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Shadow rates as a measure of the monetary policy stance: Some international evidence

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Abstract

This paper examines the usefulness of shadow rates to measure the monetary policy stance by comparing them to the official policy rates and those implied by three types of Taylor rules in both inflation-targeting countries (the UK, Canada, Australia and New Zealand) and others that have only targeted inflation at times (the United States, Japan, the Euro Area and Switzerland) over the period from the early 1990s to December 2021. Shadow rates estimated from a dynamic factor model are shown to suggest a much looser policy stance than either the official policy rates or those implied by the Taylor rules, and generally to provide a more accurate picture of the monetary policy stance during both ZLB and non-ZLB periods, since they reflect the full range of unconventional policy measures used by central banks. Furthermore, generalised impulse response analysis based on three alternative vector autoregression (VAR) models indicates that monetary shocks based on the shadow rates are more informative than those related to the official policy rates or to two- and three-factor shadow rates, especially during the Global Financial Crisis and the recent COVID-19 pandemic, when unconventional measures have been adopted. Finally, unconventional policy shocks seem to have less persistent effects on the economy in countries, which have adopted an inflation-targeting regime.

KEYWORDS
dynamic factor models, inflation targeting, monetary policy stance, shadow rates

JEL CLASSIFICATION
C38, E43, E52, E58

1 | INTRODUCTION

In recent years, a number of countries have had to lower interest rates to near-zero levels and to adopt unconventional measures to mitigate the impact of the Global Financial Crisis and of the COVID-19 pandemic on financial markets and the economy as a whole. As a result, it has become less straightforward to assess the monetary policy stance, since official policy rates do not reflect the full range of measures adopted by central banks. It has therefore been suggested that shadow rates taking those into account might be more informative about monetary policy. This issue has been analysed in several papers. For example, Lombardi and Zhu (2018) estimated shadow rates using dynamic factor models and compared them with those implied by the Taylor rule and the actual Federal Funds rate in the United States; they showed that shadow rates are a more accurate measure of monetary policy during the zero lower bound (ZLB) period, that is when the Federal Funds rate was near zero.[1] Bernanke et al. (2019) also showed that shadow rates obtained from stochastic simulation models represent the monetary policy stance well for the United States and deliver better economic outcomes during the ZLB period than Taylor rule implied rates. Wu and Zhang (2019), on the other hand, found that Taylor rules are able to explain the behaviour of the shadow rate during both ZLB and non-ZLB periods and thus provide a more accurate picture of monetary policy.

This paper revisits these issues and extends previous work in two ways. First, it carries out the analysis for a wider set of countries including both inflation-targeting ones (namely the UK, Canada, Australia and New Zealand), and others which have targeted the inflation rate only at times (more precisely the United States, Japan, the Euro Area and Switzerland). Second, it includes both the Global Financial Crisis and the COVID-19 pandemic period, during which unconventional monetary policies were used by major central banks. Using shadow rates computed from a dynamic factor model, it assesses their usefulness to measure the monetary policy stance by comparing them to the official policy rates and to those implied by three types of Taylor rules (namely a classical, an extended and an interest rate smoothing Taylor rule). It then also examines monetary policy shocks based on shadow and official rates respectively to establish how informative they are. These are obtained by estimating generalised impulse response functions (Pesaran & Shin, 1998) from two alternative vector autoregression (VAR) models; using this method, which, unlike others, is invariant to the ordering of the variables, is an additional contribution of our study to the literature on this topic. Our analysis shows that using our preferred measure of the shadow rate, which takes into account unconventional policies such as asset purchases, it is possible to capture more accurately monetary shocks, especially in inflation-targeting countries and during crisis periods, than when relying on alternative estimates from two-factor (Krippner, 2015a) or three-factor (Wu & Xia, 2016) shadow rate models.

The remainder of the paper is structured as follows: Section 2 briefly reviews the relevant literature; Section 3 outlines the methodology used for the analysis; Section 4 discusses the data and the empirical results; Section 5 offers some concluding remarks.

[1]The ZLB period is normally defined as any period during which the official central bank policy rate was at or below 25 basis points; this definition is also used in the present paper.

2 | LITERATURE REVIEW

The literature on the effects of unconventional monetary policy includes numerous papers constructing shadow policy rates and comparing them to those implied by monetary policy rules. For instance, Bauer and Rudebusch (2013) obtained shadow rates from dynamic term structure models and found that they were similar to the policy rates based on a Taylor rule; however, they advised against using the former to evaluate the monetary policy stance owing to their model dependence and the limited information provided for this purpose by the short end of the term structure. Lombardi and Zhu (2018) also used a dynamic factor model to estimate a shadow policy rate for the United States and reported that this tracks the Federal Funds rate very closely both during ZLB and non-ZLB periods and is a good measure of the policy stance vis-à-vis Taylor rule benchmarks; moreover, they showed that monetary policy shocks estimated from VAR models including the shadow rate provide a much more accurate picture of monetary policy than those based on the official policy rate during periods characterised by unconventional measures.

Bernanke et al. (2019) analysed 10 different monetary policy rules at the ZLB and found that shadow rate rules (in which the first difference in the shadow rate depends on the weighted sum of the inflation and output gaps) outperform Taylor rules. Wu and Zhang (2019) developed a New Keynesian model with a shadow rate, which captures both the standard interest rate rule during normal times and unconventional monetary policy during the ZLB period; in the latter, the central bank follows a shadow rate Taylor rule implying a negative rate, which is achieved through measures such as quantitative easing (QE) and lending policies; moreover, the shadow rate is found to track very well an index of financial conditions which is strongly correlated with the Fed's balance sheet. Ajevskis (2020) estimated a natural rate of interest from a shadow rate term structure model for the Euro Area and the United States and used it in the balance-approach version of the Taylor rule; he found that the rates implied by the latter were in line with the official policy ones. Ellington (2021) extended the model by Wu and Zhang (2019) and investigated the effectiveness of unconventional monetary policies under a binding ZLB constraint using time-varying coefficient VAR models of the shadow rate implied by the Taylor rules. He found that the shadow rate is a useful indicator of the monetary policy stance and that the sensitivity of economic fundamentals to shadow rate shocks has remained unchanged during the ZLB period, whilst that of GDP growth and inflation to Federal funds rate shocks has increased.

It should be noted that there are different possible ways to estimate shadow rates, the three most commonly used ones being three-factor term structure models (Wu & Xia, 2016), two-factor affine term structure models (Krippner, 2015a) and dynamic factor models (Lombardi & Zhu, 2018). The available empirical evidence suggests that the two-factor models produce the shadow rates most closely tracking the official policy rate and provide the most accurate assessment of the monetary policy stance during ZLB periods (Anderl & Caporale, 2022; Krippner, 2015b). However, shadow rates based on yield curve parameters generally contain a lot of noise, since they reflect market interest rate expectations which can be influenced by factors other than changes in monetary policy. By comparison, the dynamic factor model suggested by Lombardi and Zhu (2018), which extracts information from various central bank balance sheet items, is a much more reliable measure of the policy stance during unconventional periods.

3 | EMPIRICAL FRAMEWORK

3.1 | Shadow policy rate models

Following Lombardi and Zhu (2018), we estimate the shadow rate by specifying a dynamic factor model of the following form:

$$X_t = \Lambda F_t + u_t \tag{1}$$

where X_t is a time series with T observations and dimension N, F_t is an $r \times 1$ vector of factors, Λ is an $N \times r$ matrix of factor loadings, and u_t are idiosyncratic components, which are orthogonal to the factors. These are assumed to follow a VAR(p) process of the form:

$$F_t = \sum_{i=1}^{p} A_i F_{t-i} + e_t \tag{2}$$

where A_i is the coefficient matrix on past lags of the factors. Since both u_t and e_t are assumed to be *i.i.d*. and Gaussian, the dynamic factor model can be written in a state-space form and estimated with the Kalman filter. Economic variables are selected from a large dataset of monetary policy indicators to obtain the factors. The model is then estimated with the quasi maximum likelihood estimator based on the expectation maximisation (EM) algorithm proposed by Doz et al. (2012); this is similar to a two-step estimator but uses a Kalman filtering procedure, which is iterated until EM convergence is achieved and is robust to model misspecification. Furthermore, the Hallin and Liška (2007) and the Bai and Ng (2002) criteria are used to select the optimal number of factors in the model, whilst the lag length is chosen on the basis of the Bayesian–Schwarz information criterion.

Krippner (2020) comments on the sensitivity of estimated shadow rates to minor choices in their estimation and suggests a number of diagnostic procedures to vet these series. We follow his vetting approach by applying the following two tests: first, we assess the proportion of time during which the shadow rate data violates the 25 basis point lower bound specification; second, we evaluate the mean of the root mean squared errors (RMSEs) of the estimated shadow rate model relative to the data used to assess the overall fit.

3.2 | Taylor rule interest rates

We estimate the interest rate implied by the Taylor rule using three different types of rules commonly used by central banks. The first one is the classical Taylor rule which takes the following form:

$$i_t = \pi_t + \beta_\pi(\pi_t - \overline{\pi}) + \beta_y(y_t - \overline{y}_t) \tag{3}$$

where i_t is the central bank policy rate, π_t is the current rate of CPI inflation, $\overline{\pi}$ is the target rate of inflation, and $y_t - \overline{y}_t$ is the output gap estimated using the Hodrick–Prescott filter (Hodrick & Prescott, 1997). We set $\overline{\pi}$ equal to 2 for all countries, whilst the coefficients on the inflation gap β_π and the output gap β_y are set equal to 1.5 and 0.5, respectively (Gerlach & Schnabel, 2000; Taylor, 1993). The extended version of the Taylor rule for open economies which includes the real exchange rate is specified as follows:

$$i_t = \pi_t + \beta_\pi(\pi_t - \overline{\pi}) + \beta_y(y_t - \overline{y}_t) + \beta_q q_t \tag{4}$$

where q_t is the real effective exchange rate, and all other variables are defined as before. The coefficient β_q on the real exchange rate is set equal to 0.25 following the existing literature in which it is normally between 0.25 and 0.5 (Froyen & Guender, 2018; Papadamou et al., 2018), whilst the coefficients on the inflation and output gaps are again set equal to 1.5 and 0.5, respectively. Finally, we consider a Taylor rule with interest rate smoothing:

$$i_t = \rho i_{t-1} + (1 - \rho)\left(\pi_t + \beta_\pi(\pi_t - \overline{\pi}) + \beta_y(y_t - \overline{y}_t)\right) \tag{5}$$

where all variables are defined as before, and ρ is the smoothing parameter measuring the gradual adjustment over time of the current interest rate to the target rate. In most empirical studies, the interest rate smoothing parameter has been estimated to be between 0.78 and 0.92 (see, for instance, Amato & Laubach, 1999; Rudebusch, 2002; Sack & Wieland, 2000); we use its average value of 0.85 in our analysis. The Taylor rules are estimated using ex post rather than real time data, since the former are more accurate.

3.3 | A VAR model with monetary policy shocks

In order to assess the usefulness of the shadow rate to analyse monetary shocks, we estimate the following VAR model (henceforth VAR Model (1)) similar to Bernanke and Blinder (1992):

$$V_t = \sum_{i=1}^{p} B_i V_{t-i} + \varepsilon_t \tag{6}$$

where V_t is a vector of variables entering the model, B_i is the coefficient matrix, and ε_t is a vector of error terms. The variables included are the log of real GDP and CPI inflation, respectively, and either the central bank policy rate or the shadow rate. We are then able to obtain two types of monetary policy shocks, one related to the shadow policy rate and the other to the official policy rate. For this purpose, we estimate generalised impulse response functions, which do not require orthogonalisation of the shocks and are invariant to the ordering of the variables in the model (Pesaran & Shin, 1998). Although the estimated generalised impulse responses are not structural shocks, they capture well-historical correlations between the various shocks and are preferable to orthogonalised shocks requiring (to some extent arbitrary) parameterisation. Therefore they provide more robust results and allow for a meaningful interpretation of the immediate impact response of each variable to shocks to any other variables (Ewing & Payne, 2005). We also estimate a second VAR model (henceforth VAR Model (2)), similar to that suggested by Christiano et al. (1996), which includes the log of total reserves, the log of non-borrowed reserved and the log of a commodity price index as additional variables for the countries for which these series are available, that is the UK and the United States. In addition, we estimate the VAR specification suggested by Bernanke and Blinder (1992), but instead of the log of real GDP, we include the GDP growth rate in the model (henceforth referred to as VAR Model (3)) since Taylor rules are based on de-trended variables. We use the Akaike information criterion to select the optimal lag length. The aim of the analysis is to establish whether shocks related to the shadow rates provide a more accurate picture of monetary policy during times when interest rates were near zero or negative.

As a robustness check of the suitability of our estimated shadow rates, we also obtain the Wu and Xia (2016) and the Krippner (2015a) shadow rates for the countries for which they are available and estimate the corresponding VAR models for comparison purposes. Following the suggestion by Krippner (2020), we use the Candelon and Lütkepohl (2001) structural break test to rank our VAR models and to assess the time-invariance of the relationship between the shadow rate and macroeconomic data.

4 | DATA AND EMPIRICAL RESULTS

4.1 | Data description

We use monthly data for the UK, Canada, Australia and New Zealand, namely countries which have adopted an official inflation-targeting regime since the early 1990s, and also for the United States, Japan, the Euro Area and Switzerland, which have instead had other frameworks in place and only targeted inflation at times. The sample ends in December 2021 in all cases, whilst the start date differs across countries depending on data availability (see Appendix 1 for details).

The central bank policy rates for all countries are taken from the Bank for International Settlements database. The source for the real GDP and CPI inflation series are the OECD Main Economic Indicators and Inflation (CPI) databases, respectively, for all countries, except for the inflation series for Australia and New Zealand, which are instead obtained from the Bank for International Settlements Consumer Price Index database. Real effective exchange rates are taken from the Bank for International Settlements Effective Exchange Rate Narrow Indices database for all countries. Commodity price indices and total non-borrowed reserves are from the Bank of England statistics database for the UK and from the Federal Reserve Bank of St Louis Economic database for the United States, and total reserve

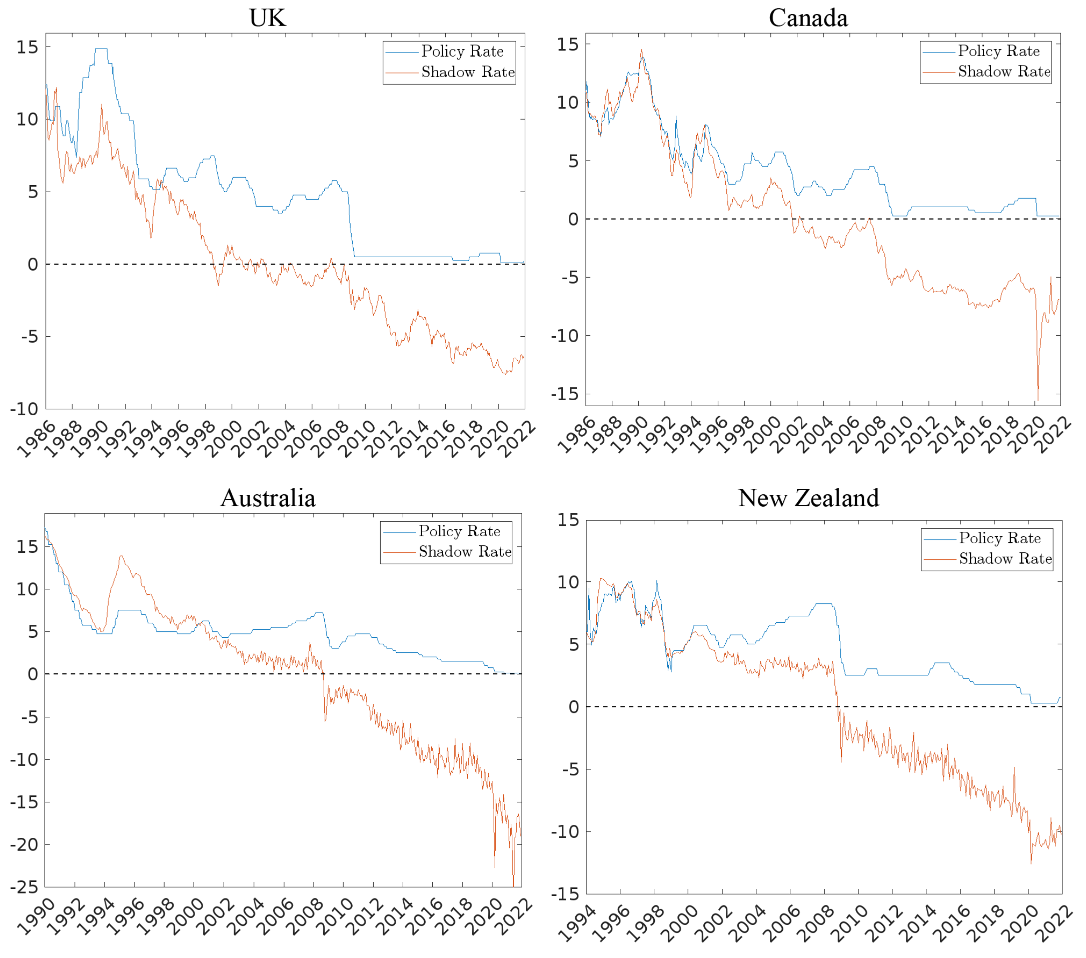

FIGURE 1 Shadow rate and central bank policy rate for inflation-targeting countries

data from the Federal Reserve Bank of St Louis economic database for both the UK and the United States—these series are unfortunately not available for the other countries in our sample.[2]

The dataset for the dynamic factor model includes variables from different categories, more precisely: (1) interest rates, (2) monetary aggregates, (3) balance sheet assets and (4) balance sheet liabilities. Details of these variables and their sources for all countries can be found in Appendix 2. Including long-term yield data and central bank balance sheet items allows us to capture the full range of unconventional monetary policies ranging from forward guidance to large-scale asset purchases. We obtain the Krippner (2015a) two-factor shadow short rates from LJK Limited for all countries in our sample, starting in January 1995, and also the Wu and Xia (2016) three-factor rates from the Cynthia Wu shadow rate database (https://sites.google.com/view/jingcynthiawu/shadow-rates) for the United States, the UK and the Euro Area. Note that the Wu and Xia (2016) shadow rates are only available from January 1990 for the United States and the UK and from September 2004 for the Euro Area.

[2]The Bank for International Settlements provides extensive datasets with central bank statistics, but only at quarterly frequency, which is unfortunately not suitable for the analysis carried out in the present paper at a monthly frequency.

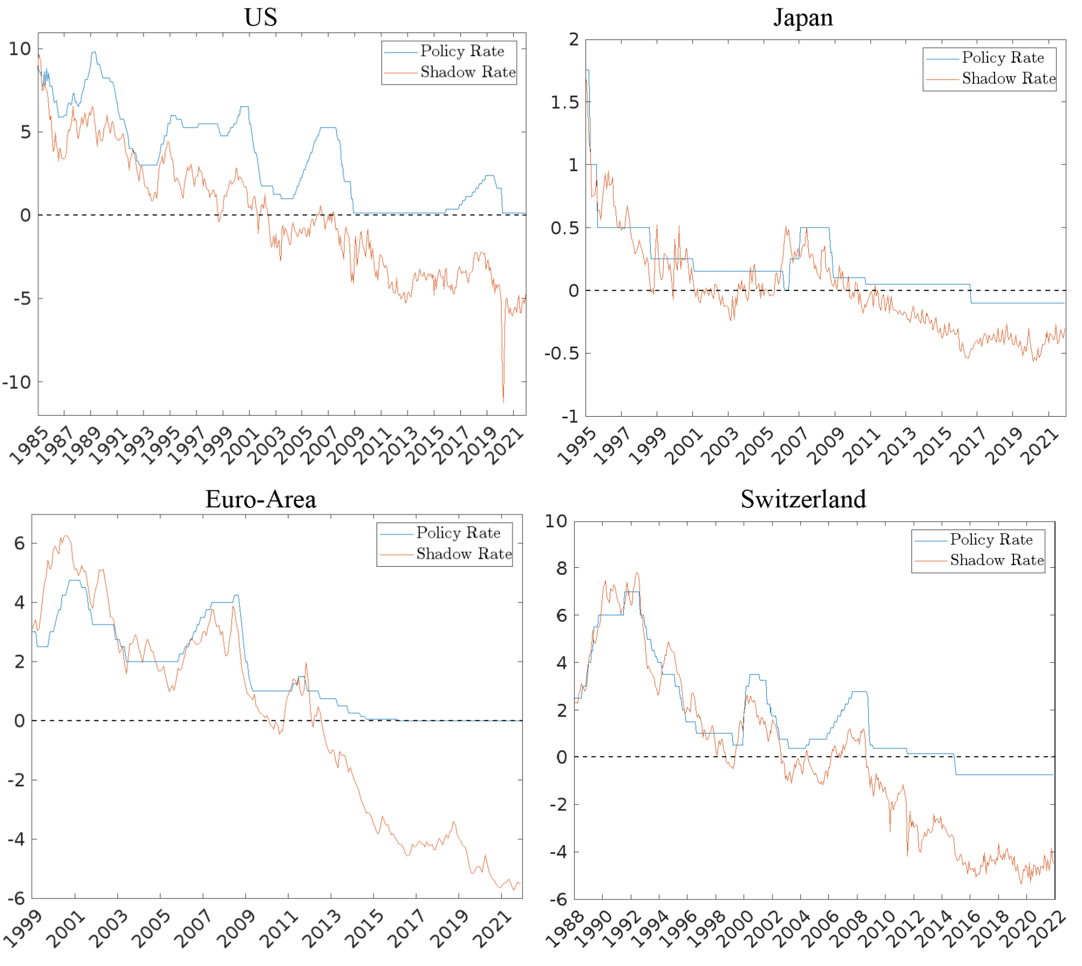

FIGURE 2 Shadow rate and central bank policy rate for non-targeting countries

TABLE 1 Shadow rate vetting tests

	Lower bound violation of estimated shadow rate	Lower bound violation of Wu and Xia shadow rate	Lower bound violation of Krippner shadow rate	RMSE
UK	60	41	35	1.09960
Canada	56		18	0.05275
Australia	42		7	1.65110
New Zealand	47		5	0.79500
US	54	25	35	0.15711
Japan	77		87	0.02800
Euro Area	47	65	40	0.19992
Switzerland	53		52	0.09467

Note: Krippner (2020) shadow rate vetting tests. Lower bound violation of the shadow rate against the data in percentage. RMSE of the shadow rate model against the data.

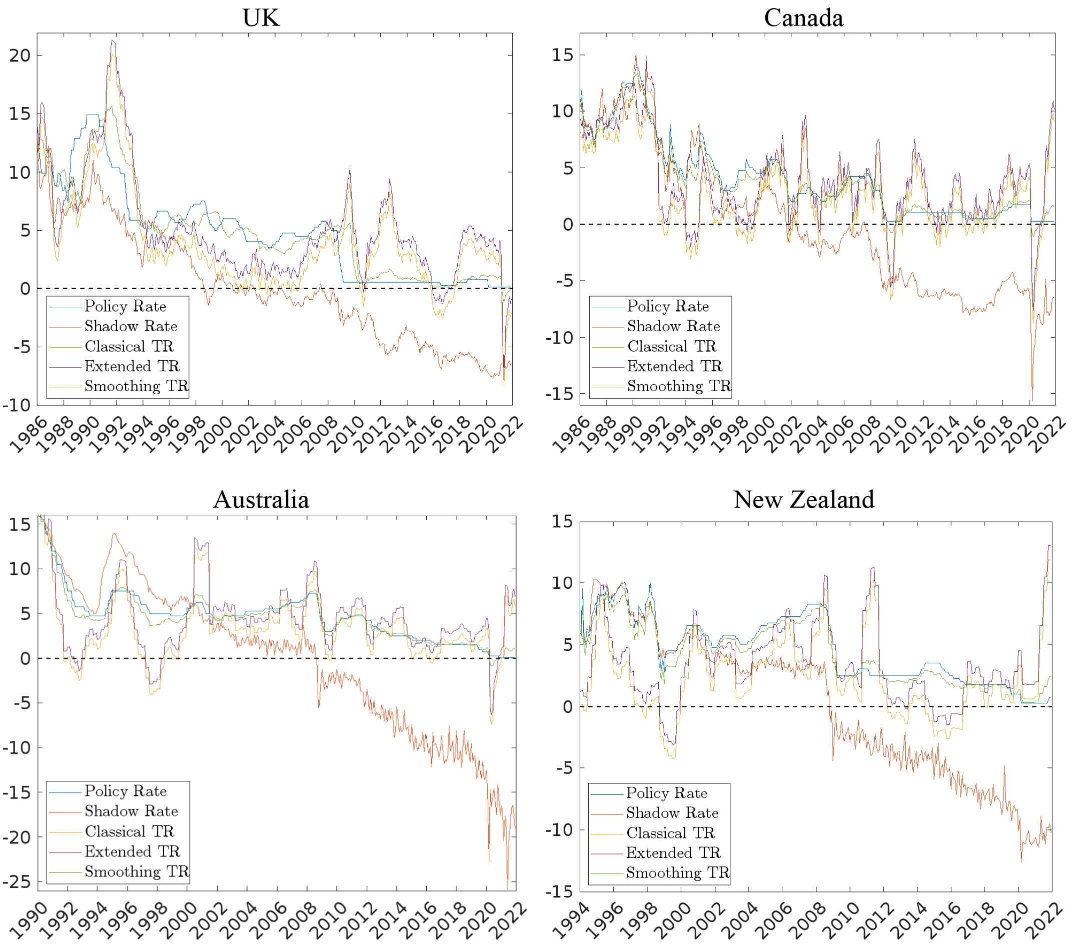

FIGURE 3 Policy rate, shadow rate and Taylor rule rates for inflation-targeting countries

4.2 | Shadow policy rates

Figures 1 and 2 display the estimated shadow rates together with the official policy ones in the inflation-targeting countries and the non-targeting ones, respectively. It can be seen that the shadow rate tracks the official policy rate very closely during the non-ZLB period in the case of Canada, New Zealand, the Euro Area and Switzerland, but less closely in all other countries. In contrast to Lombardi and Zhu (2018), who focused on the United States only, we find that shadow rates have tracked the policy rates less closely since the early 2000s in most countries: the former are based on a much wider range of policy indicators, whilst the latter do not accurately represent the full range of policy actions taken by central banks. In particular, during ZLB periods, shadow rates turn negative for all countries, as they reflect the full range of unconventional monetary stimulus measures adopted by central banks during the Global Financial Crisis and the COVID-19 pandemic. Their behaviour implies that the monetary stance was in fact much looser for a longer period of time than indicated by the official policy rate, even in the countries that allowed interest rates to become negative, that is Japan, the Euro Area and Switzerland. In fact, the monetary policy stance remained loose for the entire period from the Global Financial Crisis up until and including the recent COVID-19 pandemic, during which it became even looser as a result of further expansions of the balance sheets of central banks.

We report the results of the shadow rate vetting exercises suggested by Krippner (2020) in Table 1 below. As can be seen, the shadow rates violate the 25 basis point lower bound specification about half of the time, which is a

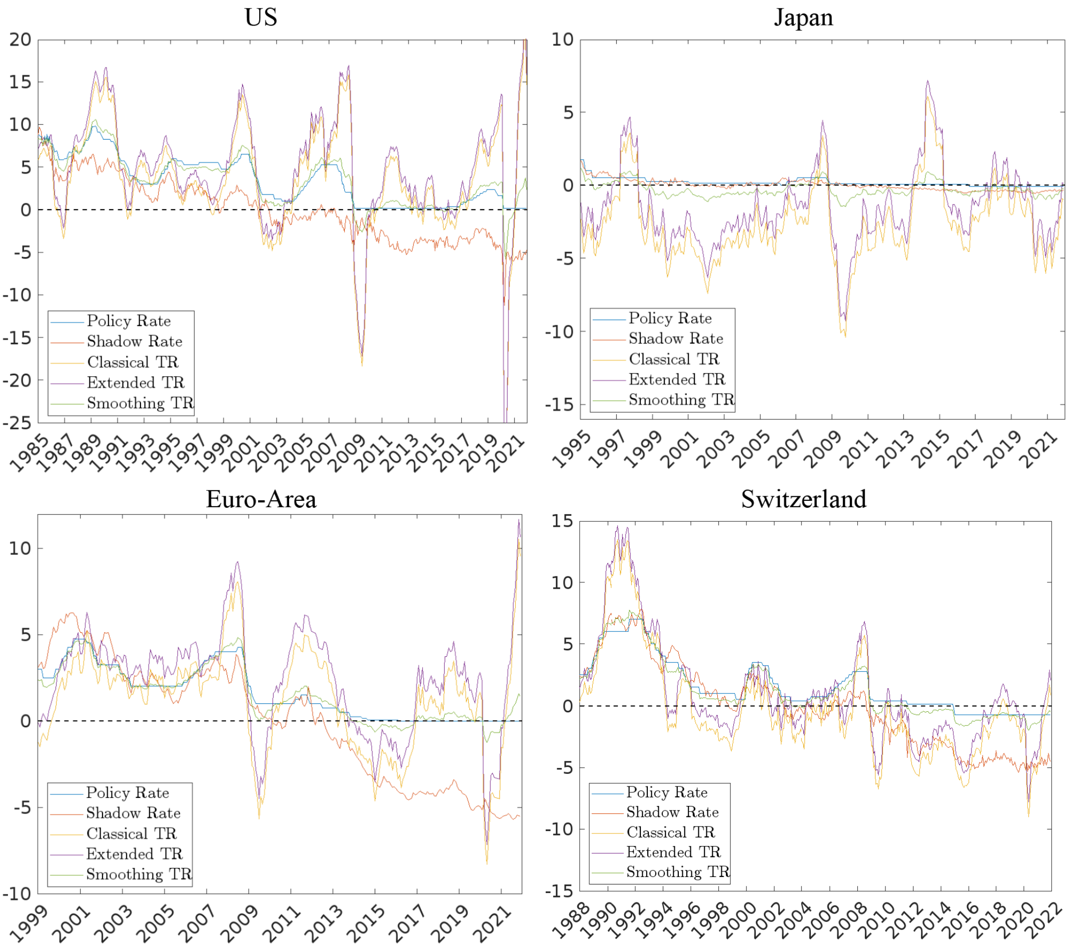

FIGURE 4 Policy rate, shadow rate and Taylor rule rates for non-targeting countries

plausible finding given the fact that our sample includes both the Global Financial Crisis period and the COVID-19 pandemic, during which interest rates remained low and unconventional monetary policies were used. Note that our shadow rates violate the lower bound specification fewer times than was found by Krippner (2020). We also include the Wu and Xia (2016) and Krippner (2020) shadow rates for comparison for the countries for which they are available; fewer violations occur in the case of these rates, which are based on two- or three-factor models and in particular on the term structure of the yield curve. These rates are noisier than our estimated shadow rates reflecting the state of central bank balance sheets, and appear to capture less accurately the monetary stance. The RMSE suggests that the estimated shadow rate model fits the data well.

4.3 | Taylor rule implied interest rates

Given that all countries in the sample have either adopted an inflation-targeting regime or at least targeted the inflation rate at times, it is interesting to compare in each case the rate implied by the Taylor rule to both the official and the shadow rate to assess the monetary policy stance. Figures 3 and 4 plot all three series for inflation-targeting and non-targeting countries, respectively. It is apparent that the interest rate implied by the Taylor rule with smoothing is the one tracking most closely the official policy rate in all countries. The rates implied by the classical and extended

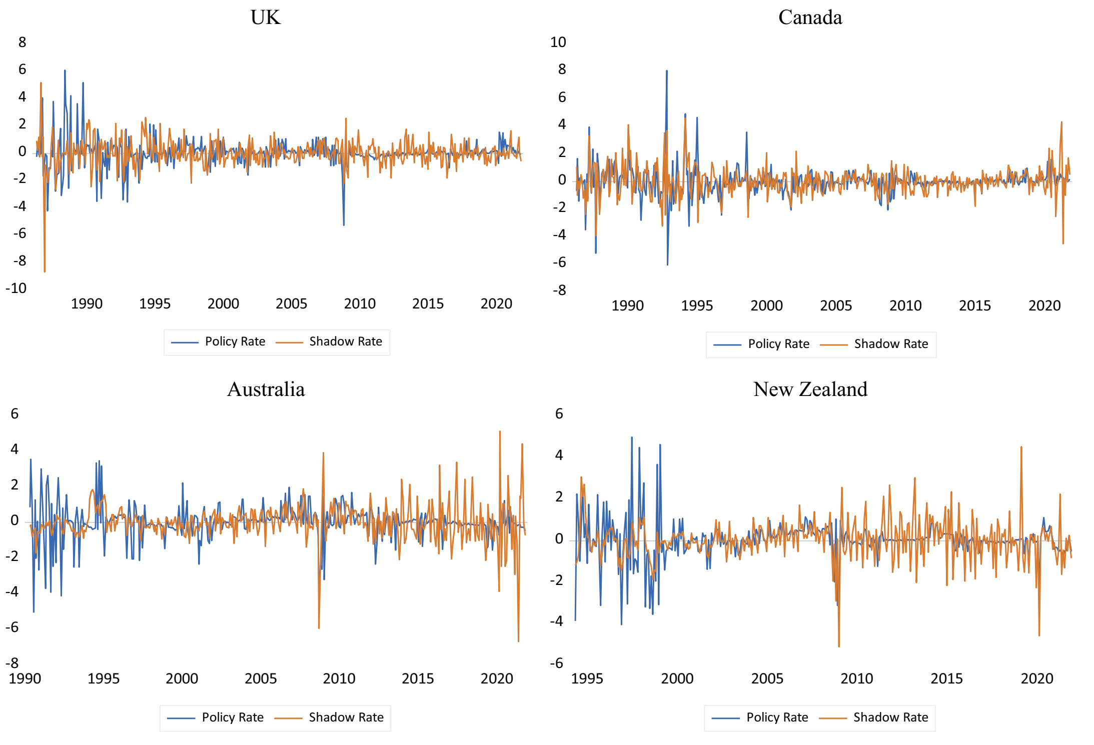

FIGURE 5 Monetary policy shocks from VAR model (1) for inflation-targeting countries

Taylor rules indicate that a much looser policy stance would have been required during the ZLB periods than that implied by the official rates, and even that in some cases negative rates would have been necessary. By contrast, the shadow rates are found to be consistently negative, especially since the early 2000s, which suggests that unconventional policy measures resulted in actual rates much closer than the official ones to those consistent with the Taylor rules during the ZLB periods, whilst during non-ZLB periods the monetary stance was much looser than required by those rules.

It is also noticeable that the shadow rates in inflation-targeting countries indicate a much looser policy stance compared with those implied by the Taylor rules than in non-targeting countries, that is that unconventional policies provided a greater stimulus in the former set of economies. One possible explanation for this finding is the higher central bank credibility usually found in inflation-targeting regimes, where it might be possible to anchor inflation expectations even in the presence of unconventional policies, and thus, central banks might have more freedom to deviate from their monetary policy rule temporarily to stimulate the economy during ZLB periods.

4.4 | VAR model results and impulse response functions

Next, we assess the usefulness of shadow rates to analyse monetary policy shocks. Figures 5 and 6 display the monetary policy shocks extracted from VAR model (1) as in Bernanke and Blinder (1992) for inflation-targeting and non-targeting countries respectively. It is clear that shocks based on the shadow rates are more informative during unconventional periods (when they do not track closely the policy rate), since they capture the effects of the wide range of measures (such as asset purchases and QE) adopted by most countries during the Global Financial Crisis and the COVID-19 pandemic. By contrast, during normal periods, such as the 1990s, shocks based on the policy

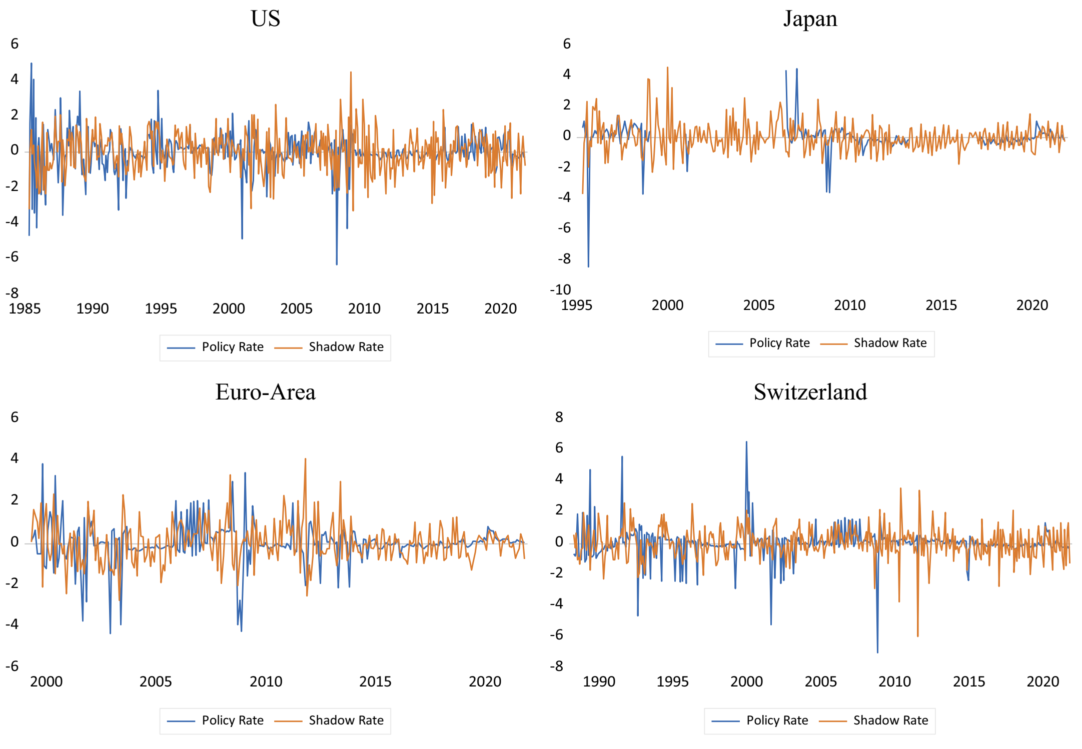

FIGURE 6 Monetary policy shocks from VAR model (1) for non-targeting countries

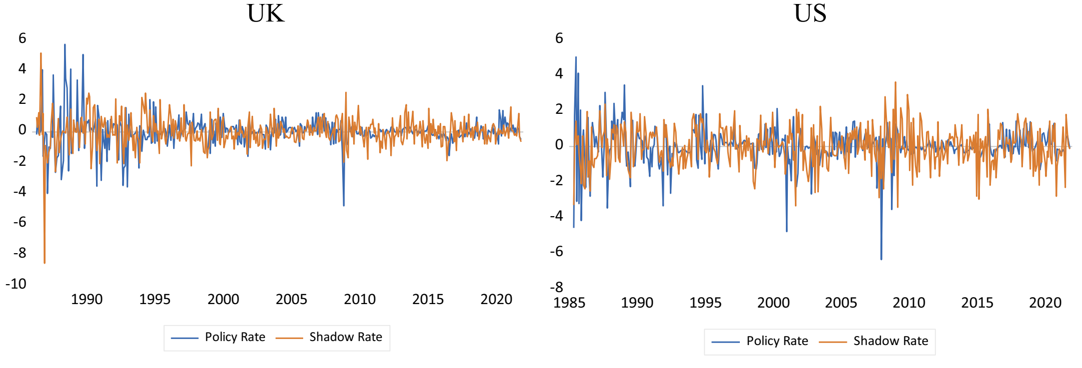

FIGURE 7 Monetary policy shocks from VAR model (2) for the UK and the United States

rates yield a sufficiently accurate picture. The difference between inflation-targeting and non-targeting countries is quite apparent during the COVID-19 pandemic, during which the shadow rate is able to capture the effects of asset purchases well in the former set of countries, which resorted to such measures heavily during this period, compared with the latter, who engaged in these policies to a lesser extent. It appears therefore that especially in inflation-targeting countries, the shadow rate is a much better measure of the monetary policy stance during periods characterised by unconventional policies. In some instances, balance sheet expansions took place at a much faster rate than during the Global Financial Crisis, which explains the much more sizable effects of monetary shocks during the COVID-19 period.

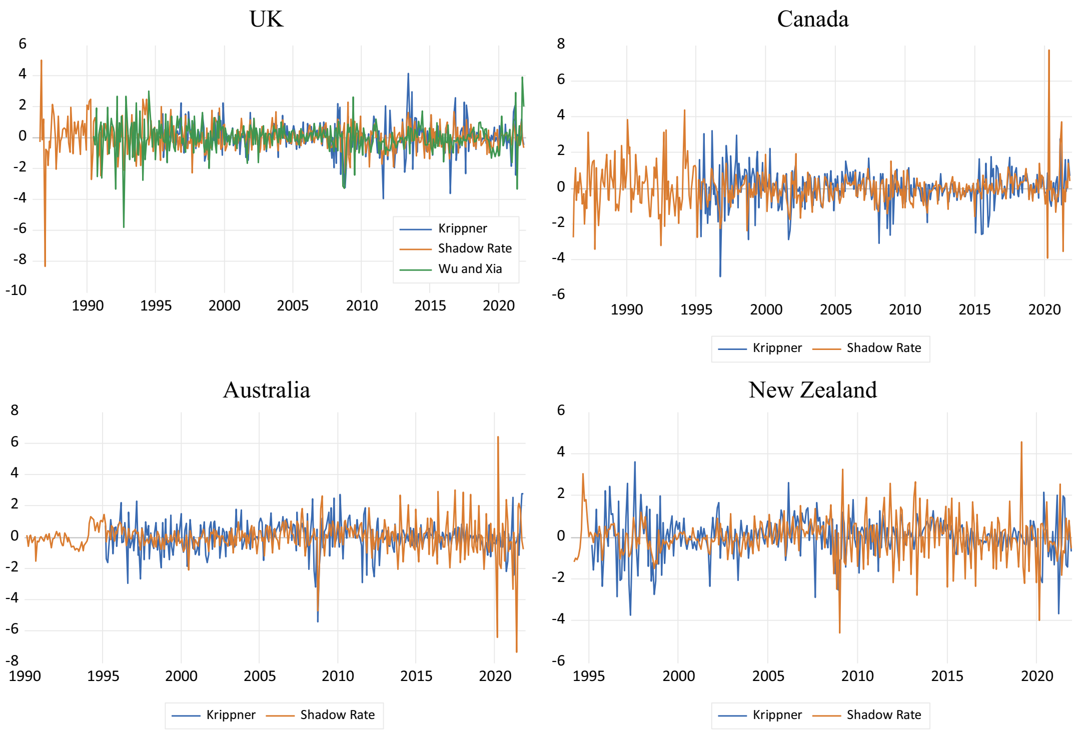

FIGURE 8 Monetary policy shocks from VAR model (3) for inflation-targeting countries using the Krippner and Wu and Xia shadow rates

Figure 7 reports the monetary policy shocks estimated using the VAR Model (2) as in Christiano et al. (1996)—for the UK and the United States only, since the additional series required are only available for these two countries. On the whole, the results are rather similar to the previous ones, and therefore it appears that VAR Model (1) might be sufficient to obtain an accurate picture of monetary policy in all countries (both inflation-targeting and non-targeting ones) in our sample. In other words, the additional variables included in VAR Model (2) to represent unconventional monetary policies (namely total and non-borrowed reserves) do not seem to play an important role since such effects are already captured by the shadow rate.

We display in Figures 8 and 9 the monetary shocks obtained from VAR Model (3) using the estimated shadow rates for inflation-targeting and non-targeting countries, respectively; for robustness purposes we also include shocks based on the Krippner (2015a) and Wu and Xia (2016) shadow rates for the countries and the time periods for which they are available. As can be seen, all three shadow rates produce similar results, but our preferred measure accounts for monetary shocks much better during the COVID-19 pandemic than the Krippner (2015a) and Wu and Xia (2016) rates. This most likely reflects the fact that our measure takes into account large-scale asset purchases and changes in central bank balance sheets to a much greater extent than the Krippner (2015a) two-factor and the Wu and Xia (2016) three-factor rates. Especially during the recent pandemic, asset purchases represented important stabilisation tools and their impact seems to be better captured by our measure of the shadow rate, which lends support to the inclusion of central bank balance sheet items in shadow rate factor models.

Below, we display the impulse responses of GDP growth and inflation to monetary shocks originating from either the official policy rate or the estimated shadow rate reported in Figures 10 and 11 for inflation-targeting countries and in Figures 12 and 13 for non-targeting ones. The results indicate that shadow rate shocks have a slightly bigger impact on both output and inflation than policy rate shocks. More precisely, output tends to recover faster after a monetary

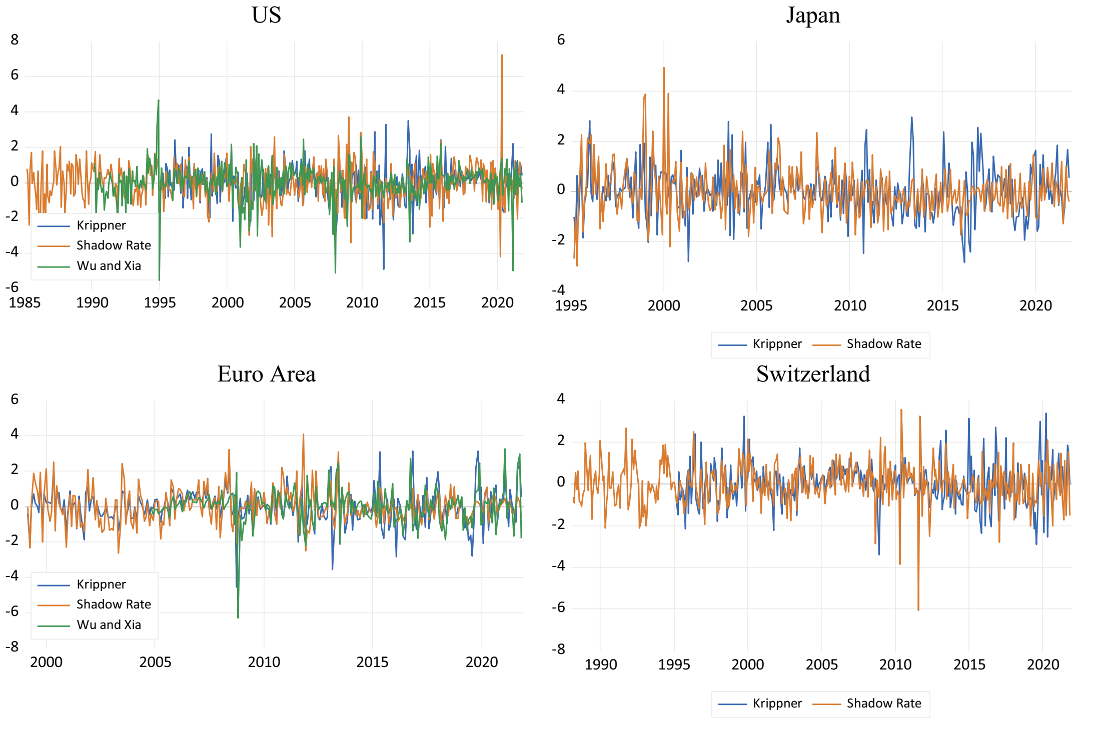

FIGURE 9 Monetary policy shocks from VAR model (3) for non-targeting countries using the Krippner and Wu and Xia shadow rates

shock of the former type, whilst the response of inflation to both types of shocks is essentially the same. Furthermore, output seems to recover and inflation to decline after the initial rise at a slightly faster rate in inflation-targeting countries than in non-targeting ones, which suggests that the former are perceived as more credible and economic expectations are better anchored under such a monetary regime. Therefore, unconventional policy shocks seem to have less persistent effects on the economy when central banks are fully committed to an inflation target.

To test for possible structural breaks in the VAR models, we use the Candelon and Lütkepohl (2001) Chow-type test for parameter constancy in multivariate models and report the results in Table 2 for all VAR models. We are unable to reject the null hypothesis of parameter stability mainly for models including the shadow rate, which do not appear to exhibit time-varying dynamics.[3]

5 | CONCLUSIONS

The aim of this paper was to examine the usefulness of shadow rates to measure the monetary policy stance in both inflation targeting (the UK, Canada, Australia and New Zealand) and non-targeting countries (the United States, Japan, the Euro Area and Switzerland) from the early 1990s until December 2021. A dynamic factor model was used to estimate the shadow rates, which were then compared with the official ones and to those implied by three different types of Taylor rules. Finally, generalised impulse functions from VAR models were estimated to obtain monetary shocks based on shadow and official rates, respectively, and assess how informative they are about monetary policy.

[3]A more thorough investigation of time variation in this context (for instance, by estimating a time-varying parameter VAR model) would be interesting since central banks' reaction functions are typically dynamic; however, this is beyond the scope of the present paper and is left for future research.

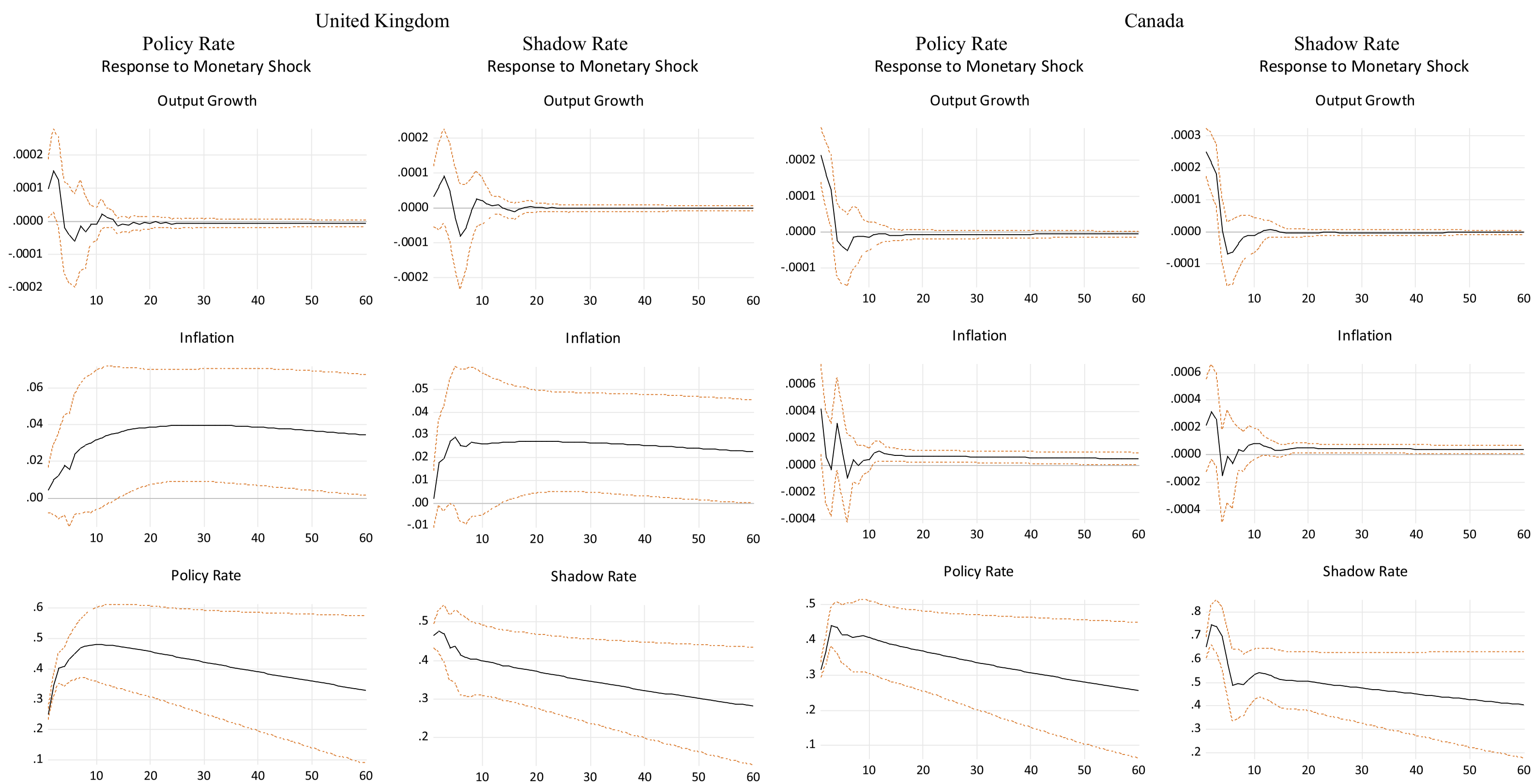

FIGURE 10 Impulse responses to monetary shocks using VAR model (3) for inflation-targeting countries. Responses to a one-unit monetary shock with one-standard error bands. The time scale is in months.

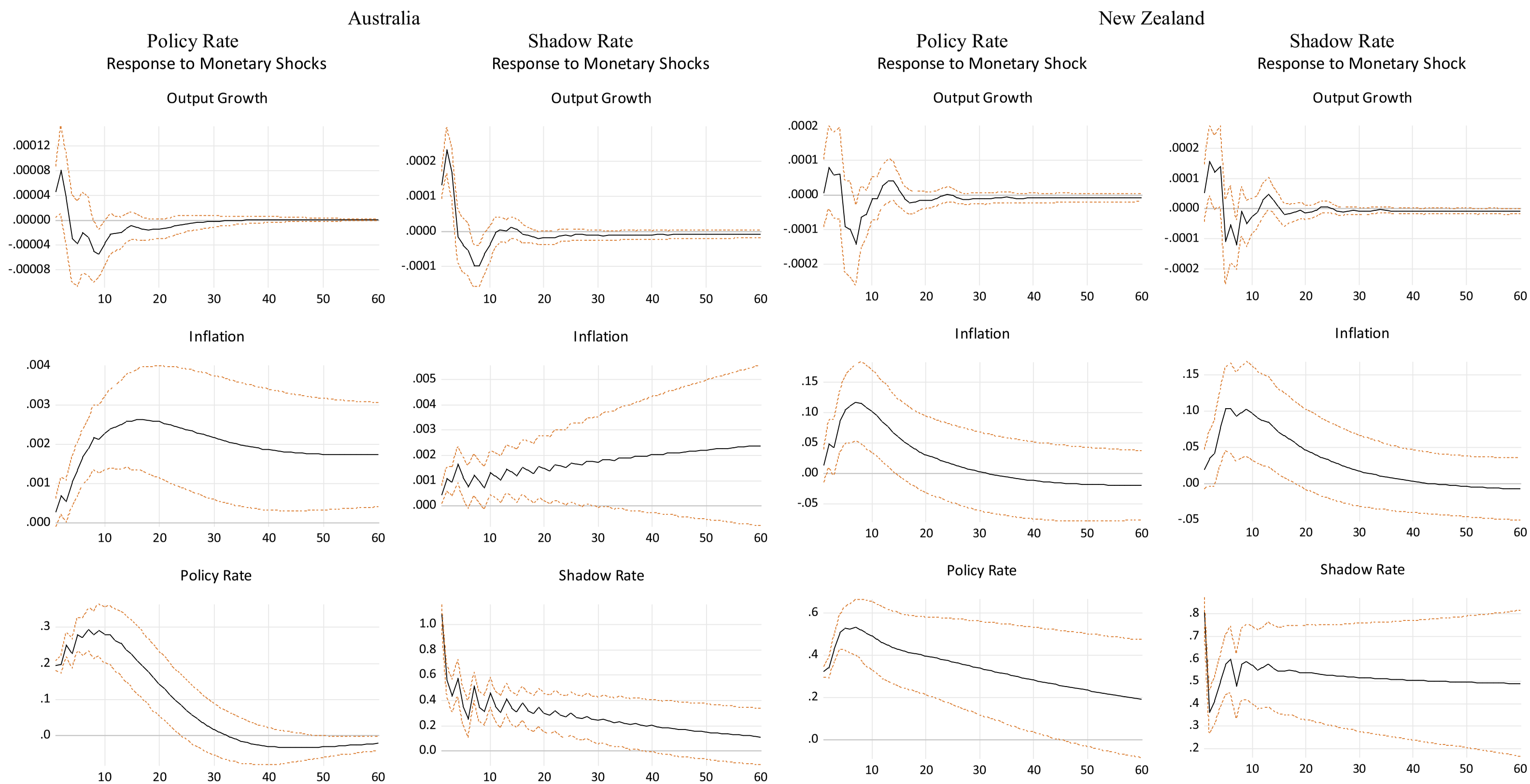

FIGURE 11 Impulse responses to monetary shocks using VAR model (3) for inflation-targeting countries. Responses to a one-unit monetary shock with one-standard error bands. The time scale is in months.

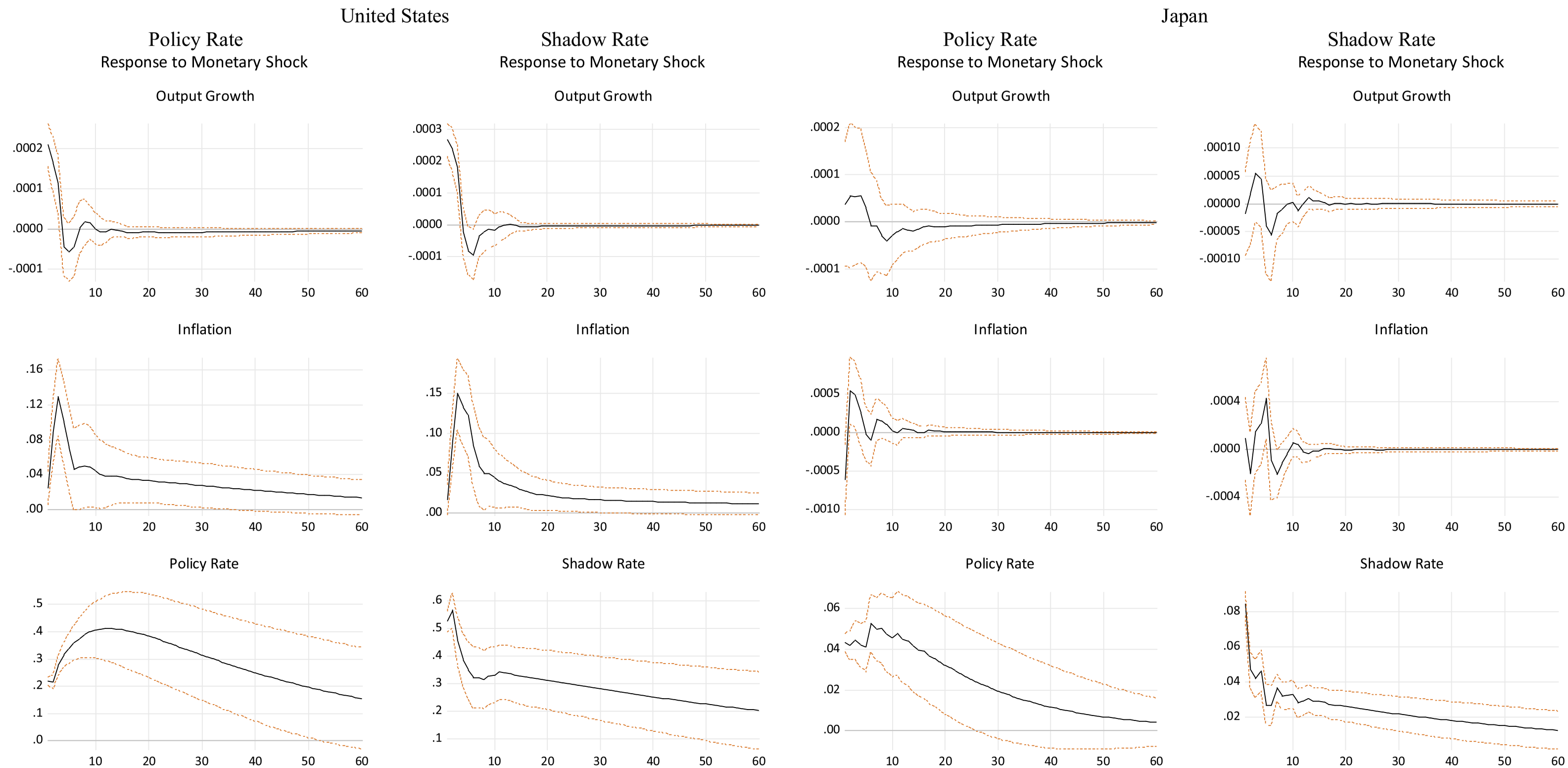

FIGURE 12 Impulse response to monetary shocks using VAR model (3) for non-targeting countries. Responses to a one-unit monetary shock with one-standard error bands. The time scale is in months.

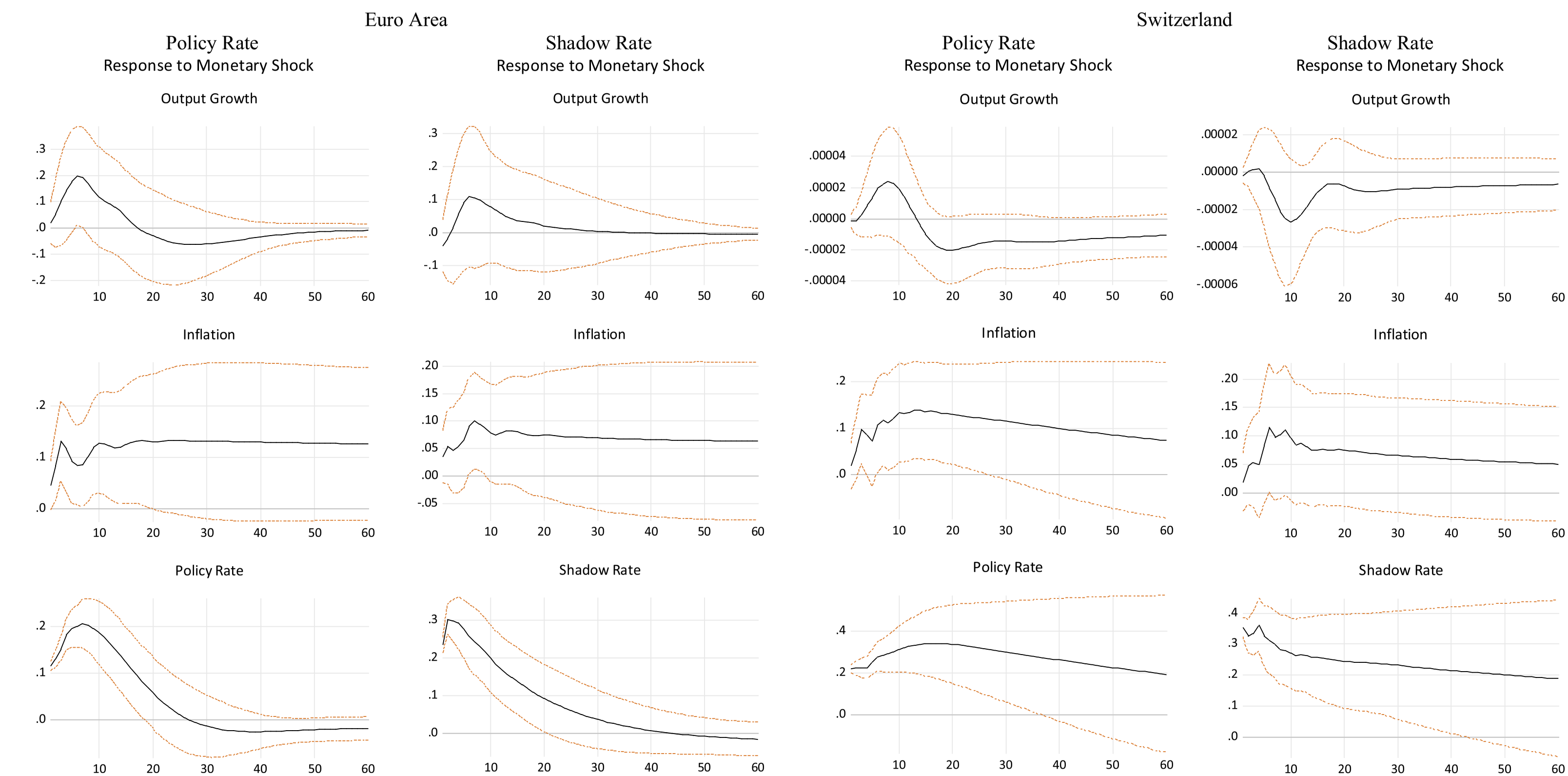

FIGURE 13 Impulse response to monetary shocks using VAR model (3) for non-targeting countries. Responses to a one-unit monetary shock with one-standard error bands. The time scale is in months.

TABLE 2 Candelon and Lütkepohl (2001) test

	VAR(1)		VAR(2)		VAR(3)	
	Policy rate	Shadow rate	Policy rate	Shadow rate	Policy rate	Shadow rate
UK	1.0000	1.0000	0.0000***	0.0000***	1.0000	1.0000
Canada	1.0000	1.0000			0.0365**	0.0561*
Australia	1.0000	1.0000			0.0034**	0.1011
New Zealand	1.0000	1.0000			1.0000	1.0000
United States	0.0016***	1.0000	1.0000	1.0000	0.0000	0.2387
Japan	1.0000	1.0000			0.0353**	0.1426
Euro Area	0.0264**	1.0000			0.0145**	0.9227
Switzerland	1.0000	1.0000			0.0000***	0.0817*

Note: Reported *p*-values of the Candelon and Lütkepohl (2001) test: H_0: parameter stability. H_1: structural break.
*Significant at 10%; **significant at 5%; ***significant at 1%.

The results can be summarised as follows. First, the shadow rates suggest a much looser policy stance than either the official policy rates or those implied by three different types of Taylor rules, especially since the early 2000s, in all countries, even those that allowed their interest rates to become negative; this is because, unlike the policy rates, they reflect the full range of unconventional policy measures adopted by central banks: Since they are constructed using term structure, monetary aggregate and balance sheet items, they provide a more comprehensive and accurate picture of the monetary policy stance. Second, monetary policy shocks based on the shadow rates are much more informative during unconventional periods (for the same reason specified before), whilst those based on the policy rates provide a sufficiently accurate picture during normal periods such as the 1990s. Third, our estimated shadow rate outperforms those obtained from two- or three-factor models in terms of tracking monetary shocks during the recent COVID-19 pandemic, which shows the crucial importance of including central bank balance sheet items in shadow rate estimations to capture unconventional monetary policy shocks. Lastly, the effects of such shocks on the economy seem to be less persistent in inflation targeting than in non-targeting countries, which suggests that central bank credibility is higher in the former. On the whole, our analysis highlights the importance for policy-makers of using shadow rates to measure accurately the tightness/looseness of monetary policy stance and the effects of monetary policy shocks.

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APPENDIX 1: ESTIMATION TIME PERIOD FOR EACH COUNTRY

Country	Sample start date	Sample end date	ZLB period
United Kingdom	January 1986	December 2021	April 2009—May 2010 March 2020—December 2021
Canada	January 1986	December 2021	August 2016—October 2017 March 2020—December 2021
Australia	January 1990	December 2021	March 2020—December 2021
New Zealand	January 1994	December 2021	March 2020—September 2021
United States	January 1985	December 2021	January 2009—December 2015 March 2020—December 2021
Japan	January 1995	December 2021	December 2008—December 2021
Euro Area	January 1999	December 2021	November 2013—December 2021
Switzerland	January 1988	December 2021	August 2011 – December 2021

APPENDIX 2: DATA FOR THE DYNAMIC FACTOR MODEL

Variable	Description	Source	Transformation to induce stationarity
1. United Kingdom			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Bank of England	Natural logarithm
0.5	6-Month treasury bill	Bank of England	Natural logarithm
1	1-Year treasury rate	Bank of England	Natural logarithm
2	2-Year treasury rate	Bank of England	Natural logarithm
3	3-Year treasury rate	Bank of England	Natural logarithm
5	5-Year treasury rate	Bank of England	Natural logarithm
7	7-Year treasury rate	Bank of England	Natural logarithm
10	10-Year treasury rate	Bank of England	Natural logarithm
Monetary aggregates			
M0	Monetary base	Bank of England	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M2	Money supply M2	Bank of England	Year-on-year growth rate
M3	Money supply M3	OECD	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	Bank of England	First differences
TS	Total securities held outright	Bank of England	First differences
DS	Debt securities	Bank of England	First differences
Balance sheet liabilities			
CCY	Currency in circulation	Bank of England	First differences
TR	Total reserves	Federal Reserve Bank of St Louis	First differences
DD	Deposits of depository institutions	Bank of England	First differences
TL	Total liabilities	Bank of England	First differences
2. Canada			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Bank of Canada	Natural logarithm
0.5	6-Month treasury bill	Bank of Canada	Natural logarithm
1	1-Year treasury rate	Bank of Canada	Natural logarithm
2	2-Year treasury rate	Bank of Canada	Natural logarithm
3	3-Year treasury rate	Bank of Canada	Natural logarithm
5	5-Year treasury rate	Bank of Canada	Natural logarithm
7	7-Year treasury rate	Bank of Canada	Natural logarithm
10	10-Year treasury rate	Bank of Canada	Natural logarithm
Monetary aggregates			
M0	Monetary base	Bank of Canada	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M2	Money supply M2	Bank of Canada	Year-on-year growth rate
M3	Money supply M3	OECD	Year-on-year growth rate

Variable	Description	Source	Transformation to induce stationarity
Balance sheet assets			
TA	Total assets	Bank of Canada	First differences
TS	Total securities held outright	Bank of Canada	First differences
DS	Debt securities	Bank of Canada	First differences
Balance sheet liabilities			
CCY	Currency in circulation	Bank of Canada	First differences
TR	Total reserves	Bank of Canada	First differences
DD	Deposits of depository institutions	Bank of Canada	First differences
TL	Total liabilities	Bank of Canada	First differences
3. Australia			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Reserve Bank of Australia	Natural logarithm
0.5	6-Month treasury bill	Reserve Bank of Australia	Natural logarithm
1	1-Year treasury rate	Reserve Bank of Australia	Natural logarithm
2	2-Year treasury rate	Reserve Bank of Australia	Natural logarithm
3	3-Year treasury rate	Reserve Bank of Australia	Natural logarithm
5	5-Year treasury rate	Reserve Bank of Australia	Natural logarithm
7	7-Year treasury rate	Reserve Bank of Australia	Natural logarithm
10	10-Year treasury rate	Reserve Bank of Australia	Natural logarithm
Monetary aggregates			
M0	Monetary base	Reserve Bank of Australia	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M2	Money supply M2	Reserve Bank of Australia	Year-on-year growth rate
M3	Money supply M3	Reserve Bank of Australia	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	Reserve Bank of Australia	First differences
TS	Total securities held outright	Reserve Bank of Australia	First differences
DS	Debt securities	Reserve Bank of Australia	First differences
Balance sheet liabilities			
CCY	Currency in circulation	Reserve Bank of Australia	First differences
TR	Total reserves	Reserve Bank of Australia	First differences
DD	Deposits of depository institutions	Reserve Bank of Australia	First differences
TL	Total liabilities	Reserve Bank of Australia	First differences
4. New Zealand			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Reserve Bank of New Zealand	Natural logarithm
0.5	6-Month treasury bill	Reserve Bank of New Zealand	Natural logarithm

(Continues)

Variable	Description	Source	Transformation to induce stationarity
1	1-Year treasury rate	Reserve Bank of New Zealand	Natural logarithm
2	2-Year treasury rate	Reserve Bank of New Zealand	Natural logarithm
5	5-Year treasury rate	Reserve Bank of New Zealand	Natural logarithm
7	7-Year treasury rate	Reserve Bank of New Zealand	Natural logarithm
10	10-Year treasury rate	Reserve Bank of New Zealand	Natural logarithm
Monetary aggregates			
M0	Monetary base	Reserve Bank of New Zealand	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M3	Money supply M3	Reserve Bank of New Zealand	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	Reserve Bank of New Zealand	First differences
TS	Total securities held outright	Reserve Bank of New Zealand	First differences
DS	Debt securities	Reserve Bank of New Zealand	First differences
Balance sheet liabilities			
CCY	Currency in circulation	Reserve Bank of New Zealand	First differences
TR	Total reserves	Reserve Bank of New Zealand	First differences
DD	Deposits of depository institutions	Reserve Bank of New Zealand	First differences
TL	Total liabilities	Reserve Bank of New Zealand	First differences
5. United States			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Federal Reserve Bank of St Louis	Natural logarithm
0.5	6-Month treasury bill	Federal Reserve Bank of St Louis	Natural logarithm
1	1-Year treasury rate	Federal Reserve Bank of St Louis	Natural logarithm
2	2-Year treasury rate	Federal Reserve Bank of St Louis	Natural logarithm
3	3-Year treasury rate	Federal Reserve Bank of St Louis	Natural logarithm
5	5-Year treasury rate	Federal Reserve Bank of St Louis	Natural logarithm
7	7-Year treasury rate	Federal Reserve Bank of St Louis	Natural logarithm
10	10-Year treasury rate	Federal Reserve Bank of St Louis	Natural logarithm
Monetary aggregates			
M0	Monetary base	Federal Reserve Bank of St Louis	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M2	Money supply M2	Federal Reserve Bank of St Louis	Year-on-year growth rate
M3	Money supply M3	OECD	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	Federal Reserve Bank of St Louis	First differences
TS	Total securities held outright	Federal Reserve Bank of St Louis	First differences
DS	Debt securities	Federal Reserve Bank of St Louis	First differences

Variable	Description	Source	Transformation to induce stationarity
Balance sheet liabilities			
CCY	Currency in circulation	Federal Reserve Bank of St Louis	First differences
TR	Total reserves	Federal Reserve Bank of St Louis	First differences
DD	Deposits of depository institutions	Federal Reserve Bank of St Louis	First differences
TL	Total liabilities	Federal Reserve Bank of St Louis	First differences
6. Japan			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Bank of Japan	Natural logarithm
0.5	6-Month treasury bill	Bank of Japan	Natural logarithm
1	1-Year treasury rate	Bank of Japan	Natural logarithm
2	2-Year treasury rate	Bank of Japan	Natural logarithm
3	3-Year treasury rate	Bank of Japan	Natural logarithm
5	5-Year treasury rate	Bank of Japan	Natural logarithm
7	7-Year treasury rate	Bank of Japan	Natural logarithm
10	10-Year treasury rate	Bank of Japan	Natural logarithm
Monetary aggregates			
M0	Monetary base	Bank of Japan	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M2	Money supply M2	Bank of Japan	Year-on-year growth rate
M3	Money supply M3	OECD	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	Bank of Japan	First differences
TS	Total securities held outright	Bank of Japan	First differences
DS	Debt securities	Bank of Japan	First differences
Balance sheet liabilities			
CCY	Currency in circulation	Bank of Japan	First differences
TR	Total reserves	Bank of Japan	First differences
DD	Deposits of depository institutions	Bank of Japan	First differences
TL	Total liabilities	Bank of Japan	First differences
7. Euro Area			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	European Central Bank	Natural logarithm
0.5	6-Month treasury bill	European Central Bank	Natural logarithm
1	1-Year treasury rate	European Central Bank	Natural logarithm
2	2-Year treasury rate	European Central Bank	Natural logarithm
3	3-Year treasury rate	European Central Bank	Natural logarithm
5	5-Year treasury rate	European Central Bank	Natural logarithm
7	7-Year treasury rate	European Central Bank	Natural logarithm
10	10-Year treasury rate	European Central Bank	Natural logarithm

(Continues)

Variable	Description	Source	Transformation to induce stationarity
Monetary aggregates			
M0	Monetary base	European Central Bank	Year-on-year growth rate
M1	Money supply M1	OECD	Year-on-year growth rate
M2	Money supply M2	European Central Bank	Year-on-year growth rate
M3	Money supply M3	OECD	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	European Central Bank	First differences
TS	Total securities held outright	European Central Bank	First differences
DS	Debt securities	European Central Bank	First differences
Balance sheet liabilities			
CCY	Currency in circulation	European Central Bank	First differences
TR	Total reserves	European Central Bank	First differences
DD	Deposits of depository institutions	European Central Bank	First differences
TL	Total liabilities	European Central Bank	First differences
8. Switzerland			
Interest rates			
Policy rate	Central bank policy rate	Bank for International Settlements	Natural logarithm
0.25	3-Month treasury bill	Swiss National Bank	Natural logarithm
0.5	6-Month treasury bill	Swiss National Bank	Natural logarithm
1	1-Year treasury rate	Swiss National Bank	Natural logarithm
2	2-Year treasury rate	Swiss National Bank	Natural logarithm
3	3-Year treasury rate	Swiss National Bank	Natural logarithm
5	5-Year treasury rate	Swiss National Bank	Natural logarithm
7	7-Year treasury rate	Swiss National Bank	Natural logarithm
10	10-Year treasury rate	Swiss National Bank	Natural logarithm
Monetary aggregates			
M0	Monetary base	Swiss National Bank	Year-on-year growth rate
M1	Money supply m1	Swiss National Bank	Year-on-year growth rate
M2	Money supply m2	Swiss National Bank	Year-on-year growth rate
M3	Money supply M3	Swiss National Bank	Year-on-year growth rate
Balance sheet assets			
TA	Total assets	Swiss National Bank	First differences
TS	Total securities held outright	Swiss National Bank	First differences
DS	Debt securities	Swiss National Bank	First differences
Balance sheet liabilities			
CCY	Currency in circulation	Swiss National Bank	First differences
TR	Total reserves	Swiss National Bank	First differences
DD	Deposits of depository institutions	Swiss National Bank	First differences
TL	Total liabilities	Swiss National Bank	First differences