**Systematic Monetary Policy in a SVAR for Australia**

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**Abstract**

A SVAR is estimated over the period of conventional monetary policy in Australia. The monetary policy shock is identified by imposing sign restrictions on the coefficients in the structural equation for the cash rate. There is very high posterior probability on structural models which imply a fall in output and prices, in response to a contractionary monetary policy shock, though the posterior probability of a price puzzle is somewhat higher than for other puzzles. The posterior median estimate of the systematic response of the cash rate to inflation increases noticeably when a price puzzle is ruled out.

*Key Words*: monetary policy shocks, structural equations, puzzles, identified set of responses
*JEL Classification*: C30, C51, E52

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## 1. Introduction

Over the three decades up until the end of 2019, the Reserve Bank of Australia (RBA) used 'conventional' monetary policy to achieve its policy objectives. Conventional monetary policy involves the RBA changing a target for its policy interest rate – the cash rate – to influence inflation and growth in the economy to be consistent with its objectives. Even through the Global Financial Crisis (GFC) period (2007-2009), the RBA conducted conventional monetary policy as Australia was less affected by the crisis than other advanced economies. During the GFC, the RBA used the cash rate as its principal instrument for monetary policy as it was far from the zero lower bound (ZLB). The central banks of other economies, notably the US, used a variety of measures, collectively known as 'unconventional' monetary policy. In Australia, it was only with the COVID-19 pandemic that began in early 2020, that the RBA started to implement 'unconventional' monetary policy measures to complement its longstanding approach to setting the cash rate. Among the 'unconventional' measures were the introduction of a term funding facility to support the banking system to increase lending to businesses, an expansion of the RBA's balance sheet through the purchase of a wide range of private sector assets (quantitative easing) to lower interest rates across the maturity spectrum, and forward guidance as to the intended stance of monetary policy.[1]

In this paper, we examine the economic effects of an unanticipated shock to monetary policy in a structural vector-autoregression (SVAR) for Australia, under the assumption that the cash rate is the instrument of monetary policy. Thus, our SVAR is designed to model the effects of shocks to conventional monetary policy in Australia. Accordingly, the SVAR is estimated over the sample that ends in the fourth quarter of 2019. We comment briefly on the results when the sample is extended to cover the COVID-19 pandemic, bearing in mind that the SVAR is not designed for periods of both conventional and unconventional monetary policy.

In this paper, we identify the shock to conventional monetary policy using sign restrictions on the contemporaneous coefficients in the structural equation for the cash rate in the SVAR. This is the approach of Arias et al. (2019) who estimate their SVAR up to mid-2007, the period of conventional monetary policy in the US. With the onset of the GFC in late 2007, the Federal Reserve undertook unconventional monetary policy, and again, more recently during COVID-19. Their approach is motivated, in their words, by "the fact that policy choices in general, and monetary policy choices in

[1] A chronology of the measures undertaken by the RBA to support the economy and financial system in response to COVID-19, is provided in the appendix to the speech 'Monetary Policy During Covid', by Guy Debelle, RBA, Shann Memorial Lecture, 6 May 2021.

particular, do not evolve independently of economic conditions" (Arias et al. (2019); p. 2). In this paper, the cash rate is allowed to respond immediately to "economic conditions", which are the other variables that appear in the SVAR. The immediate movement of the cash rate is sign determined as the identification method restricts the signs of the contemporaneous coefficients in the structural equation for the cash rate. Throughout the paper, this structural equation is referred to as the monetary policy equation, and the sign restrictions on its coefficients as the baseline identification. For example, the coefficient on contemporaneous inflation is restricted to be positive so the cash rate immediately increases when inflation rises. Other coefficients in the monetary policy equation are similarly sign restricted. These sign restrictions constrain how monetary policy is systematically related to "economic conditions", i.e., to macroeconomic variables.

While we follow the approach of Arias et al. (2019), we implement it using the method of SRC – sign restrictions based on coefficients – in Ouliaris and Pagan (2016). This method is implemented along the following lines. We first take a draw for each of the coefficients in the monetary policy equation. Each draw is such that the sign restriction on the coefficient is satisfied. For example, the draw for the coefficient on contemporaneous inflation is always a positive number. Having obtained a draw for each contemporaneous coefficient, the monetary policy equation is obtained and the estimated shock from it is the monetary policy shock. This equation is treated as the first equation in the SVAR. The remaining equations in the SVAR are set-up as a triangular system and are estimated recursively by instrumental variables. This follows the recommendation in Ouliaris and Pagan (2021). We now have estimates for all the structural shocks. We calculate the impulse responses of the variables to the first shock as we are only interested in the responses to the shock identified as the monetary policy shock. The responses are retained only if the response of the cash rate is positive, as our focus is on the responses of the variables to a contractionary monetary policy shock. We then repeat this procedure for another draw of the coefficients in the monetary policy equation and stop when one-thousand sets of responses are retained. These are referred to as the identified set of impulse responses. We fully describe this set and draw inferences about the effects of contractionary monetary policy. In addition, our implementation allows for parameter uncertainty in the reduced-form vector-autoregression (VAR) in a standard Bayesian framework.

Brischetto and Voss (1999) is an important early study of the effects of a monetary policy shock in a small SVAR for Australia. Their SVAR is fully identified by imposing zero parametric restrictions on the contemporaneous coefficients in each structural equation. Whereas we impose sign restrictions on the contemporaneous coefficients in the structural equation for the cash rate, they impose zero restrictions on some of these coefficients. In their preferred and smallest dimensioned SVAR, the cash rate depends contemporaneously only on the US federal funds rate, and the

USD/AUD nominal exchange rate. The shock associated with this equation is the monetary policy shock and they find no evidence of a puzzle in the impulse responses of prices, output, and the exchange rate to this shock.[2]

Instead of utilising parametric restrictions to identify the structural shocks, many recent studies have utilised traditional sign restrictions in SVARs. These restrictions are on the signs of the impulse responses to the shocks, rather than on the contemporaneous coefficients in a structural equation as in Arias et al. (2019) and here. Examples which utilize Australian data are Jääskelä and Jennings (2010), Fisher and Huh (2016), and Kim and Lim (2018). The sign restrictions require an immediate fall in the response of prices (or inflation) and output to a contractionary monetary policy shock, so there is no price or output puzzle. In Kim and Lim, there is the requirement of an immediate fall in the response of the monetary aggregate as well, so there is no liquidity puzzle. While the sign restrictions rule out these puzzles, there is no sign restriction on the response of the exchange rate. The key finding of each study is that the domestic currency appreciates on impact to a contractionary monetary policy shock, so there is no exchange rate puzzle. These studies model small open economies, share many of the same variables and treat the foreign variables as an exogenous block. Kim and Lin (2018) identify only the monetary policy shock by sign restrictions using the method of Scholl and Uhlig (2008). In Fisher and Huh (2016), all the structural shocks are identified by sign restrictions on the responses, so the multiple shocks problem of Fry and Pagan (2011) does not arise. Jääskelä and Jennings (2010) remark that this problem can arise in their SVAR because they leave one structural shock unidentified and the responses to this shock can resemble those of an identified shock, bringing into question its uniqueness. In a related study, Finlay and Jääskelä (2014) estimate a SVAR for three small open economies, including Australia, and find the responses of the domestic variables to both domestic and foreign credit demand and supply shocks. All the shocks in the SVAR are identified by sign and zero restrictions on the impulse responses and are unique. The approach of Arias et al. (2019), which is the approach followed here, partially identifies the SVAR as it identifies only one shock, the monetary policy shock, and is susceptible to the multiple shocks problem.

Other researchers using Australian data have identified a monetary policy shock using the approach of Romer and Romer (2004). This approach involves removing systematic changes in the

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[2] From standard macroeconomics, it is expected that the impact response of prices and output will be negative in response to a monetary policy shock which raises the cash rate, i.e., to a contractionary monetary policy shock. If the price response is positive, there is a price puzzle, and if the output response is positive, there is an output puzzle, both of which are often reported in the literature. Similarly, the impact response of the home currency to a contractionary monetary policy shock is expected to be an appreciation. If there is a depreciation, an exchange rate puzzle is said to occur.

cash rate that are due to the response of the RBA to its own forecasts about economic activity. Changes in the cash rate purged of this influence are treated as the unanticipated monetary policy shock. Bishop and Tulip (2017) find that an increase in this shock (an unanticipated tightening of monetary policy) raises inflation so that there is a price puzzle. Beckers (2020) argues that the RBA has systematically responded to movements in credit spreads, in addition to its own forecasts, and provides narrative evidence of this, particularly for the months surrounding the GFC. Following Finlay and Jääskelä (2014), Beckers measures the credit spread as the difference between the average large business variable lending rate and the 3-month bank bill rate. When the cash rate is purged of the systematic response of the RBA to the credit spread, as well as to its own forecasts, a contractionary monetary policy shock lowers inflation on impact and output after two quarters.

In this paper, we find that the identified set of responses to a contractionary monetary policy shock under the baseline identification, places small posterior probability mass on structural models which imply a price puzzle, and even smaller posterior mass on structural models which imply either an output or an exchange rate puzzle. We conclude that the SVAR under the baseline identification reliably identifies the monetary policy shock with very high posterior probability. In response to a contractionary monetary policy shock, output and prices fall, and the unemployment rates rises, on impact and over the next few quarters, with high posterior probability. The real exchange rate also appreciates with high posterior probability. We then find the identified set of impulse responses under the baseline identification augmented with restrictions on the impulse responses which rule out one or more of the puzzles. In each case, we find that the identified set of responses changes little. However, under the baseline identification together with the restriction that rules out a price puzzle, the estimated coefficient on inflation in the monetary policy equation increases noticeably. This implies that if the RBA were to adjust the cash rate in response to a contemporaneous movement in inflation according to the size of this estimated coefficient, there is zero posterior probability mass on structural models which imply a price puzzle.

The structure of the paper is as follows. Section II presents both the reduced-form and structural models and provides a treatment of the identification and estimation of the SVAR. This is followed by a detailed description of the data. Section III presents the empirical results and Section IV concludes.

## 2. The econometric model

### *2.1. The VAR and SVAR*

The econometric framework is developed for a system with one lag, although it can be easily generalized to systems of arbitrary lag length. Consider the VAR(1):

$$y_t = c + D_1 y_{t-1} + F_0 x_t + F_1 x_{t-1} + e_t \tag{1}$$

with $E(e_t e_t') = \Omega.$ The domestic variables are in the vector $y_t$ and they are treated as endogenous. The foreign variables are in the vector $x_t$ and they are treated as predetermined or exogenous. There are six domestic variables so that $y_t$ is a 6×1 vector of endogenous variables and $D_1$ is a 6×6 matrix of coefficients on the lagged endogenous variables. There are four foreign variables so that $x_t$ is a 4×1 vector of exogenous variables. The 6×4 matrices $F_0$ and $F_1$ are, respectively, the matrix of coefficients on the contemporaneous and once lagged exogenous variables.

The SVAR(1) is

$$A_0 y_t = a + A_1 y_{t-1} + B_0 x_t + B_1 x_{t-1} + \varepsilon_t \tag{2}$$

with $E(\varepsilon_t \varepsilon_t') = \Sigma,$ a diagonal matrix. The $\varepsilon_t$ shocks are orthogonal to each other and are referred to as structural shocks. The elements along the principal diagonal of $A_0$ are normalised to unity so that $a_{ii}^0 = 1$ for $i = 1, 2, ..., 6.$ In this case, each element in $\Sigma$ is the variance of the corresponding structural shock in $\varepsilon_t$. The corresponding relationships between the SVAR and VAR coefficients are: $a = A_0 c,$ $A_1 = A_0 D_1,$ $B_0 = A_0 F_0$ and $B_1 = A_0 F_1.$ The structural shocks are related to the VAR errors by $\varepsilon_t = A_0 e_t$ and further $\Sigma = A_0 \Omega A_0'.$

The six domestic variables are: the cash rate $r_t,$ the log of the real exchange rate $q_t,$ the credit spread $cs_t,$ the log of the index of consumer goods prices, $p_t,$ the log of real output $gdp_t,$ and the unemployment rate $u_t.$ The real exchange rate, the consumer goods price index, output and the unemployment rate are I(1) variables and the interest rate and credit spread are I(0) variables. The domestic variables enter the SVAR as:

$$y_t = (r_t \quad \Delta q_t \quad cs_t \quad \Delta p_t \quad \Delta gdp_t \quad \Delta u_t)'$$

i.e., the I(1) variables enter in first difference form.[3] The four exogenous variables are: the foreign policy interest rate $r_t^*,$ the log of the index of commodity prices $pc_t^*,$ the log of the index of foreign

[3] The first difference of the log real exchange rate, log prices and log output are multiplied by 100 so the first difference is the percentage change in these variables. For example, the first difference of log consumer prices

consumer goods prices $p_t^*$, and the log of foreign output $gdp_t^*$. Foreign consumer prices and output, and commodity prices, are I(1) while the foreign interest rate is I(0). The exogenous variables enter the SVAR as:

$$x_t = (r_t^* \quad \Delta pc_t^* \quad \Delta p_t^* \quad \Delta gdp_t^*)'$$

The I(1) foreign variables enter the SVAR similarly as the I(1) domestic variables.

*2.2. Identification*

The first equation in the SVAR is the structural equation for the cash rate. This equation shows how the cash rate responds systematically to economic conditions. Accordingly, it is interpreted as the monetary policy equation (or monetary policy reaction function or rule) and its structural shock is named the monetary policy shock. This equation, the first in the SVAR(1), is:

$$r_t = a_1 + a_{12}^0 \Delta q_t + a_{13}^0 cs_t + a_{14}^0 \Delta p_t + a_{15}^0 \Delta gdp_t + a_{16}^0 \Delta u_t + b_1^0 x_t + \{lags\} + \varepsilon_{rt} \tag{3}$$

where $a_1$ is the intercept and $b_1^0$ is the first row of $B_0$. The term $\{lags\}$ refers to the one period lagged domestic and foreign variables. Because the structural equation is normalized with a coefficient of one on the interest rate, the monetary policy shock $\varepsilon_{rt}$ has a size of one standard deviation i.e., its standard deviation is the square root of the element (1,1) in the diagonal matrix $\Sigma$. We impose the following sign restrictions on the coefficients in the monetary policy equation:

- The coefficients on consumer prices (inflation) and output are positive while the coefficient on the unemployment rate is negative, i.e., $a_{14}^0 > 0,\ a_{15}^0 > 0,\ a_{16}^0 < 0$. These say the RBA increases the cash rate contemporaneously with an increase in prices and output and reduces it with an increase in the unemployment rate.
- The coefficient on the credit spread is negative i.e., $a_{13}^0 < 0$. The credit spread increases when liquidity in credit markets is tight so that borrowing costs rise, dampening economic activity. The RBA reacts to a rise in the credit spread by reducing the cash rate contemporaneously.
- The coefficient on the real exchange rate is positive i.e., $a_{12}^0 > 0$. Here the real exchange rate is defined as the number of Australian goods per unit of the foreign good so that a fall in its

is the percentage change in consumer prices or simply the percent inflation rate over the period. The first difference of the unemployment rate is in percent as the unemployment rate itself is in percent.

value is a real appreciation of the Australian dollar. As an appreciation dampens economic activity, the RBA reacts by reducing the cash rate contemporaneously.

The coefficients in the vector $b_1^0$ are not restricted.

*2.3. Implementation and Estimation*

It is convenient to write the SVAR(1), shown by equation (2), in terms of the reduced form innovations $e_t$, see, for example, Ramey (2016). From the VAR(1), given by equation (1), write

$$e_t = y_t - c - D_1 y_{t-1} - F_0 x_t - F_1 x_{t-1} \quad (4)$$

and from this write equation (2) as

$$A_0(c + D_1 y_{t-1} + F_0 x_t + F_1 x_{t-1} + e_t) = a + A_1 y_{t-1} + B_0 x_t + B_1 x_{t-1} + \varepsilon_t \quad (5)$$

which can be expressed as

$$A_0 e_t = a - A_0 c + (A_1 - A_0 D_1) y_{t-1} + (B_0 - A_0 F_0) x_t + (B_1 - A_0 F_1) x_{t-1} + \varepsilon_t \quad (6)$$

From the relationships between the VAR and SVAR coefficients, shown under equation (2), it is the case that $a = A_0 c,\ \ A_1 = A_0 D_1,\ B_0 = A_0 F_0$, and $B_1 = A_0 F_1$. Then equation (6) is:

$$A_0 e_t = \varepsilon_t \quad (7)$$

The first equation in (7) is the equivalent representation of the monetary policy equation in (3) and it is:

$$e_{rt} = a_{12}^0 e_{qt} + a_{13}^0 e_{cst} + a_{14}^0 e_{pt} + a_{15}^0 e_{gdpt} + a_{16}^0 e_{ut} + \varepsilon_{rt} \quad (8)$$

The coefficients in this equation, i.e., the coefficients in the first row of $A_0$, namely, $a_{1j}^0$, are generated. The draw of each coefficient is obtained as follows:

- $a_{12}^0 = \dfrac{\theta_1}{1-\theta_1},\ \theta_1 \sim U(0,1)$. This says that $\theta_1$ is drawn randomly from the uniform probability density function defined over the interval (0,1). In this case, $a_{12}^0 \in (0,\infty)$ so that the coefficient on the real exchange rate in the monetary policy equation is positive and can be anywhere on the positive part of the real number line.

- $a_{13}^0 = \frac{\theta_2}{1-abs(\theta_2)}, \ \theta_2 \sim U(-1,0).$ Here *abs* is the absolute value and $\theta_2$ is drawn randomly from the uniform probability density function defined over the interval (-1,0). In this case, $a_{13}^0 \in (-\infty, 0)$ so that the coefficient on the credit spread in the monetary policy equation is negative and can be anywhere on the negative part of the real number line.
- Similarly, $a_{14}^0 = \frac{\theta_3}{1-\theta_3}, \ \theta_3 \sim U(0,1)$ and $a_{15}^0 = \frac{\theta_4}{1-\theta_4}, \ \theta_4 \sim U(0,1)$ so that $a_{14}^0 \in (0,\infty)$ and $a_{15}^0 \in (0,\infty).$ The coefficient on prices and GDP are both positive.
- Finally, $a_{16}^0 = \frac{\theta_5}{1-abs(\theta_5)}, \ \theta_5 \sim U(-1,0)$ so that $a_{16}^0 \in (-\infty, 0).$ The coefficient on the unemployment rate is negative.

For the draw of the $a_{1j}^0$ coefficients, the monetary policy shock is obtained by forming the residuals from equation (8), and this will be $\hat{\varepsilon}_{rt}$. Having found the monetary policy shock, we now need to find the contemporaneous response of all the variables to it. From equation (7), we have $e_t = A_0^{-1}\varepsilon_t$, and from this the VAR equations for the remaining variables are estimated as follows:

$$e_{qt} = a_0^{21}\hat{\varepsilon}_{rt} + v_{qt} \tag{9}$$

$$e_{cst} = a_0^{31}\hat{\varepsilon}_{rt} + v_{cst} \tag{10}$$

$$e_{pt} = a_0^{41}\hat{\varepsilon}_{rt} + v_{pt} \tag{11}$$

$$e_{gdpt} = a_0^{51}\hat{\varepsilon}_{rt} + v_{gdpt} \tag{12}$$

$$e_{ut} = a_0^{61}\hat{\varepsilon}_{rt} + v_{ut} \tag{13}$$

where the coefficients are the elements of the first column of $A_0^{-1}$. The $v_{jt}$ are linear combinations of the structural shocks in $\varepsilon_t$ excluding $\varepsilon_{rt}$, the first structural shock, which is the monetary policy shock. Equations (9) to (13) are estimated consistently by OLS since $\varepsilon_{rt}$ is uncorrelated with each of the $v_{jt}$ errors. The generated coefficients, $a_{1j}^0, \ j = 2,...,6$ together with the estimated coefficients $a_0^{k1}, \ k = 2,...,6$ allow the contemporaneous impulse responses to the monetary policy shock $\varepsilon_{rt}$ to be recovered. From this, and the moving average representation of the VAR, the impulse responses of the variables to the monetary policy shock can be found for all horizons.

We allow for estimation uncertainty in the parameters of the VAR(1) by specifying the prior distribution for the VAR coefficients, conditional of $\Omega,$ as normal, and the prior distribution for $\Omega$ as inverse Wishart. This prior is conjugate, so that the posterior distribution has the same functional form as the prior, namely, normal, inverse Wishart. Peersman (2005) is an example of the use of this prior. The method begins by taking a draw of $c,\ D_1,\ F_0,\ F_1,$ and $\Omega$ from the posterior distribution for the VAR coefficients and variance-covariance matrix of VAR residuals. For this draw, we obtain the VAR residuals $e_t$ from equation (4), which allows us to obtain the monetary policy equation, equation (8) once we obtain a draw for the generated coefficients. We then obtain the monetary policy shock and calculate the impulse responses of all the variables to a one-standard deviation shock to it. The responses of the variables that enter the SVAR in first differences are accumulated to arrive at the responses in the levels of the series. The responses are accepted provided the impact response of the interest rate is positive as our focus is on the responses to a contractionary monetary policy shock. We then take another draw of the VAR coefficients from the posterior distribution and another draw of the generated coefficients to obtain the monetary policy equation from which we obtain the responses of the variables to the monetary policy shock, which are accepted provided the impact response of the interest rate is positive. The procedure is repeated until one-thousand sets of impulse responses are accepted which are then summarised.

The identified set is summarized in the following way. The one-thousand responses of a variable to the monetary policy shock at each horizon are arranged into ascending order. The maximum and minimum responses are connected pointwise across horizons, respectively, to form the maximum and minimum impulse responses. The region between them encompasses all one-thousand responses and indicates their range. It is important to show the range since each response is consistent with the data covariance matrix $\Omega$ and are therefore observationally equivalent. As the range is often wide, it is common to report the 68% and 95% pointwise posterior probability bands along with the median (50th percentile) response.[4] A percentile response (e.g., the median) does not correspond to a single SVAR as Fry and Pagan (2011) have pointed out. They developed a metric to find a single SVAR (i.e., that which corresponds to a single draw of the $a_{1j}^0$ coefficients) for which the responses of all the variables to a shock are 'closest' to the median responses. They name these the median-target responses. In the figures, we show the range and the 68% pointwise posterior band for the identified set of responses, together with the median and median-target responses.

[4] The 68% posterior band is the region between the 16th and 84th percentile responses. These are connected pointwise at each horizon. Similarly, the 95% posterior band is the region between the 2.5th and 97.5th pointwise connected percentile responses.

Our method is subject to the critique of Baumeister and Hamilton (2015) who showed that the identified set of responses is influenced by the generation method used in sign restrictions. In our case, the method we use to generate the coefficients in the monetary policy equation, i.e., in equation (3) or equivalently, equation (8), can influence the set of accepted impulse responses. Therefore, it is may not be meaningful to report percentiles of the identified set of responses as we do. In response to this issue, Ouliaris and Pagan (2016) suggest that one report the maximum and minimum of the identified set of responses as these seem less likely to be influenced by different generation methods. We follow their suggestion and report the maximum and minimum reponses and show the region between them.

### *2.4. Data*

The data is quarterly, and the sample is 1990 Q1 to 2019 Q4, the period of conventional monetary policy in Australia.[5] The cash rate, the instrument of monetary policy, is the interbank overnight cash rate in percent per year. The real exchange rate is the real trade-weighted exchange rate index, and it is the price of one unit of the foreign good in terms of the Australian good. A fall in the index is a real appreciation of the Australian dollar as the price of the foreign good in terms of the Australian good is cheaper. The credit spread is the average variable lending rate to large businesses less the three-month bank accepted bill rate (percent per year). The measure of consumer prices is the consumer price index for all groups. The output measure is real GDP (chain volume measure). The unemployment rate is measured as the number of unemployed persons as a percentage of the labour force. The foreign interest rate is the Wu-Xia (2016) shadow US federal funds rate. The shadow rate shows the stance of US monetary policy during periods when the federal funds rate is close to the zero lower bound (ZLB), necessitating the Federal Reserve to undertake unconventional monetary policy as happened during the GFC, and more recently during COVID-19.[6] Foreign output is US real GDP and foreign prices is the US consumer price index, all urban consumers. Commodity prices is the RBA's index of commodity prices, measured in US dollars. Where the data is monthly, it is averaged over the quarter. The appendix provides a detailed description of the data and where it is sourced.

## 3. Empirical results

[5] The sample is extended to 2021 Q3, which is the latest data available, to investigate how observations from the COVID-19 and unconventional monetary policy period influence our results, which are for the period of conventional monetary policy only.

[6] Wu and Xia (2016) show that the shadow federal funds rate interacts with US macro variables similarly as the federal funds rate did historically when it was far from the ZLB. Therefore, the shadow rate can be used in SVARs for which the sample covers periods where the actual federal funds rate is close to the ZLB and conveys no information about the stance of monetary policy.

We present the identified set of impulse response functions (IRFs) to a contractionary monetary policy shock of one-standard error, and then discuss the posterior estimates of the contemporaneous coefficients in the monetary policy equation. We do this under the identification in Section II(ii), which we call the baseline identification, and then under the baseline identification augmented with sign restrictions on the impulse responses to rule out so-called puzzles. The SVAR is estimated over the sample 1990 Q1 – 2019 Q4 with one lag.[7]

*3.1. Baseline identification*

Figure 1 shows the identified set of IRFs to the contractionary monetary policy shock under the baseline identification. In the figure, the solid (black) lines show the point-wise posterior median IRFs while the blue lines show the posterior median-target IRFs. The lightly shaded (light green) band shows the range of the identified set of IRFs, i.e., the region between the point-wise posterior maximum and minimum IRFs. The heavily shaded (dark green) band shows the region between the point-wise 16th and 84th percentile IRFs, which is the 68% equal-tailed posterior probability interval. The posterior median responses show an immediate increase in the cash rate of 0.03 percentage points, i.e., three basis points, and an immediate increase in the credit spread of 0.09 percentage points, i.e., nine basis points, due to the contractionary monetary policy shock. The tightening of monetary policy leads posterior median prices and output to fall immediately, by 0.06 and 0.14 percent, respectively, and the posterior median unemployment rate to rise immediately by 0.04 percentage points. The median exchange rate appreciates immediately by 0.92 percent. While the impact responses can be seen in Figure 1, they are shown numerically in Table 1 for closer analysis, along with the 68% and 95% posterior probability intervals, and the range (the Min-Max interval). Based on the 68% posterior interval, which many studies report, there is neither an output, unemployment, exchange rate or liquidity puzzle as, in each case, all the probability mass is on the 'correct' side of zero. However, the 68% posterior interval for the response of prices, does not rule out the price puzzle. From Table 1, it is [-0.22; 0.02] so there is small posterior probability of obtaining a price puzzle on a draw, as most of the mass of the posterior distribution is on the 'correct' (negative) side.

However, the 68% posterior interval is one characteristic of the identified set. Another is the 95% posterior interval and yet another is the posterior median. Rather than reporting characteristics of the identified set of IRFs, Baumeister and Hamilton (2018) argue that the 'identified set' itself

[7] The SBC selected a one lag model while the AIC selected two lags. For the SVAR(2), the range of the posterior impulse responses for prices and output is much wider at long horizons than from the SVAR(1), which may suggest some instability in the SVAR(2). In any case, the I(1) variables enter the SVAR(1) in first differences, so when the SVAR(1) is expressed in levels of all of the variables, two lags of the I(1) variables will appear.

should be described fully, as all the IRFs are consistent with the data covariance matrix. Ouliaris and Pagan (2016) suggest that the minimum and maximum point-wise IRFs be reported as these are the limits of the identified set, i.e., they encompass all one-thousand accepted IRFs, in our case. The point-wise posterior range of responses are shown in Figure 1, and the last row of Table 1 shows the posterior range of the immediate (impact) responses of the variables to the monetary policy shock. This row shows that the posterior distribution of the IRFs does have some mass on each puzzle (an incorrect impact sign response) but most of its mass is on the 'correct' sign response. We conclude that there is likely (i.e., with very high posterior probability) to be no puzzles in the responses of the variables to a contractionary monetary policy shock at the immediate horizon on a draw under the baseline identification. However, while there is some mass on a price puzzle for the 68% posterior probability interval, there is no mass on the other puzzles, until the 95% posterior interval and the range are considered. This suggests that of all the puzzles, the price puzzle is the more likely to arise in Australian data, though with low posterior probability.

Following the immediate decline in median output and prices, and the immediate rise in the median unemployment rate, monetary policy is loosened. The median cash rate falls by 0.10 percentage points by eight quarters and then gradually rises to its initial level. Median prices fall by 0.15 percentage points by 10 quarters and remain at that level so the fall in prices is permanent. The response of output is strongly negative, and the response of the unemployment rate strongly positive, out to a horizon of 10 quarters, with high posterior probability following the contractionary monetary policy shock, and then both gradually return to their initial level. This shows that monetary policy shocks have significant real effects, with high posterior probability. The median real exchange rate appreciates further, and by 10 quarters it has appreciated by 2 percent, and remains at that new level permanently. The monetary policy shock has a permanent effect on both prices and the real exchange rate. The median spread begins to fall after two quarters and by about 20 quarters has returned to its initial level. By comparison with the median responses, the median-target responses show a stronger immediate interest rate rise and a subsequent stronger loosening of monetary policy. The immediate fall in median-target prices is considerably greater (0.29 versus 0.06 percent), and so too is the long-run permanent fall in prices (0.6 versus 0.15 percent). The differences between the median and median-target responses are not as pronounced for the other variables.

Table 2 shows the posterior median estimates of the contemporaneous coefficients in the monetary policy equation. The posterior median of $a_{14}^{0}$, the coefficient on inflation $\Delta p_t$, is 0.29 while the posterior median of $a_{15}^{0}$, the coefficient on output growth $\Delta gdp_t$, is 0.28. Both coefficients are approximately the same but are considerably less than one meaning the cash rate moves considerably less than one-for-one to contemporaneous movements in inflation and output growth. The cash rate moves more strongly to contemporaneous movements in the unemployment rate (its posterior median is -0.39), though the (absolute) response is still considerably less than one-for-one. The median cash rate falls by 0.60 percent following a contemporaneous increase in the credit spread of one percent and rises by only 0.07 percent following an immediate one percent appreciation of the real exchange.

*3.2. Baseline identification with a price puzzle ruled out*

In the previous section, it was seen that an accepted set of IRFs has a very low posterior probability of displaying a puzzle, and among the puzzles, there was somewhat higher posterior probability on a price puzzle, though still low, arising in the responses. To restrict the identified set further, the baseline identification is augmented with the restriction that the immediate response of prices to the contractionary monetary policy shock is negative, so that the price level falls, ruling out the price puzzle. The modification to the baseline algorithm is that the set of impulse responses is accepted provided the impact response of the interest rate is positive *and* the impact response of prices is negative to the contractionary monetary policy shock. Figure 2 shows the median IRFs (black line) and the median-target IRFs (blue line) under this identification, together with the 68% posterior probability interval and the range i.e., the Min-Max interval. In Figure 2, there is zero mass on an immediate positive response of prices to the contractionary monetary policy shock because a set of responses which has this feature is not accepted as it is not in the identified set. This can also be seen from Table 3, where the posterior probability intervals for the response of prices are all on the left (negative) side of zero. The immediate fall in the median response of prices is 0.11 percent, considerably larger than 0.06 percent, which was the immediate fall under the baseline identification. The long-run fall in the median response of prices is also larger (0.20 versus 0.15 percent). Apart from this, the immediate median responses of the other variables to the monetary policy shock are very similar, as can be seen from a comparison of Table 3 with Table 1. The median responses are very similar at horizons extending beyond the immediate horizon as well under both identifications. The median-target responses are somewhat different under this identification. The subsequent loosening of monetary policy and the long-run fall in prices, evident in the median-target responses in Figure 2, are less pronounced than before, and an exchange rate puzzle occurs as there is a slight immediate depreciation of the real exchange rate.

Table 4 shows the posterior median estimates of the contemporaneous coefficients in the monetary policy equation under this identification. The posterior median of $a_{14}^{0}$ is estimated to be 0.44, considerably larger than its estimate of 0.29 reported in Table 2. This implies that the posterior probability mass on SVAR models which imply a price puzzle becomes smaller when the increase in the cash rate to a contemporaneous increase in inflation becomes larger, all else constant. The posterior probability is zero when $a_{14}^{0}$ is 0.44. The estimates of the posterior medians of the other contemporaneous coefficients are very similar to those reported in Table 2.

*3.3. Baseline Identification with other and multiple puzzles ruled out*

Table 5 shows the posterior median estimates of the contemporaneous coefficients in the monetary policy equation under the baseline identification augmented with a sign restriction on the impact response of some of the variables to the contractionary monetary policy shock. Rows (a) and (b) show, respectively, the posterior median estimates from the baseline identification and from it augmented with the sign restriction that rules out the price puzzle. These reproduce the posterior median estimates, reported in Tables 2 and 4, respectively, and are reported here for ease of reference. Row (c) reports the posterior median estimates under the baseline identification together with the restriction that rules out an exchange rate puzzle. This restriction rules out an immediate positive response of the real exchange rate to the contractionary monetary policy shock, so there cannot be an impact depreciation. Here the set of impulse responses is accepted provided the impact response of the interest rate is positive *and* the impact response of the real exchange rate is negative (i.e., an appreciation). Row (d) reports the posterior median estimates under the baseline identification together with the restriction that rules out an output puzzle. Here the set of impulse responses is accepted provided the impact response of the interest rate is positive *and* the impact response of output is negative. When the baseline identification is augmented with either the no exchange rate or no output puzzle restriction, the posterior estimates remain practically unchanged from those in row (a). This implies that the posterior distribution over the identified set of IRFs under the baseline identification, has little probability mass on structural models which imply an exchange rate or an output puzzle.

The last part of the table shows the posterior estimates from the baseline identification together with the no price puzzle restriction, *and* either the no exchange rate or no output puzzle restriction. For the former, the posterior estimates are shown in row (e) and for the latter, in row (f) of the table. In both cases, the posterior median estimates are very similar to those reported in row (b), the baseline plus no price puzzle case. This implies that the posterior distribution over the identified set of IRFs under the baseline plus no price puzzle identification has little probability mass on structural models that imply exchange rate or output puzzles.

Taken together, the results show that under the baseline identification, the posterior distribution over the identified set of IRFs places small probability mass on structural models that imply a price puzzle, and much less mass on structural models that imply an exchange rate or an output puzzle. However, when the baseline identification is augmented to rule out a price puzzle, the posterior estimate of the median coefficient on inflation in the monetary policy equation increases noticeably, and changes little when the identification is further augmented to rule out an exchange rate or an output puzzle.

### *3.4 Results for the sample that includes COVID-19 period observations*

The baseline SVAR was estimated with data to 2021 Q3, and covers the period of unconventional monetary policy, which commenced in 2020 Q1, in response to the COVID-19 pandemic. For the extended sample and baseline identification, the posterior median responses show an immediate increase in the cash rate of 0.02 percentage points, about the same as before, and an immediate fall in prices and output of 0.12 and 0.24 percent, respectively, concurrent with the contractionary monetary policy shock. The immediate fall in prices and output is considerably larger than that shown in Table 1 for the sample to 2019 Q4. At long horizons, the posterior median response of prices and output both show a fall of 0.3 percent, considerably larger than before. The posterior median response of the unemployment rate shows a rise of 0.1 percentage points after two quarters, and a rise of 0.05 percentage points in the long-run, whereas for the pre-COVID-19 sample, these were 0.04 and nearly zero percentage points, respectively. Moreover, the posterior median estimate of the contemporaneous coefficient on output growth in the monetary policy equation is 0.46, considerably larger than its estimate in the pre-COVID-19 sample.

For the extended sample, the posterior median responses show a much larger fall in prices and output, and a considerably larger rise in the unemployment rate, even though the posterior median impact response of the cash rate is approximately the same as for the pre-COVID-19 sample. It appears that the monetary policy shock in the baseline SVAR over the extended sample is being conflated with a large negative aggregate demand shock, which is one economic interpretation for COVID-19, in which case the SVAR is not reliably identifying the monetary policy shock nor accounting for its effects.

## **4. Conclusion**

This paper estimates a SVAR to model the effects of conventional monetary policy in Australia. The monetary policy shock is identified by imposing sign restrictions on the coefficients in the structural equation for the cash rate. Under the baseline identification, we find that there is very high posterior probability on structural models which imply that output falls in response to the contractionary monetary policy shock. The posterior probability is also high, but not quite as much, on structural models which imply that prices fall. When the baseline identification is augmented with the sign restriction that the impact response of prices cannot rise, the identified set of responses does not change much. However, the posterior median estimate of the contemporaneous coefficient on inflation in the monetary policy equation increases considerably.

The sample was extended with data from 2020 Q1 to 2021 Q3, the period of unconventional monetary policy in Australia where the cash rate was near the ZLB in response to the COVID-19 pandemic. When the SVAR was estimated over the extended sample, the contractionary monetary policy shock has a very large negative impact on output and prices, and resembles a large negative aggregate demand shock, which is one interpretation of the type of shock COVID-19 represents. Thus, the interpretation of the identified shock as a monetary policy shock in the SVAR over the extended sample is questionable. Recently, Inoue and Rossi (2021) have developed a new method which identifies shocks as a shift in a function, rather than as a scalar shock, which is what the literature has done and what we have done here. In the context of monetary policy, their method identifies a monetary policy shock as a shift in the entire term structure of interest rates. This shock encompasses the effects of conventional monetary policy, which influences short-term rates, and unconventional monetary policy, such as quantitative easing and forward guidance, which influences medium and long-term rates. The application of their method to modelling the effects of monetary policy in Australia over the period of both conventional and unconventional monetary policy is an area for future research.

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## Data Appendix

***Domestic variables***

*Policy rate*: Interbank Overnight Cash Rate, Monthly average, Percent, Statistical Table F1.1, Series ID: FIRMMCRI. Reserve Bank of Australia.

*Real exchange rate*: Australian Real Trade-Weighted Index, Quarterly, 1995=100, Statistical Table F15, Series ID: FRERTWI. Reserve Bank of Australia.

*Credit spread*: It is the bank lending rate less the short rate, percent per annum.

*Bank lending rate*: Large Business; Weighted-average rate on credit outstanding; variable rate, percent per annum, Statistical Table F5, Series ID: FILRLBWAV. Reserve Bank of Australia. This data is available up to September 2019. Data thereafter is the series: Large Business variable rate, percent per annum, Statistical Table F7, Series ID: FLRBFOLBV. Reserve Bank of Australia.

*Short rate*: Rate on 3-month Bank Accepted Bills/Negotiable certificates of deposits, monthly percent, Statistical Table F1.1, Series ID: FIRMMBAB90. Reserve Bank of Australia.

*Consumer prices*: Australian Consumer Price Index, All groups, Quarterly, 2011/12=100, Statistical Table G1, Series ID: GCPIAG. Reserve Bank of Australia.

*Real Output*: Australian Gross Domestic Product, Chain Volume, Quarterly, seasonally adjusted, $ million, Statistical Table H1, Series ID: GGDPCVGDP. Reserve Bank of Australia.

*Unemployment rate*: Unemployed Persons as Percentage of the Labour Force, Monthly, seasonally adjusted, percent, Statistical Table H5, Series ID: GLFSURSA. Reserve Bank of Australia.

***Foreign variables***

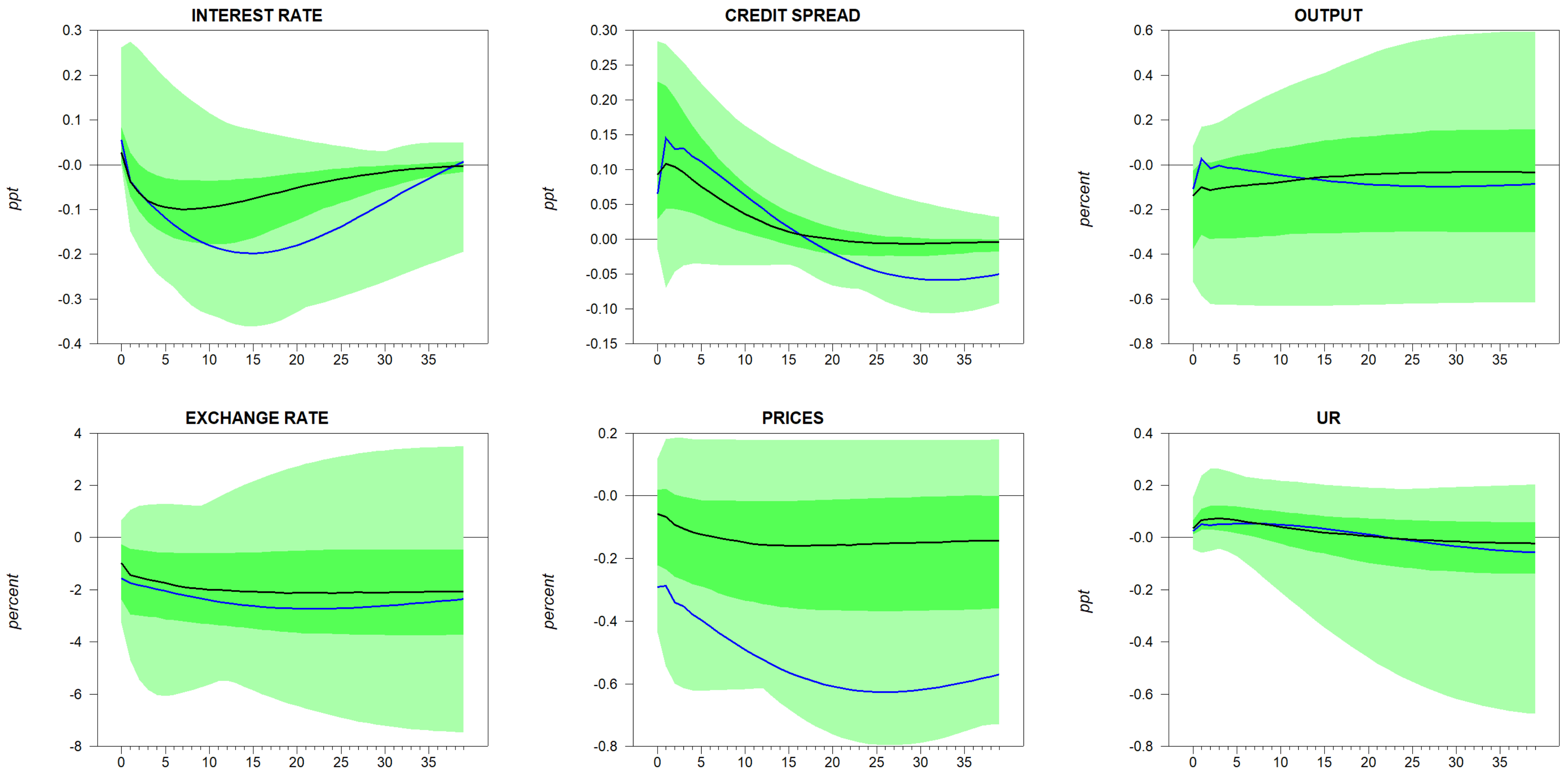
*Policy rate*: Wu-Xia shadow federal funds rate, last business day of the month, percent, Center for Quantitative Economic Research, Federal Reserve Bank of Atlanta.
https://www.atlantafed.org/cqer/research/wu-xia-shadow-federal-funds-rate

*Commodity prices*: Index of commodity prices, All items, in US$, 2019/20=100, monthly, Statistical Table I2, Series ID: GRCPAIUSD. Reserve Bank of Australia.

*Consumer prices*: United States Consumer Price Index for All Urban Consumers, 1982/84=100, monthly, seasonally adjusted, Federal Reserve Economic Data (FRED) database, Series ID: CPIAUCSL. Federal Reserve Bank of St. Louis.

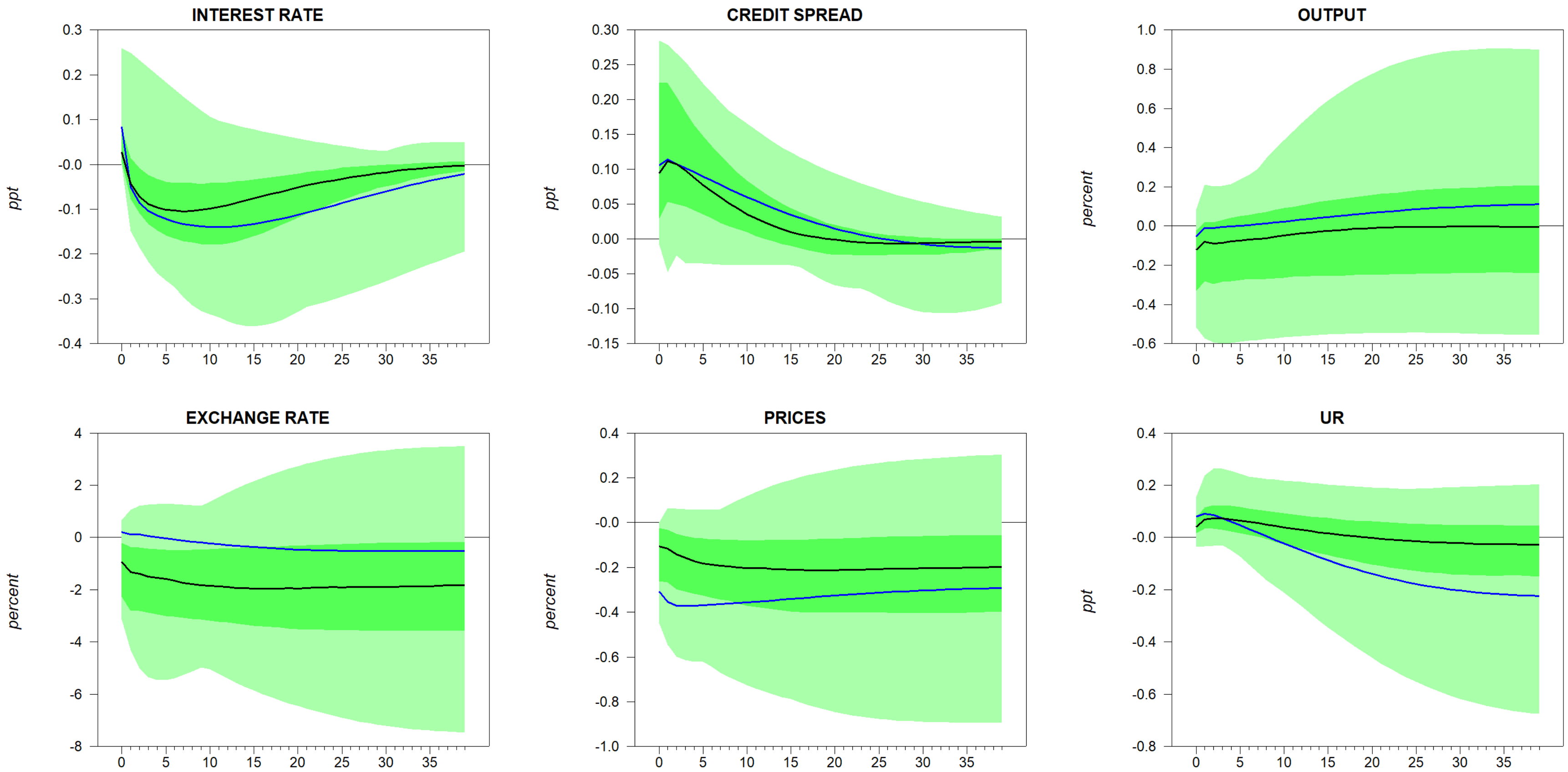
*Real output*: United States Real Gross Domestic Product, billions of chained 2012 dollars, quarterly, seasonally adjusted annual rate, Federal Reserve Economic Data (FRED) database, Series ID: GDPC1. Federal Reserve Bank of St. Louis.

**Figure 1.** Posterior median impulse responses to a contractionary monetary policy shock under baseline identification.




*Notes*: The point-wise posterior median impulse response is shown by the black line while posterior median-target response is shown by the blue line. The dark green shaded region is the 68% equal-tailed point-wise probability band and the light green shaded region is the point-wise range.

**Figure 2.** Posterior median Impulse responses to a contractionary monetary policy shock under baseline identification with restriction of no price puzzle.




*Notes*: The point-wise posterior median impulse response is shown by the black line while posterior median-target response is shown by the blue line. The dark green shaded region is the 68% equal-tailed point-wise probability band and the light green shaded region is the point-wise range.

**Table 1**

Impulse response of the variables at the immediate horizon to a contractionary monetary policy shock under baseline identification.

| Variable | $i_t$ | $q_t$ | $cs_t$ | $p_t$ | $gdp_t$ | $u_t$ |
|---|---|---|---|---|---|---|
| Response | Percentage Point | Percent | Percentage Point | Percent | Percent | Percentage Point |
| Median | 0.03 | -0.98 | 0.09 | -0.06 | -0.14 | 0.04 |
| Median-Target | 0.06 | -1.56 | 0.06 | -0.29 | -0.11 | 0.02 |
| 68% Prob. Interval | [0.01; 0.08] | [-2.37; -0.25] | [0.03; 0.23] | [-0.22; 0.02] | [-0.38; -0.03] | [0.01; 0.07] |
| 95% Prob. Interval | [0.00; 0.17] | [-2.98; 0.18] | [0.01; 0.28] | [-0.38; 0.06] | [-0.49; 0.03] | [-0.01; 0.12] |
| Min-Max Interval | [0.00; 0.26] | [-3.27; 0.68] | [-0.01; 0.28] | [-0.44; 0.12] | [-0.53; 0.08] | [-0.04; 0.16] |

*Notes*: The entries in the table denote the posterior median response of a variable at the immediate horizon to a one-standard error monetary policy shock under the baseline identification. Also shown is the posterior median-target response of the variables at the immediate horizon. The 68% and 95% equal-tailed posterior probability intervals and the Min-Max interval are reported in brackets. The Min-Max interval denotes the posterior range of the immediate responses.

**Table 2**

Contemporaneous coefficients in the monetary policy equation under baseline identification.

| Variable | $\Delta q_t$ | $cs_t$ | $\Delta p_t$ | $\Delta gdp_t$ | $\Delta u_t$ |
|---|---|---|---|---|---|
| Coefficient | $a_{12}^{0}$ | $a_{13}^{0}$ | $a_{14}^{0}$ | $a_{15}^{0}$ | $a_{16}^{0}$ |
| Median | 0.07 | -0.60 | 0.29 | 0.28 | -0.39 |
| Median-Target | 0.09 | -0.44 | 0.80 | 0.24 | -0.12 |
| 68% Prob. Interval | [0.02; 0.15] | [-2.30; -0.14] | [0.06; 0.72] | [0.06; 0.87] | [-1.06; -0.10] |
| 95% Prob. Interval | [0.00; 0.22] | [-8.29; -0.02] | [0.01; 1.44] | [0.01; 1.62] | [-2.25; -0.02] |
| Min-Max Interval | [0.00; 0.36] | [-43.4; -0.00] | [0.00; 2.21] | [0.00; 2.37] | [-3.40; -0.00] |

*Notes*: The entries in the table denote the posterior median estimates of the contemporaneous coefficients in the monetary policy equation under the baseline identification. Also shown are the posterior median-target estimates. The 68% and 95% equal-tailed posterior probability intervals and the Min-Max interval are reported in brackets. The Min-Max interval denotes the posterior range of the coefficients.

**Table 3**

Impulse response of the variables at the immediate horizon to a contractionary monetary policy shock under baseline and no price puzzle identification.

| Variable | $i_t$ | $q_t$ | $cs_t$ | $p_t$ | $gdp_t$ | $u_t$ |
|---|---|---|---|---|---|---|
| Response | Percentage Point | Percent | Percentage Point | Percent | Percent | Percentage Point |
| Median | 0.03 | -0.94 | 0.09 | -0.11 | -0.12 | 0.04 |
| Median-Target | 0.08 | -0.22 | 0.11 | -0.31 | -0.05 | 0.08 |
| 68% Prob. Interval | [0.01; 0.08] | [-2.26; -0.20] | [0.03; 0.23] | [-0.26; -0.02] | [-0.33; -0.02] | [0.02; 0.07] |
| 95% Prob. Interval | [0.00; 0.17] | [-2.92; 0.24] | [0.01; 0.27] | [-0.40; -0.00] | [-0.47; 0.03] | [0.00; 0.12] |
| Min-Max Interval | [0.00; 0.26] | [-3.14; 0.66] | [-0.01; 0.28] | [-0.45; -0.00] | [-0.52; 0.08] | [-0.04; 0.16] |

*Notes*: The entries in the table denote the posterior median response of a variable at the immediate horizon to a one-standard error monetary policy shock under the baseline identification augmented with the restriction that rules out the price puzzle. Also shown is the posterior median-target response of the variables at the immediate horizon. The 68% and 95% equal-tailed posterior probability intervals and the Min-Max interval are reported in brackets. The Min-Max interval denotes the posterior range of the immediate responses.

**Table 4**

Contemporaneous coefficients in the monetary policy equation under baseline and no price puzzle identification.

| Variable | $\Delta q_t$ | $cs_t$ | $\Delta p_t$ | $\Delta gdp_t$ | $\Delta u_t$ |
|---|---|---|---|---|---|
| Coefficient | $a_{12}^0$ | $a_{13}^0$ | $a_{14}^0$ | $a_{15}^0$ | $a_{16}^0$ |
| Median | 0.06 | -0.61 | 0.44 | 0.26 | -0.45 |
| Median-Target | 0.00 | -0.63 | 0.67 | 0.18 | -0.89 |
| 68% Prob. Interval | [0.02; 0.14] | [-2.33; -0.15] | [0.18; 0.85] | [0.06; 0.70] | [-1.24; -0.11] |
| 95% Prob. Interval | [0.00; 0.22] | [-7.47; -0.02] | [0.05; 1.52] | [0.01; 1.49] | [-2.26; -0.02] |
| Min-Max Interval | [0.00; 0.28] | [-27.0; -0.00] | [0.00; 2.55] | [0.00; 2.37] | [-3.40; -0.00] |

*Notes*: The entries in the table denote the posterior median estimates of the contemporaneous coefficients in the monetary policy equation under the baseline identification augmented with the restriction that rules out the price puzzle. Also shown are the posterior median-target estimates. The 68% and 95% equal-tailed posterior probability intervals and the Min-Max interval are reported in brackets. The Min-Max interval denotes the posterior range of the coefficients.

**Table 5**

Contemporaneous coefficients in the monetary policy equation under baseline plus sign restrictions on impulse responses identification.

| Variable | $\Delta q_t$ | $cs_t$ | $\Delta p_t$ | $\Delta gdp_t$ | $\Delta u_t$ |
|---|---|---|---|---|---|
| Median estimate of | $a_{12}^{0}$ | $a_{13}^{0}$ | $a_{14}^{0}$ | $a_{15}^{0}$ | $a_{16}^{0}$ |
| (a): Baseline | 0.07 | -0.60 | 0.29 | 0.28 | -0.39 |
| (b): (a) + No Price-P | 0.06 | -0.61 | 0.44 | 0.26 | -0.45 |
| (c): (a) + No Ex-Rate-P | 0.07 | -0.65 | 0.28 | 0.30 | -0.39 |
| (d): (a) + No GDP-P | 0.07 | -0.62 | 0.28 | 0.32 | -0.41 |
| (e): (b) + No Ex-Rate-P | 0.07 | -0.64 | 0.42 | 0.27 | -0.44 |
| (f): (b) + No GDP-P | 0.07 | -0.61 | 0.40 | 0.30 | -0.47 |

*Notes:* The entries in the table denote the posterior median estimates of the contemporaneous coefficients in the monetary policy equation under the baseline identification augmented with the restrictions on the immediate response of the variables to rule out various puzzles. No Price-P, No Ex-Rate-P and No GDP-P refer to the sign restriction which rules out a price, exchange rate and output puzzle, respectively. For example, row (e) shows the posterior median estimates under the baseline identification together with the sign restriction on the immediate response of prices and the exchange rate which rule out a price and an exchange rate puzzle.