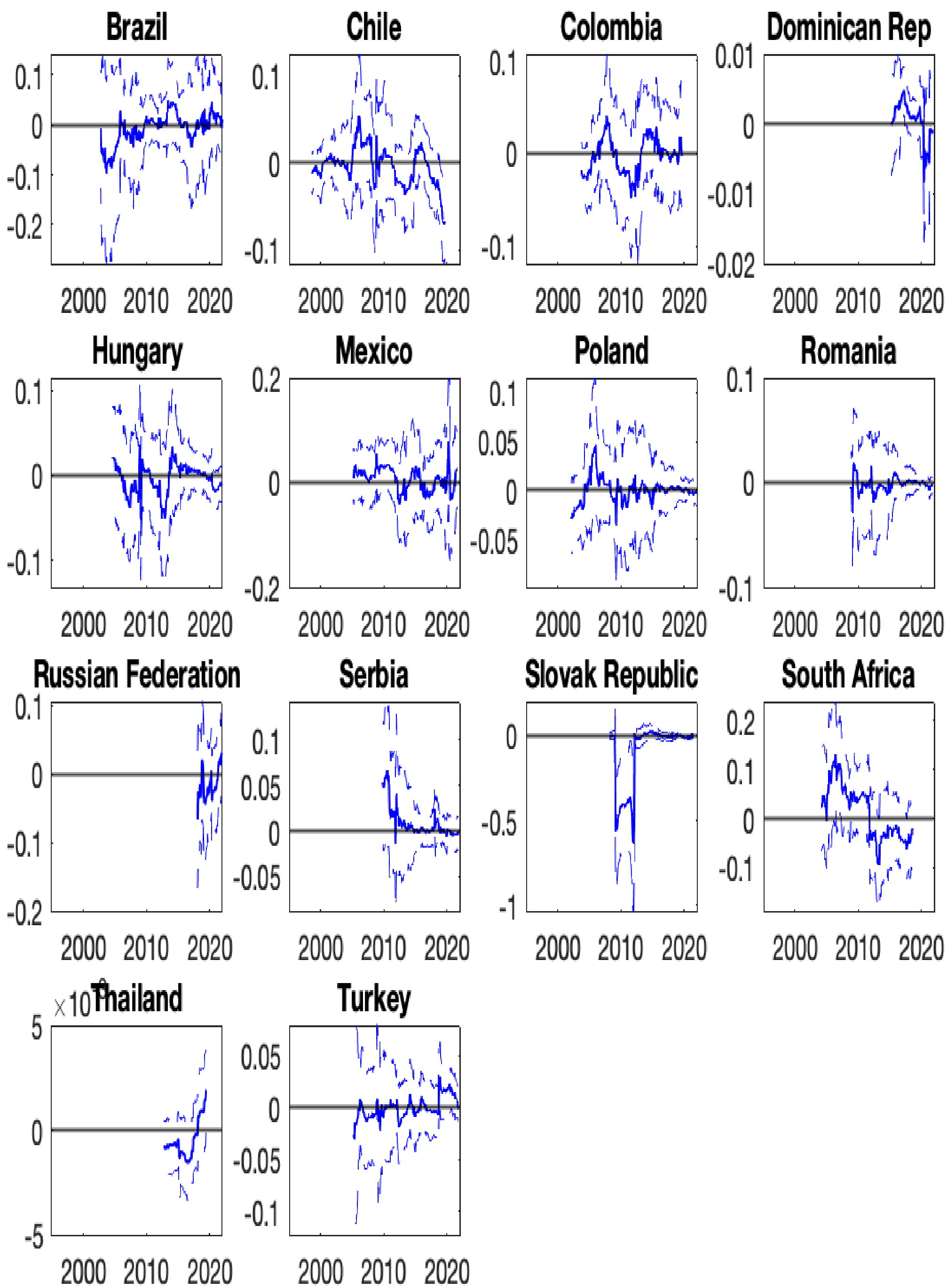


Figure 35: Output gap differential (EME)

Notes:This figure presents dynamic coefficient estimation for output gap differential in homogeneous finite-difference Taylor (FDT-hom.) model from 1995 to 2021 for 14 EMEs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the EMEs have persistently significant coefficient for output gap differential.

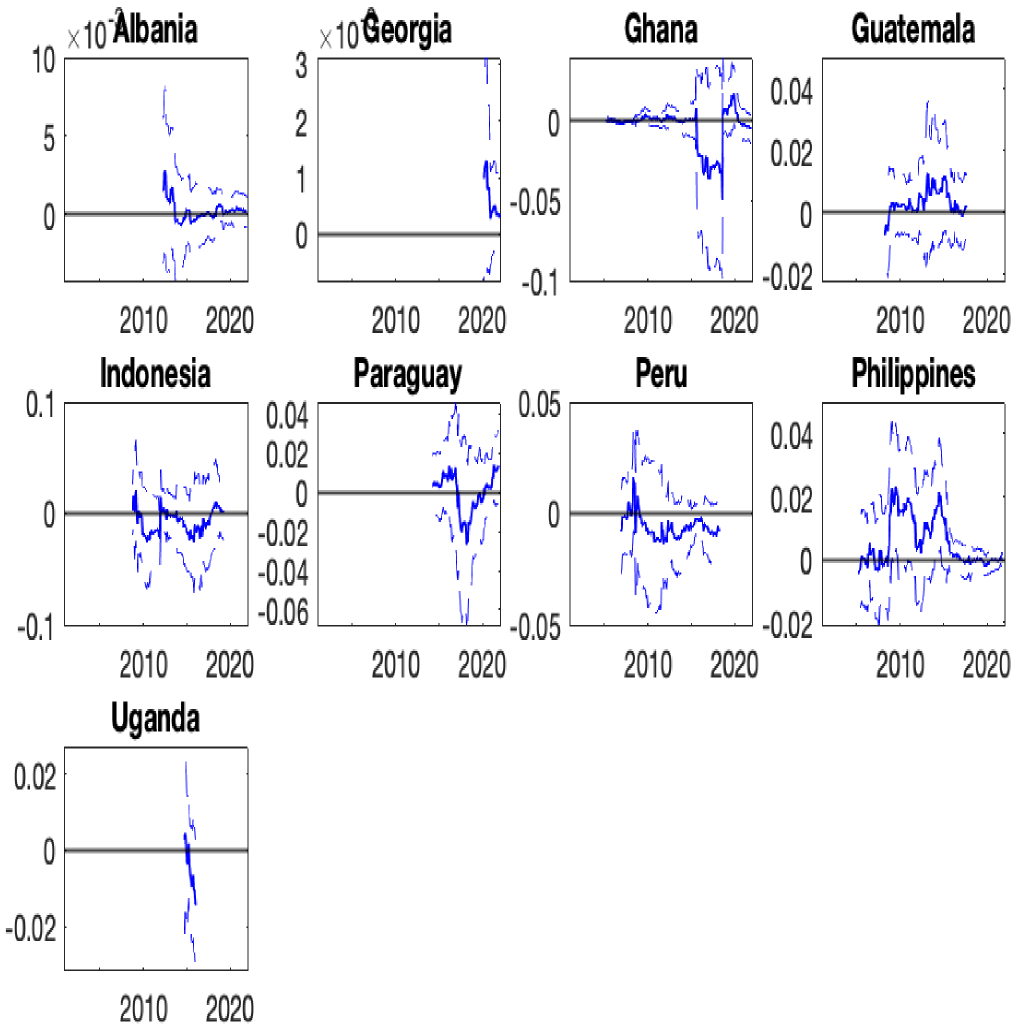


Figure 36: Output gap differential (LIC)

Notes:This figure presents dynamic coefficient estimation for output gap differential in homogeneous finite-difference Taylor (FDT-hom.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point.It can be seen that none of the LICs have persistently significant coefficient for output gap differential.

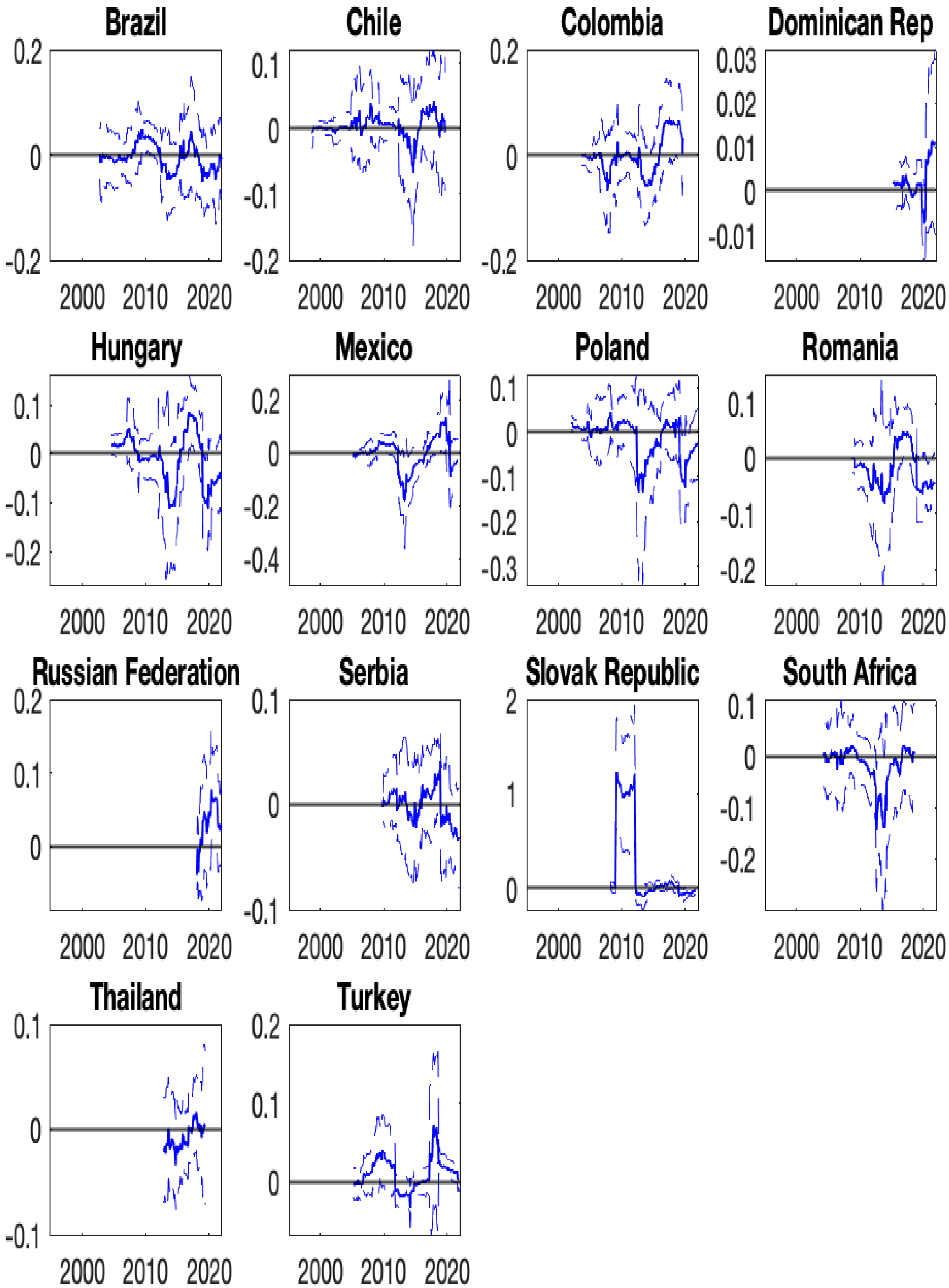


Figure 37: Interest rate differential (EME)

Notes:This figure presents dynamic coefficient estimation for interest rate differential in homogeneous finite-difference Taylor (FDT-hom.) model from 1995 to 2021 for 14 EMEs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the EMEs have persistently significant coefficient for inteterest rate differential.

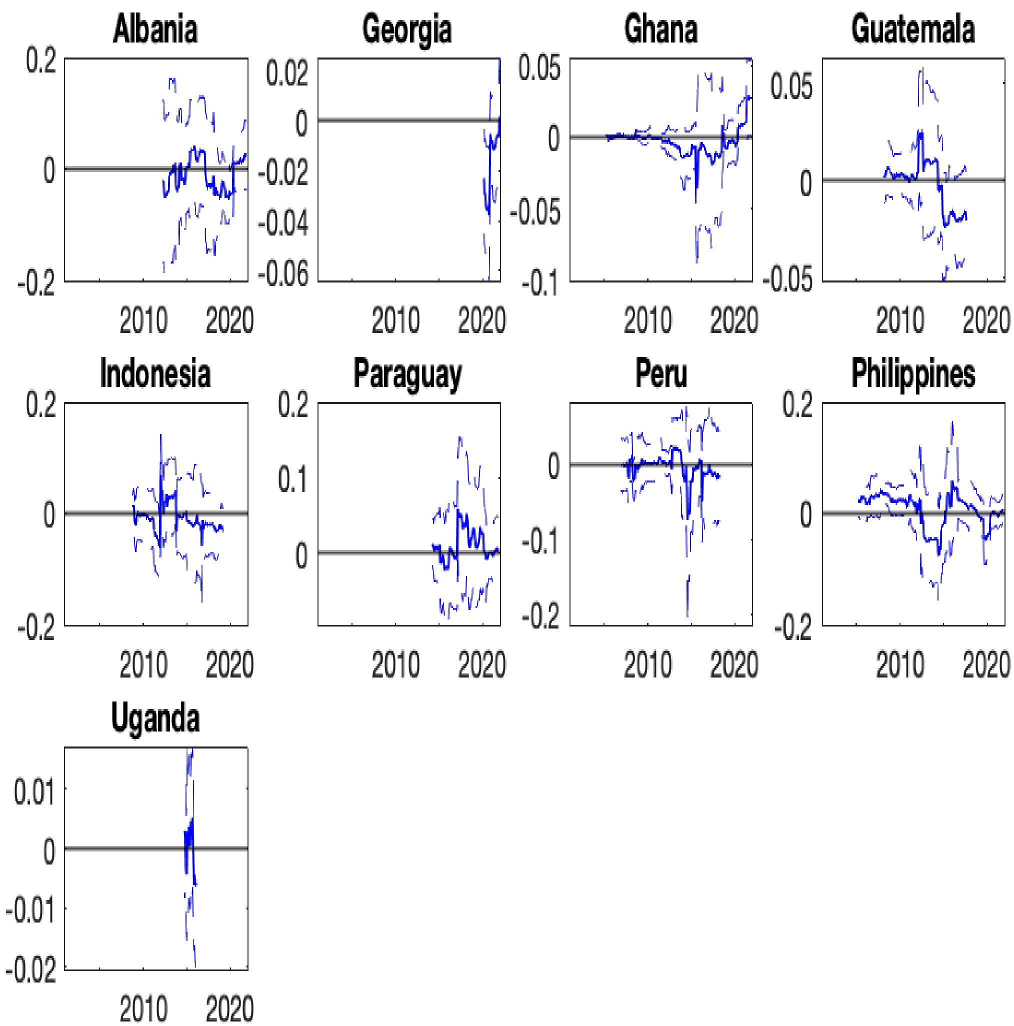


Figure 38: Interest rate differential (LIC)

Notes:This figure presents dynamic coefficient estimation for interest rate differential in homogeneous finite-difference Taylor (FDT-hom.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the LICs have persistently significant coefficient for interest rate differential.

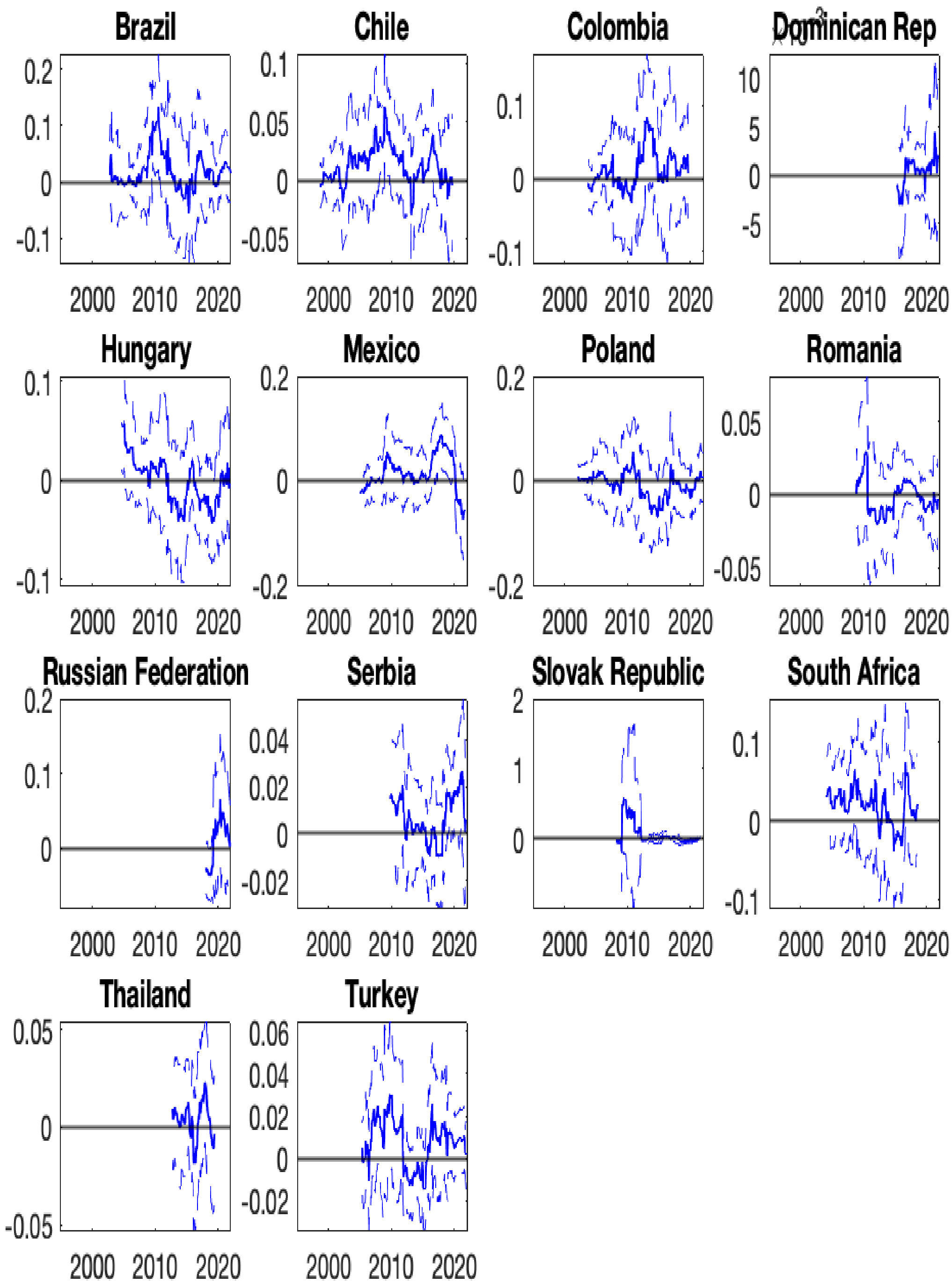


Figure 39: Inflation in EMEs

Notes:This figure presents dynamic coefficient estimation for inflation in heterogeneous finite-difference Taylor (FDT-het.) model from 1995 to 2021 for 14 EMEs. Dashed lines are upper and lower bounds for 95% confidence interval.When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point.. It can be seen that none of the EMEs have persistently significant coefficient for inflation.

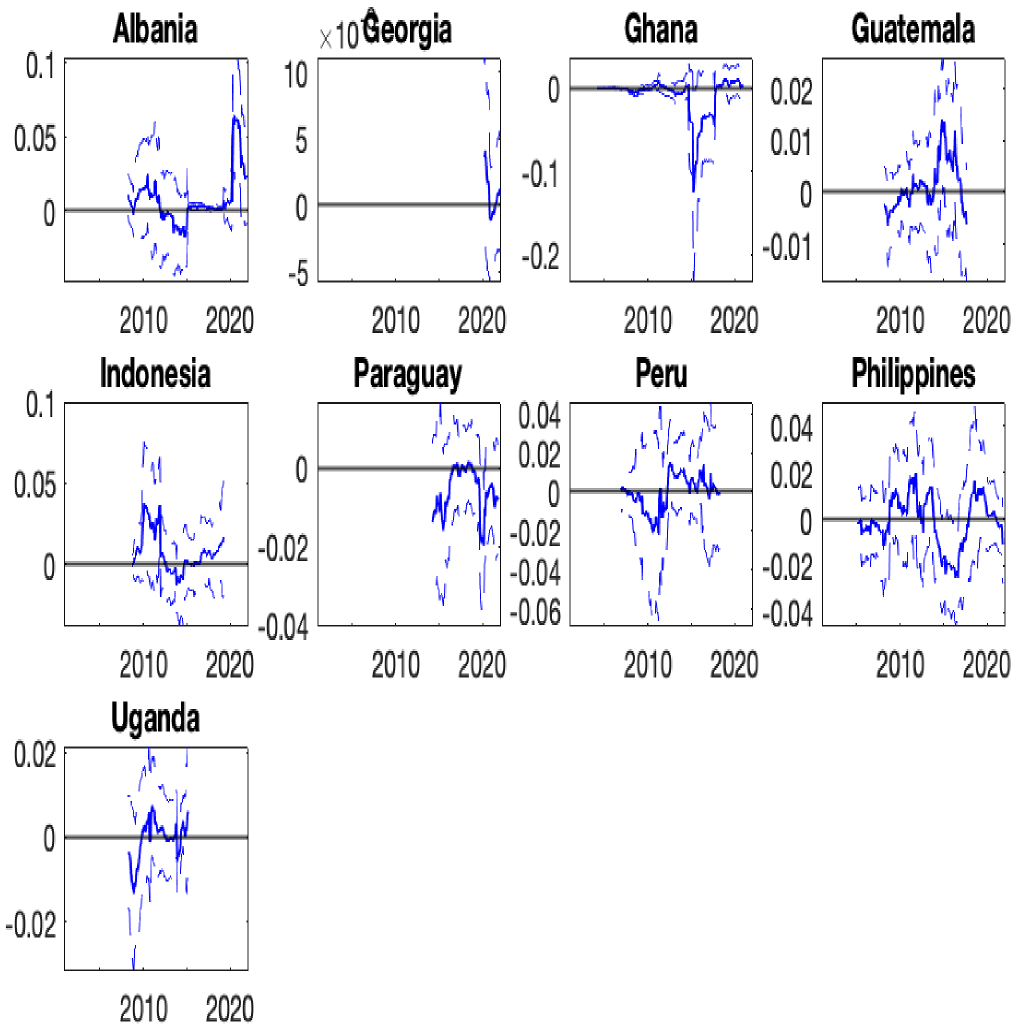


Figure 40: Inflation in LICs

Notes:This figure presents dynamic coefficient estimation for inflation in heterogeneous finite-difference Taylor (FDT-het.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the LICs have persistently significant coefficient for inflation.

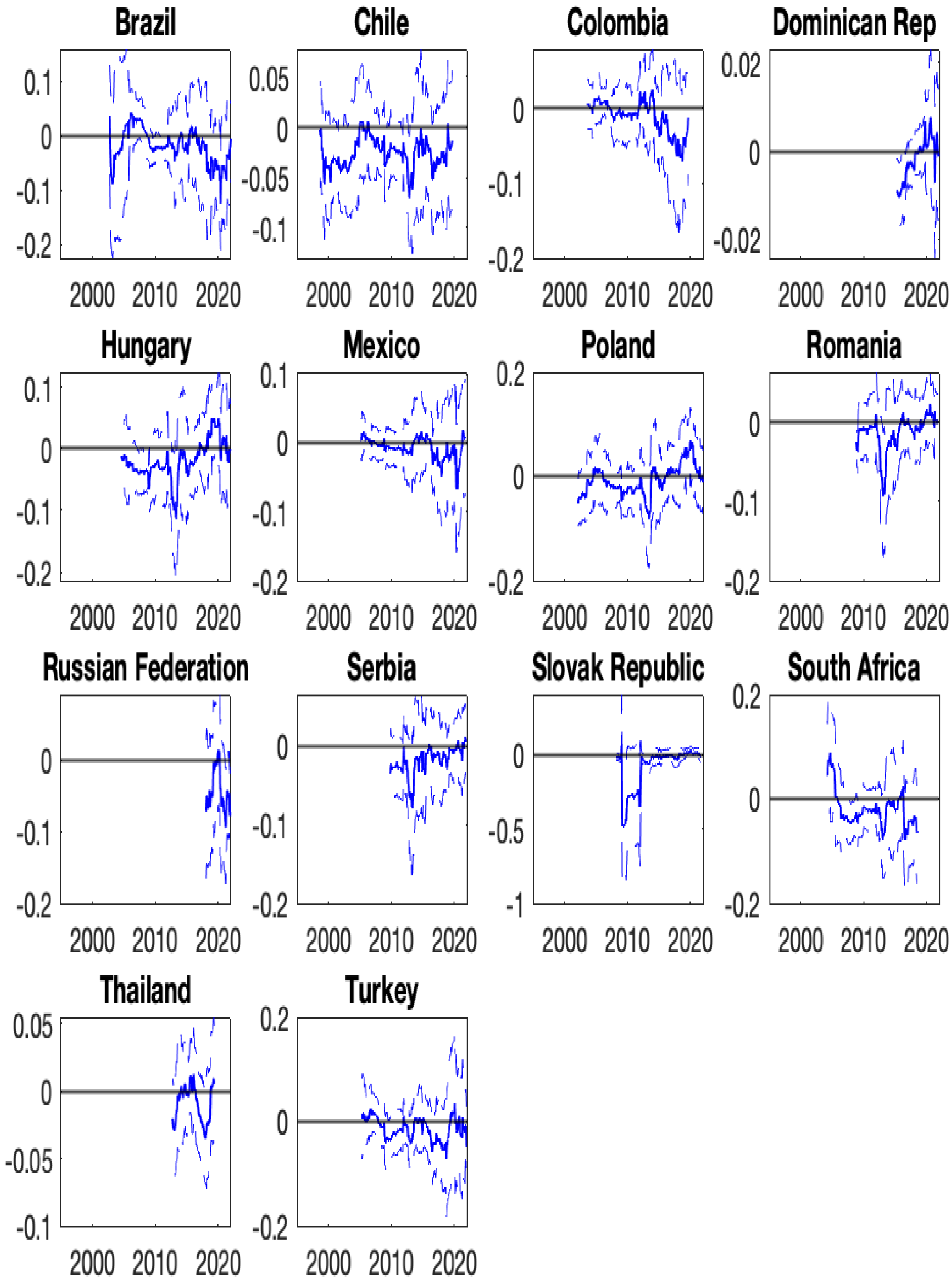


Figure 41: US Inflation (EME)

Notes:This figure presents dynamic coefficient estimation for US inflation in heterogeneous finite-difference Taylor (FDT-het.) model from 1995 to 2021 for 14 EMEs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the EMEs have persistently significant coefficient for US inflation.

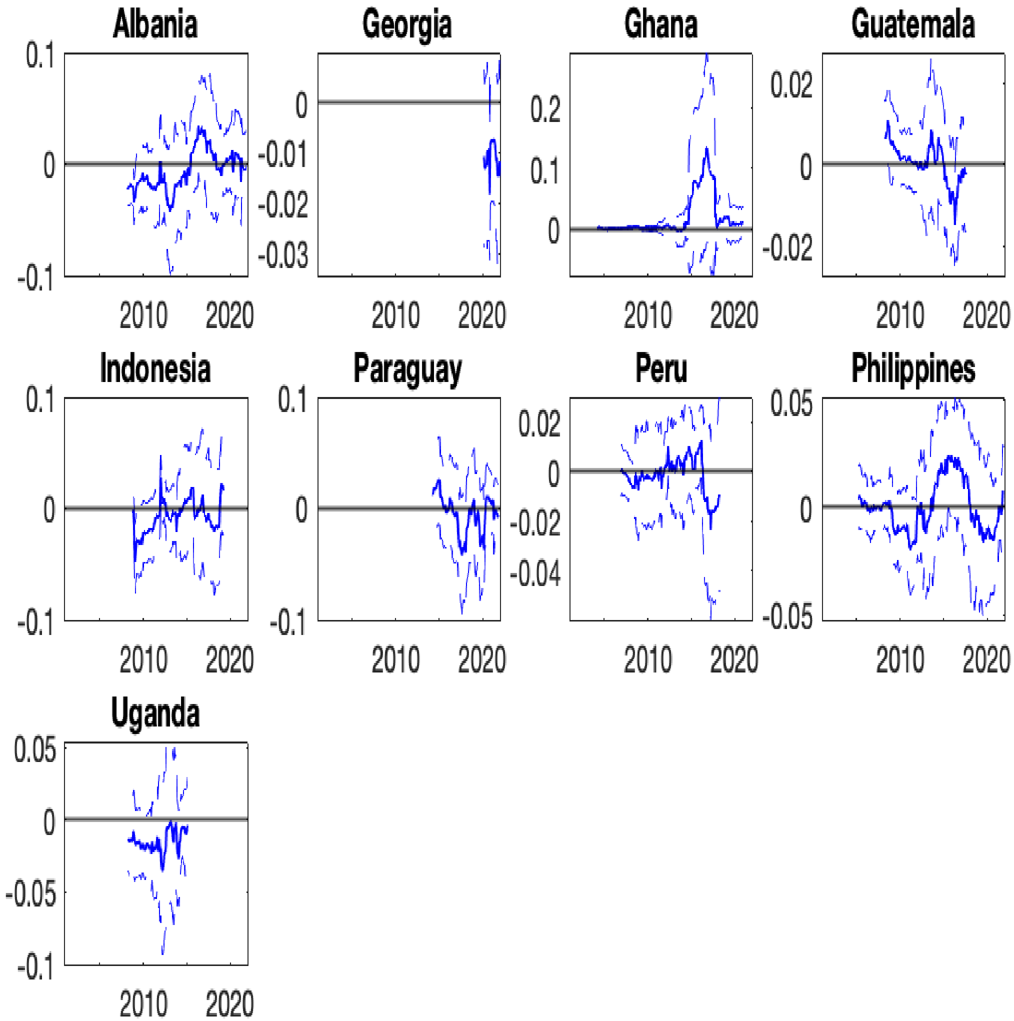


Figure 42: US Inflation (LIC)

Notes:This figure presents dynamic coefficient estimation for US inflation in heterogeneous finite-difference Taylor (FDT-het.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point.. It can be seen that none of the LICs have persistently significant coefficient for US inflation.

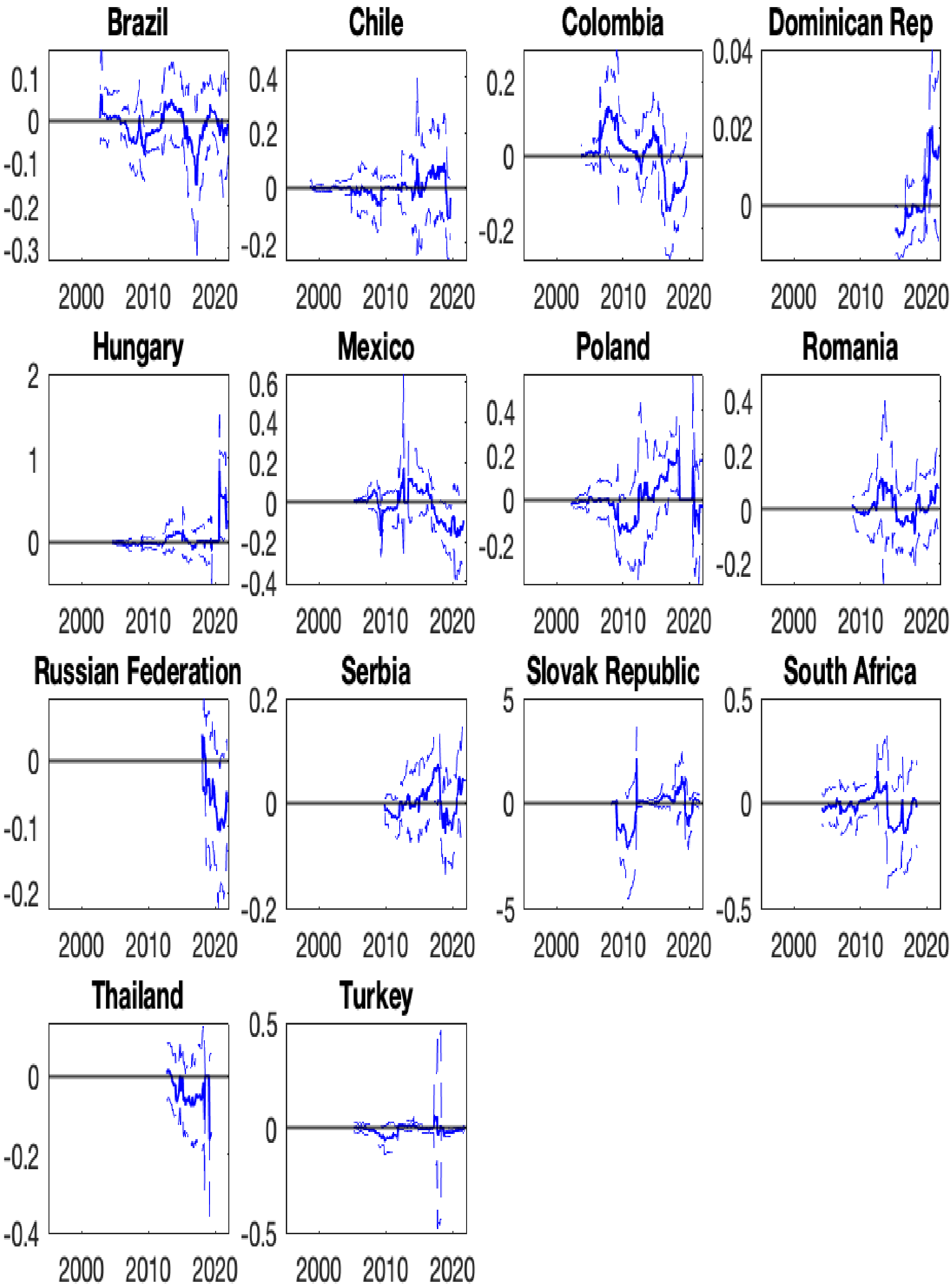


Figure 43: EME interest rate(EME)

Notes:This figure presents dynamic coefficient estimation for interest rate in heterogeneous finite-difference Taylor (FDT-het.) model from 1995 to 2021 for 14 EMEs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the EMEs have persistently significant coefficient for interest rate.

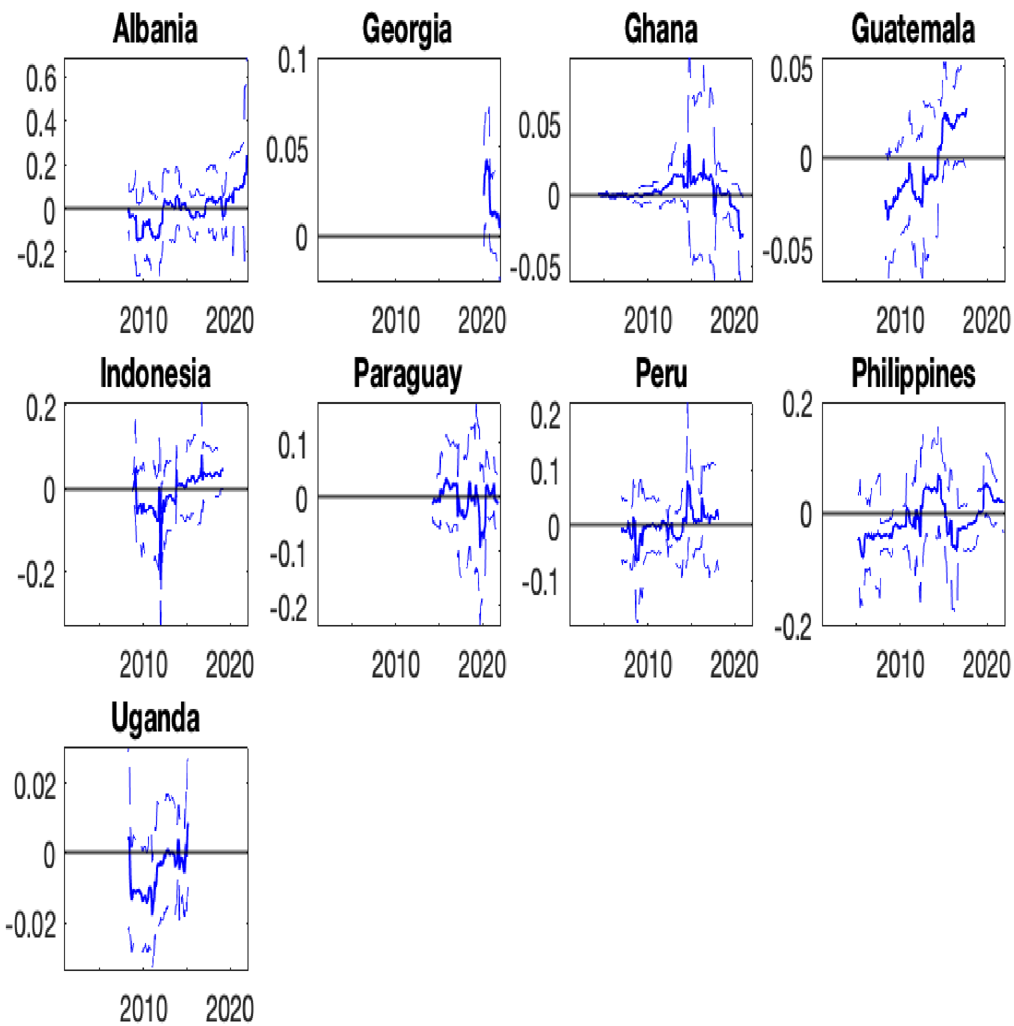


Figure 44: LIC interest rate(LIC)

Notes:This figure presents dynamic coefficient estimation for interest rate in heterogeneous finite-difference Taylor (FDT-het.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point.. It can be seen that none of the LICs have persistently significant coefficient for interest rate.

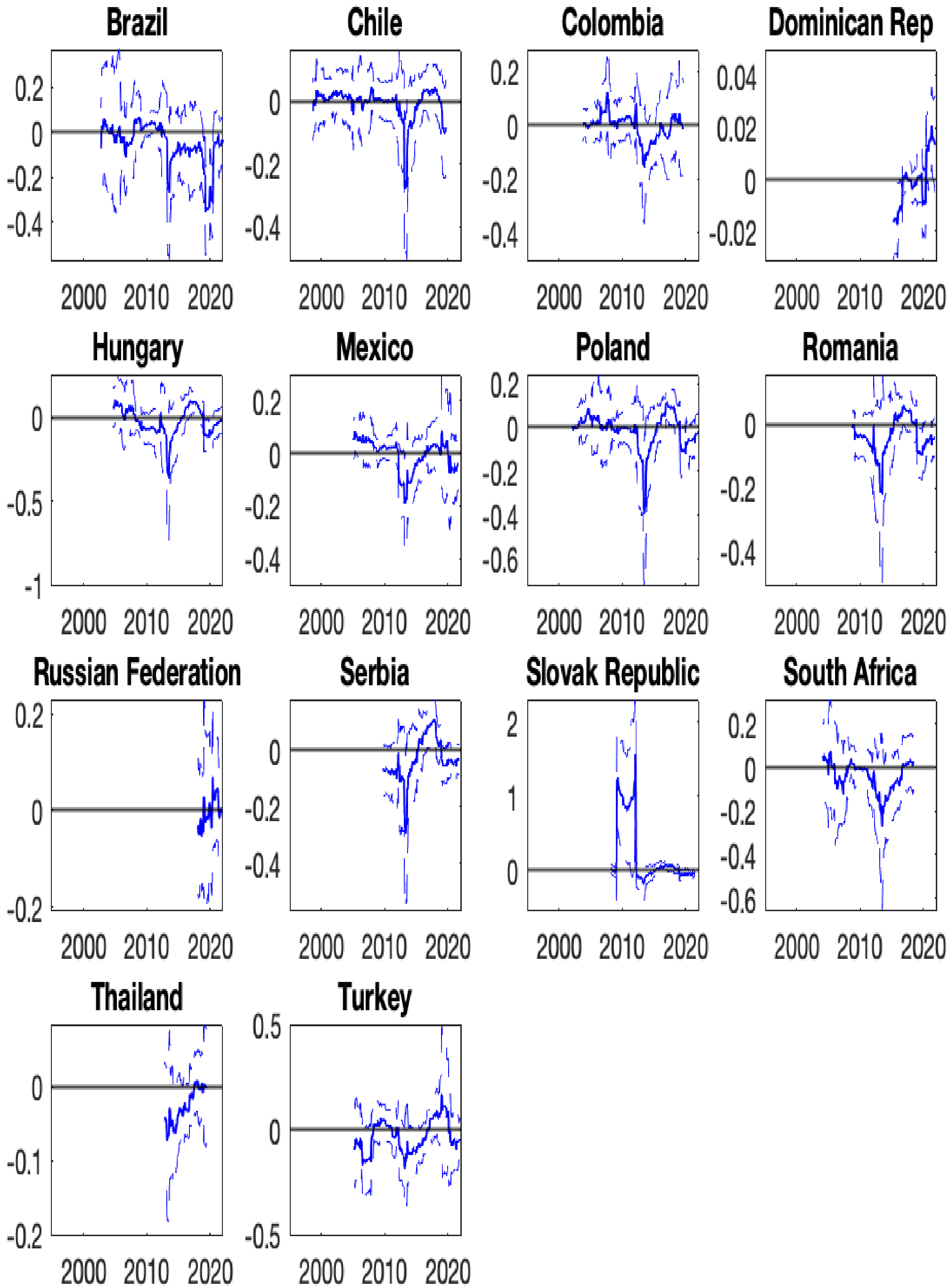


Figure 45: US interest rate(EME)

Notes:This figure presents dynamic coefficient estimation for US interest rate in heterogeneous finite-difference Taylor (FDT-het.) model from 1995 to 2021 for 14 EMEs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the EMEs have persistently significant coefficient for US interest rate.

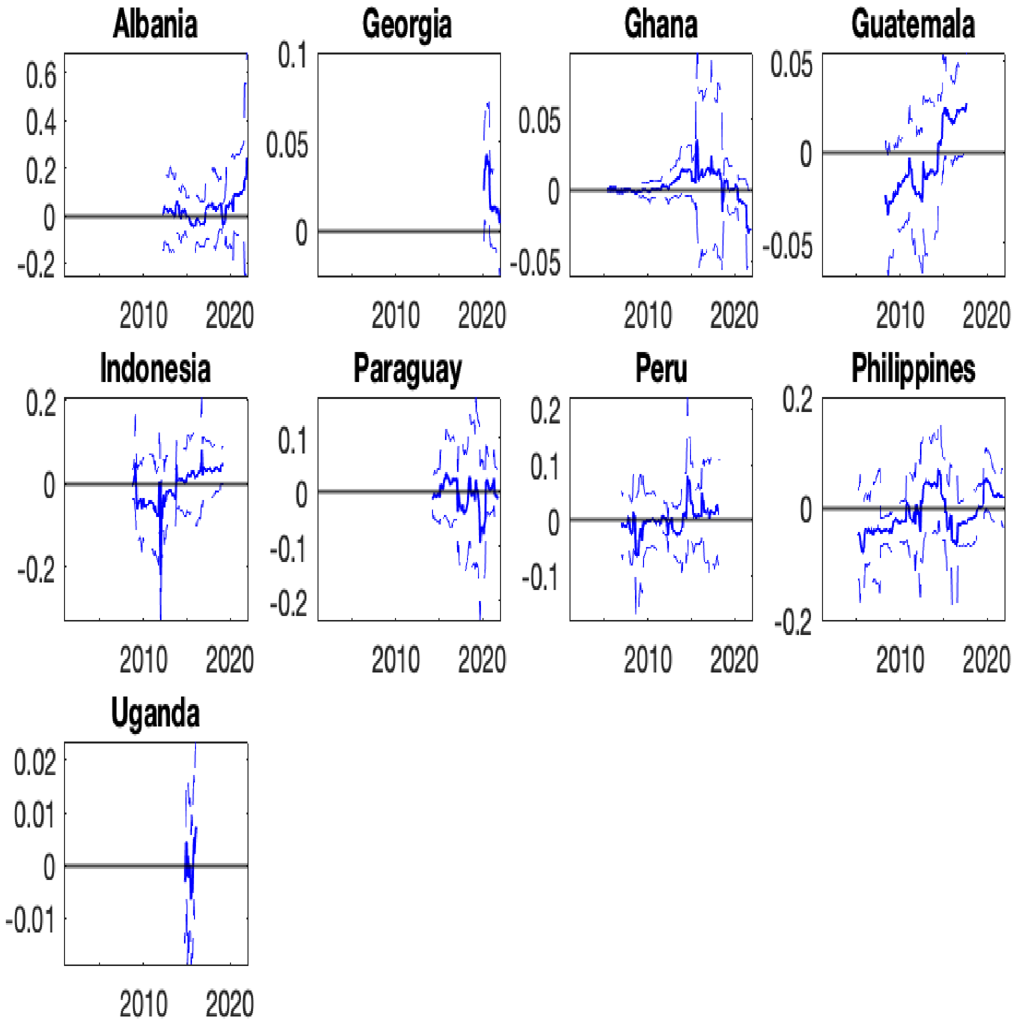


Figure 46: US interest rate(LIC)

Notes:This figure presents dynamic coefficient estimation for US interest rate in heterogeneous finite-difference Taylor (FDT-het.) model from 2001 to 2021 for 9 LICs. Dashed lines are upper and lower bounds for 95% confidence interval. When zero value is inside the confidence interval, it implies that estimated coefficient is indifferent relative to zero at that time point. It can be seen that none of the LICs have persistently significant coefficient for US interest rate.

Statutory Declaration:

I declare that I have developed and written the enclosed PhD Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. The PhD Thesis was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

Nottingham, 14th Jan 2023 — Wenjiao Hu