# Which monetary shocks matter in small open economies? Evidence from Canada

Jongrim Ha and Inhwan So*

PRELIMINARY AND INCOMPLETE. PLEASE DO NOT CITE.

*April 2019*

***Abstract:*** Using a structural vector-autoregressive model, we study domestic and international monetary policy transmission in a representative small open economy – Canada. This paper provides new insights to the literature by using a novel set of external instruments to identify monetary policy shocks in both focal and center countries (the latter is proxied by the United States) in a unified framework. This allows us to explore key aspects of the recent debates on the Mundell-Fleming Trilemma. The empirical results are three-fold. First, domestic monetary policy transmission operates though interest rate and credit channels in Canada. That said, our results also suggest that US monetary policy shocks have sizeable and persistent effects on domestic financial and credit conditions in Canada, supporting the international credit and risk-taking channels of monetary policy spillovers. Finally, as the overshooting theory predicts, foreign exchange rates flexibly respond to both domestic and foreign monetary shocks. Our results imply that international capital mobility can challenge monetary policy independence in a small open economy.

***JEL code***: E44, E52

***Keywords***: Monetary policy transmission, external instrument identification, structural vector autoregressive model, open economies

* J. Ha: World Bank; email: jongrimha@worldbank.org. I. So: Bank of Korea; email: ihsoh@bok.or.kr, We thank Yu-chin Chen, Fabio Ghironi, Andrew Karolyi, Ji Hyung Lee, Karel Mertens, Christopher Nimark, Eswar Prasad, Karl Shell, Lei Sandy Ye, and all the seminar participants at the Cornell University, the Bank of Korea, the University of Washington and the 18th Annual SAET conference. The findings, interpretations, and conclusions expressed in this article are entirely those of the authors and they do not necessarily represent the views of the Bank of Korea or the World Bank.

## 1. Introduction

The *Mundell-Fleming's trilemma*, which posits that only two choices among exchange rate stability, domestic monetary autonomy and open capital account are simultaneously compatible, has been a central building block in international macroeconomics (Shambaugh 2004, Obstfeld et al. 2005, Edwards 2012). However, as global financial markets become increasingly integrated and global factors become crucial drivers of local financial market development, there have been extensive debates on the role of global factors and the effectiveness of domestic monetary policy in small open economies.

On the one hand, recent views that emphasize on the role of global factors in driving domestic monetary policies have received much attention (Rey 2015; 2016). These studies argue that flexible foreign exchange rate systems do not necessarily guarantee monetary policy independence in a world of open financial and capital markets. This is because monetary policy decisions in large economies inevitably affect global financial conditions, in turn impacting small open economies, which typically have high dependency on foreign currency borrowing, through a variety of channels. In addition, to the extent that market interest rates in small open economies are significantly influenced by global financial conditions, their movements often deviate from a central bank's policy stance (Turner 2013, Obstfeld 2015). More recent literature highlights this aspect by focusing on international credit or risk-taking channel (Bekaert et al. 2013, Rey 2015; 2016, Passari and Rey 2015; Bruno and Shin 2014; 2015).[1] As a result, central banks in small open economies can face a *dilemma*, not trilemma, and focusing only on domestic short-term rates can deliver policy errors in achieving macroeconomic stability.

On the other hand, another group of studies provide evidence and maintain that the trilemma remains alive (Obstfeld 2015, Aizenman et al. 2016, Obstfeld et al. 2017, and Bekaert and Mehl 2019). These studies argue that exchange rate flexibility is still crucial in preserving the independence of monetary policy, and that in an era of global economic and financial integration, it requires more a nuanced approach to understand the nature of monetary policy transmission than before. For instance, the studies argue that the

[1] These studies suggest that changes in credit condition or risk appetite in international financial markets transmit into local financial markets in open economies through global financial factor or global financial intermediaries.

increased comovement of interest rates across countries can be largely attributable to business cycle synchronization rather than intensified financial interlinkage across jurisdictions (Caceres et al. 2016, Aizenman et al. 2016, Klein and Shambaugh 2015). In addition, according to their views, financial integration can even enhance the effectiveness of monetary policy to the extent that currency appreciation after policy rate rises debases the value of foreign asset, thereby causing an aggregate demand-reducing negative wealth effect (Georgiadis and Mehl 2016).

Despite these theoretical debates, empirical studies on monetary policy transmission in small open economies are nascent, surrounded by two limitations. First, the main focus of the literature has been on the transmission of monetary shocks into macroeconomic variables without considering the consequence on a variety of financial indicators (Dedola et al. 2017). The two opposing views on the trilemma above often define monetary policy independence in different perspectives, by focusing on different types of financial asset prices (Gai and Tong 2019).[2] Besides, there is still no consensus on the dynamic relationship between monetary policy and foreign exchange rate, which is a key variable in the transmission of the shock. On the one hand, many earlier studies pointed out that conditional movements of foreign exchange rates exhibit puzzling deviations from predictions by Dornbusch's (1976) Overshooting theory (Eichenbaum and Evans 1995 and Grilli and Roubini 1995). With a positive domestic monetary shock, for instance, the currency either depreciates, exhibiting the so-called foreign exchange rate puzzle or, if it appreciates, it does so only gradually for prolonged periods of up to a few years, demonstrating delayed overshooting.[3] On the other hand, another group of studies find that exchange rate movements following monetary policy shocks are consistent with the theoretical predictions (Bjørnland 2009 and Cushman and Zha 1997).

---

[2] For example, when assessing monetary policy autonomy, Rey (2015; 2016) pay attention to the covarying general financial conditions among countries and conclude that non-US central banks lose their control over local financial conditions. To the contrary, Obstfeld et al. (2017) focus on the movements in short-term interest rates by implicitly assuming frictionless transmission of monetary shocks to the macroeconomy through capital and financial markets.

[3] Despite many existing results on the puzzling movements of exchange rates in response to monetary policy shocks, e.g., foreign exchange rate and delayed overshooting, only a few recent studies reconcile the empirical results with theories (Bruno and Shin 2015).

Second, the literature has typically not considered the consequence of domestic and foreign monetary policy shocks in a unified framework. Bernanke (2017) points out that the standard Mundell-Fleming model does not predict that small open economies can completely insulate its economy from policy shifts in a center country. It only implies that, under flexible exchange rate system, countries can insulate domestic macroeconomic situation from external shocks by steering interest rates. This calls for a broader and more balanced view in understanding the Trilemma debates. Put differently, investigating the effectiveness of domestic monetary policy is equally as important as examining the transmission of international monetary shocks.

In this context, we seek to contribute to the literature in the following two respects. First, we investigate both international spillovers and domestic transmission of monetary policy shocks in a unified SVAR framework. The model allows us to compare the impact of domestic and foreign (for which the United State is the proxy) monetary policy shocks on multiple market interest rates at a variety of maturities, credit costs, and capital flows in a focal small open economy. In addition, we test monetary policy transmission into the national currency market, in light of prior theoretical and empirical findings that foreign exchange rates play an important role in domestic and foreign monetary policy transmission in open economies.

Second, we seek to avoid the simultaneity problem involving monetary policy actions and other macroeconomic or financial variables by identifying the monetary shocks using a novel set of *external instruments,* instead of imposing arbitrary assumptions about causal relationship among endogenous variables.[4] To do this, we propose and use various

---

[4] Identification of structural monetary policy shocks in SVAR can be quite challenging, however, especially in a model with multiple financial variables, because of simultaneity issues. Most studies with an open-economy setting often impose arbitrary relationships on endogenous variables (e.g. a recursive structure or Cholesky restriction), which specify that some structural shocks have no contemporaneous effect on one or more financial variables, thereby facing difficulties in sorting out the contemporaneous movements of monetary policy shocks, exchange rates, long-term yields, etc (Faust, Rogers, Swanson, Wright 2003; Gertler and Karadi 2015). In addition, identified monetary structural shocks in such a model can be different from each other to the extent depending on assumptions regarding the identification of such shocks (Rudebush 1998). This may work as a critical limitation when interpreting empirical results pertaining to the dynamic relationship between structural shocks and endogenous variables, e.g., impulse response functions (IRFs) and decomposition of forecast error variances. Regarding the simultaneity problem, see for instance, Gertler and Karadi (2015) or Bjørnland (2009).

instrumental variables that proxy monetary policy shocks in Canada, including high-frequency financial data as well as other measures obtained from econometric models. More specifically we use, *inter alia*, three types of instrumental variables: (i) market-based, (ii) model-based, and (iii) survey-based instrumental variables. The external instrument identification scheme, initially proposed by Stock and Watson (2012) and Mertens and Ravn (2013), has considerable appeal because it exploits the attractive features of SVARs while addressing the identification issues raised above by using information from external instruments. In the studies on monetary policy transmission, Gertler and Karadi (2015) combine a SVAR set-up with such an identification scheme, exploiting high-frequency external instrument variables, obtained from federal funds and euro dollar futures rates. Unlike the findings in the literature on US markets, this identification method has not yet been actively applied to related studies on other economies.[5] One critical reason for this omission may be that there are no futures markets with active trading in such monetary policy operating targets in those countries, and thus external information on monetary policy surprise is not easily obtainable.

We choose Canada as a focal small open economy, as in many earlier studies. Given that our focus is on the transmission of domestic and foreign monetary policy shocks into a small open economy, Canada is a perfect candidate for this study. First, Canada is an open economy, equipped with developed financial and credit markets. This allows us to test a variety of channels of domestic and international monetary transmissions. Second, Canada has adopted inflation targeting since the 1990s, when it has taken the flexible exchange rate regime and have used short-term interest rates as the operating target for monetary policy. The records of monetary policy reports enable us to extract the information on the Bank of Canada's own expectations of future macroeconomic situation and monetary policy stance. Finally, among other small open economies, Canada shows the greatest macroeconomic and financial linkages with the United States, which helps validate our selection of the United States as a center country.

Our empirical findings are summarized as follows. On the one hand, domestic transmission of monetary policy shocks appears to operate through a variety of channels. First, both short-term and long-term rates react significantly to domestic monetary policy shocks,

[5] One exception is the case of the United Kingdom; see for instance Cesa-Bianchi et al. (2016).

confirming the role of the conventional interest rate channel. Second, foreign exchange rates in this process also respond significantly to monetary policy shocks, as the overshooting theory of Dornbusch (1976) predicts. Contrary to a group of earlier findings that report counterevidence for the overshooting hypothesis, we find that an increase in local policy rates causes the nominal exchange rate to appreciate instantaneously and then to depreciate gradually, in line with uncovered interest parity. Third, contractionary monetary policy shocks, both domestic and foreign, generate an increase in credit spreads in Canada. This is consistent with the predictions by the credit and risk-taking channels of monetary policy transmission, both from domestic and international perspectives. Reflecting the pass-through of monetary policy shocks into financial and credit markets, macroeconomic conditions (output and price levels) significantly respond to monetary policy shocks as the New Keynesian theory would predict.

On the other hand, international spillovers of monetary policy shocks also play an important, and possibly stronger, role in driving financial and macroeconomic conditions in Canada. Following a contractionary US monetary policy shock, market interest rates in Canada (both short- and long-term maturities) significantly increase and the impact persists for a prolonged period. More interestingly, overnight rates in Canada, which is a monetary policy tool, also respond to the US monetary policy shocks. Following the contractionary US monetary policy shock, credit spreads increase substantially along with an immediate outflow of international capital investments. This is consistent with the predictions by the credit and risk-taking channels of monetary policy transmission both from domestic and international perspectives (Rey 2015; 2016, Hofmann et al. 2017). Finally, the response of macroeconomic variables is divergent across the two types of monetary policy shocks; contractionary US monetary shocks show expansionary and inflationary consequences on the variables in Canada. This may partly reflect the expenditure-switching effects of contractionary US monetary shocks, offsetting negative impacts of tightened financial condition on the real economy in Canada.

Our results collectively provide a different perspective of the recent debates on the trilemma. While the cross-border monetary spillovers from a financial center country become evident in a financially globalized world, domestic monetary policy is still effective in controlling domestic financial and real variables when exchange rates freely float. The upshot is that monetary policy implementation in Canada can be hampered significantly due to spillover effects from the center country, especially when the directions of the monetary policies are diverging.

The rest of this paper is organized as follows. In section 2, we provide an overview of the theoretical relationships among endogenous variables in the context of open-economy structural models. In section 3, we specify a SVAR model and its identifying restrictions. Section 4 summarizes the empirical results and section 5 concludes.

## 2. Monetary Policy Transmission in an Open Economy

In this section, we motivate the SVAR exercise by revisiting theoretical channels of domestic and international transmission of monetary policy shocks in a small open economy. Our main focus is to understand the role of each transmission channel on monetary policy independence of the economy in the context of the trilemma theory.

### 2.1. Domestic monetary policy transmission

We first unravel the channels of domestic monetary policy transmission because their effectiveness is crucial in understanding the monetary policy independence in the economy. Standard New-Keynesian models, which assume sticky prices and frictionless financial markets, indicate that monetary policy shocks are transmitted to credit costs and thus to aggregate spending operates via yield curves. Given the expectation hypothesis of the term structure, the effect of monetary policy decisions on the paths of current and expected short-term interest rates is summarized in (1):

$$r_t^m = m^{-1}E_t\left[\sum_{i=0}^{m-1} r_{t+j}\right] + \xi_t^m \qquad (1)$$

where $r_t^m$ is an *m*-period zero-coupon government bond yield at time *t*, $r_t$ is a short-term interest rate (e.g., the central bank policy rate), and $\xi_t^m$ is an *m*-period term premium.

The term premium captures additional compensation for interest rate (duration) risk inherent in medium- or long-term bond positions as well as residual effects of idiosyncratic market factors. If the premium is assumed to be constant over time, changes in the path of short-term rates will dominate changes in long-term rates and this allows central banks to influence movements of output and inflation (*interest rate channel*).

In addition, with some degree of financial frictions, credit markets are expected to play an important role in the transmission of monetary shocks into financial and macroeconomic conditions (Bernanke and Gertler 1995). For instance, corporate bond yields ($r_t^{cb}$) usually exceeds the sovereign bond rates with a same maturity ($r_t^m$) to compensate for external finance premium ($x_t^m$), as in equation (2):

$$r_t^{cb} = r_t^m + x_t^m \tag{2}$$

The *credit channel* particularly highlights the accelerating effect of a monetary policy shock; for instance, contractionary monetary policy shocks tighten financial constraints in the private credit market and thus raise credit spreads.[6]

Finally, monetary policy shifts in a small open economy affect the value of domestic currency as indicated in the uncovered parity condition in (3). Changes in foreign exchange rates then bring about changes in relative price of tradable goods and in the value of assets denominated in foreign currency, and finally foreign demand for domestic products (*exchange rate channel*).

$$r_t = r_t^* + E\Delta(e_t) + \rho_t \tag{3}$$

where $e_t$ is the nominal exchange rate vis-à-vis US dollar and $\rho_t$ is the currency risk premium in open economies at time *t*.

### 2.2. International monetary policy spillovers

The impact of foreign monetary shock on domestic economy is another key important issue in understanding the monetary policy independence. This is because the extent of a central bank's control, especially when looking through the lens of a small open economy

[6] On the empirical evidence on the credit channel of monetary policy transmission, see, for instance, Gertler and Karadi (2015).

in a financially integrated world, over macroeconomic developments is controversial; policy and other monetary shocks migrate from other countries under financial globalization, possibly causing *monetary spillovers* even when exchange rates float freely (Obstfeld 2015, Bruno and Shin 2015, Rey 2016, Passari and Rey 2015). The international monetary transmission mechanisms are considered to be operating with the following, direct and indirect, channels through short- and long- term yield structure.

With high level of capital and financial market integration, a country's manipulation of short-term rates ($r_t^*$), especially if it is a large open economy such as the United States, directly affects short-term rates ($r_t$) in other countries following the interest-parity relationship represented in (3).

Although, according to the Mundell-Fleming model, changes in the interest rate difference between two countries are assumed to be absorbed mainly by adjustments in exchange rates, market interest rates in an open country are likely to be influenced by foreign monetary policy shocks, depending on the behavior of the exchange rate and the risk premium. For instance, the international linkage between each country's long-term bond yields can be navigated in the form (4) which combines equations (1) and (3):

$$r_t^m = \underset{(i)}{r_t^{*m}} + m^{-1}E_t\left[\sum_{i=0}^{m-1}\left(\underset{(ii)}{\Delta e_{t+j}} + \underset{(iii)}{\rho_{t+j}}\right)\right] + \underbrace{\xi_t^m - \xi_t^{*m}}_{(iv)} \tag{4}$$

Equation (4) implies that unexpected monetary policy shocks in a foreign country at first adjust market interest rates in a certain open economy (*i*). In addition, they put additional pressure on the market rates depending upon the responses of exchange rates and risk (term) premia. If borrowers' and lenders' balance sheets in the open economy are denominated by the US dollar, for instance, the strong dollar (*ii*) caused by contractionary US monetary shocks can tighten credit conditions in the open economy as well. This is because borrowers' balance sheet becomes weak due to high liabilities relative to assets and creditors' lending capacity also drops. This retards economic activity and deteriorates government fiscal position in the open economy. In addition, US monetary tightening may also raise perceived risk and uncertainty in international financial markets. Consequently, the tightening can boost tail risks for small open economies' sovereign bonds (*iii*) and compress capital flows into those bonds (*iv*), thereby leading to potential unintended pro-cyclical dynamics in their bond markets (*risk-taking channel*, Bruno and Shin 2015, Hofmann et al. 2017).

The aforementioned channels work reversely when US dollar becomes weaker against a small open economy currency in the case of monetary policy easing in the United States. A weak US dollar tends to reduce dollar borrowers' liabilities and raise their assets. Then, the improvement in borrows' dollar balance sheet and increased lenders' willingness to extend credit will boost economic activity in small open economies and ameliorate government fiscal position. As a consequence, this mitigates tail risks and increases portfolio inflows to the country.

Finally, in a highly integrated financial market, particularly where the US dollar is predominant as a funding and an investing currency, US monetary policy shocks can also influence the net worth of agents through corporate bond markets in small open economies, and thus make their financial conditions comove (*international credit channel*, Passari and Rey 2015, Rey 2016, and Cesa-Bianchi and Sokol 2017).[7]

## 3. Estimation of SVAR model

### 3.1. SVAR modeling

We assume the economy is described by a structural form equation (5):

$$AY_t = \sum_{i=1}^{p} B_i Y_{t-i} + \varepsilon_t \tag{5}$$

where $Y_t$ is an $n \times 1$ vector of macroeconomic and financial variables, $A$ and $B_i (\forall i \geq 1)$ are nonsingular coefficient matrices, and $\varepsilon_t$ is an $n \times 1$ structural disturbances vector. $\varepsilon_t$ is serially uncorrelated and $E(\varepsilon_t \varepsilon_t^{'}) = I$ where $I$ is the identity matrix; therefore, structural disturbances are assumed to be mutually uncorrelated. For notational brevity, the

[7] As in Bernanke (2017), if $R_t$ denotes a shadow price of credit, equation (3) or (4) captures foreign credit availability in an open economy and $\rho_t$ reflects external finance premium.

specification in (5) omits deterministic terms and exogenous regressors.

By pre-multiplying each side of the equation by $A^{-1}$, we obtain a reduced form representation (6):

$$Y_t = \sum_{i=1}^{p} \alpha_i Y_{t-i} + e_t \qquad (6)$$

where $\alpha_i = A^{-1}B_i$, and $e_t$ are the reduced form residuals which are related to the structural shocks by (7):

$$e_t = \begin{bmatrix} e_t^p \\ e_t^q \end{bmatrix} = S\varepsilon_t = \begin{bmatrix} s^p & s^q \end{bmatrix} \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^q \end{bmatrix} \qquad (7)$$

with $S = A^{-1}$. $e_t^p$ are the residuals of domestic and foreign monetary policy instruments (i.e., $e_t^p = \begin{bmatrix} e_t^{MP*} & e_t^{MP} \end{bmatrix}'$) and $e_t^q$ is a vector for the residuals of the other variables, and the analogous definition applies to structural shocks $\varepsilon_t^p$ and $\varepsilon_t^q$. $s^p$ and $s^q$ denote the column in matrix *S* that corresponds to the impact on each element of the vector of reduced-form residuals $e_t$ of structural policy shocks $\varepsilon_t^p$ and $\varepsilon_t^q$, respectively. The variance–covariance matrix of the reduced-form VAR is $\Sigma = E[e_t e_t'] = \mathrm{E}[SS']$.

The structural moving average (or Wold) representation as a function of structural shock is given as (8):

$$Y_t = \sum_{j=0}^{\infty} C_j S \varepsilon_{t-j} = \sum_{j=0}^{\infty} C_j s^p \varepsilon_{t-j}^p + \sum_{j=0}^{\infty} C_j s^q \varepsilon_{t-j}^q \qquad (8)$$

where $C_j$ denotes the coefficients of the structural MA form. Accordingly, if the endogenous variable responds to monetary policy innovations, the impulse response function (IRF), which is the dynamic response of the *k*-th element of vector *Y* ($Y_k$) to a unit shock of $\varepsilon_t^p$ at time *t+j*, can be obtained by (9):

$$IRF_{k,j} = \frac{\partial Y_{k,t+j}}{\partial \varepsilon^{p}_{k,t}} = C_{k,j} s^{p} \tag{9}$$

where $C_{k,j}$ is the *k*-th row of $C_j$.

### 3.2. External instrument identification scheme

Identifying 'exogenous' monetary policy shocks is challenging in the SVAR analysis because the response of variables to any endogenous policy actions cannot distinguish the movement in economy due to the policy action itself and to the variable that spurred that action. If identification restrictions are imposed without reflecting the true relationships among the variables, the model generates biased inferences on the dynamic responses of endogenous variables to the identified structural shocks.[8]

In the monetary SVAR literature, short-run zero restrictions have been conventionally assumed, which orthogonalize reduced-form disturbances by the Cholesky decomposition. This assumes that monetary policy transmission is occasionally uni-directional, i.e., monetary policy shocks do not affect contemporaneously macroeconomic variables while the latter affect monetary policy decisions, and(or) the impacts of monetary policy surprises in the financial market propagate only in one direction, from the short-term to the long-term rate. Such restrictions, however, may distort the true relationships because within a given period policy shifts not only influence financial variables but may also respond to them (Gertler and Karadi 2015). Even if the central bank does not directly respond to financial indicators, it may respond to underlying correlated variables left out of the VAR. Furthermore, there is a growing body of literature, including Carlstroma, Fuerst, and Paustian (2009), which suggest that monetary policy can influence economic variables simultaneously and that Cholesky identification can distort the results, producing price puzzles or muted responses of inflation and output.[9]

---

[8] In this respect, Rudebusch (1998) criticizes the limitations of applying VAR methodology in monetary policy analyses. He showed that structural shocks stemming from a recursively identified VAR may not be identical to monetary policy shocks identified outside the VAR.

[9] Since the 1990s, the Federal Reserve and central banks in other developed countries have increasingly relied on communication to influence market beliefs about the expected paths of policy rates and economic conditions, and in this way MP may have immediate effects on macroeconomic variables. If central banks have

In order to avoid such potential identification issues, we employ the *external instrument identification strategy*, which avoid imposing any strong assumptions on the contemporaneous interactions among endogenous variables. Initially proposed by Stock and Watson (2012) and Mertens and Ravn (2013), the identification scheme offers attractive features for measuring the effects of structural shocks in the sense that it utilizes an information set pertaining to exogenous shocks that are identified outside the VAR. The required restrictions for the identification of structural parameters are thus supplemented by the moment conditions between external instruments and endogenous variables in the VAR. Gertler and Karadi (2015), who adopt this approach in the study of monetary policy transmission in the United States, show that it can be applied to monetary VAR analyses by using external monetary policy shocks with high-frequency financial data.

Expanding on the study, we recover structural parameters related to monetary policy shocks using a variety of instrumental variables. The novel part of our analysis is that we consider the transmission of domestic and foreign monetary policy shocks together in a single framework while avoiding the simultaneity problem. This enables us to evaluate and compare the overall impacts of each shock in an open economy. Existing studies which adopt this external instrument identification method have often concentrated only on either domestic or foreign monetary shock. Moreover, this unified empirical set-up helps analyze the impact of foreign monetary shocks while we control for the impact of domestic shocks, and vice versa. Without considering both types of the monetary policy shocks, especially in a highly open economy such as Canada, the identification of monetary policy shocks and their dynamic impacts can be biased due to omitted variables' problem. After identifying both types of monetary policy shocks, we follow Mertens and Ravn (2013) and orthogonalize the shocks by assuming that US monetary policy shocks have contemporaneous impact on local (Canada) monetary policy but not vice versa.[10] The

---

more information on the future economic situation, e.g., on aggregate demand and inflation, than the public, an announcement by central banks may change agents' expectations and thereby economic activity. A statement that causes economic agents to expect accommodative future aggregate demand, for example, may lead to a spontaneous increase in current consumption and output.

[10] In this two-country VAR model, we also impose a block exogeneity restriction in equation (6). Put differently, we assume that a small open economy, Canada, does not have any feedback effects on foreign country or world economy, the United States. See for example, Cushman and Zha 1996, Kim and Roubini 2000, Dedola et

procedures for exploiting the two shocks in a proxy VAR approach are summarized in Appendix.

### 3.3. Data

Existing open-economy SVAR analysis typically considers short-term interest rates, foreign exchange rates, and macroeconomic variables such as output and price as endogenous variables for domestic economy in studying the monetary policy transmission. (Kim 2001 and Bjørnland 2009, among many others). Expanding on this, we also consider the transmission through the reactions of financial conditions such as in sovereign and corporate bond, and capital markets. The SVAR model in this paper thus includes a variety of financial and credit instruments.

Specifically, we choose nine monthly macroeconomic and financial variables in the SVAR, reflecting the theoretical set-up described in section 2: logs of seasonally adjusted Canadian consumer price index (*P*, 'price' hereafter), logs of seasonally adjusted industrial production (*Y*, 'output' hereafter), domestic and foreign policy interest rates (*MP* and *MP**), three-month and ten-year Canadian government bond yields (*R3m*, *R10y*),[11] short- and long-term credit spread (*CS3m*, *CS3y*), capital inflows to Canada (*CF*), logs of the nominal foreign exchange rate against one unit of the US dollar (*FX*). In addition, following the prior literature, four external variables are included in the SVAR system to isolate exogenous latent factors that can influence endogenous variables simultaneously: the international commodity price index, a dummy variable for the global financial crisis, the CBOE volatility index (VIX), and the dollar index. Sample period is January 2000 – March 2017. Table 1 summarizes the detailed description of the data.

As explained in the introduction, there are several reasons why we choose Canada as the focal open economy. Canada relies heavily on foreign economies, especially the United States, from both real economic and financial market sides (see Cushman and Zha 1996 for instance). Canada has adopted inflation targeting in 1993 as a monetary policy regime and used short-term interest rates as a monetary policy operating instrument. Moreover,

---

al. 2017, Cesa-Bianchi and Sokol 2017.

[11] The variables are specified in levels to implicitly determine any potential co-integrating relationship between them; see Hamilton (1994).

the country is equipped with well-developed financial markets with sufficient trading volume to validate our use of financial asset prices as instrumental variables.

### 3.4. Instrumental variables (IVs)

A valid instrument for monetary policy shocks should satisfy the following two conditions:

$$rank(E[Z_t \varepsilon_t^p]) = L \quad \text{(relevancy)} \tag{10}$$

$$E[Z_t \varepsilon_t^q] = 0 \quad \text{(orthogonality)}$$

where $L$ is the number of endogenous variables.

To the extent that effects of monetary policy on the economy are determined by the market participants' reaction to monetary policy shocks, the literature has extensively used the changes in short-term futures rates around the announcements of monetary policy decision as proxy of monetary policy surprise (Kuttner 2001, Gürkaynak et al. 2005, Gertler and Karadi 2015, Cesa-Bianchi et al. 2016, Miranda-Agrippino 2016, and Jarocinski and Karadi 2018).[12] Such variations reflect changes in the expectations of market participants on future interest rates (or monetary policy stance).

Following Gertler and Karadi (2015) and Gürkaynak et al. (2005), in identifying US monetary policy shocks, we use changes in the federal fund futures rates and Euro dollar futures rates with a variety of maturities, within a narrow (30-minute) window around FOMC meetings. We extend the high frequency series of US monetary policy shocks from Gertler and Karadi (2015)'s to March 2017.[13]

Most of the other economies, including Canada as our focal economy, however, are not yet equipped with derivative markets for monetary policy instruments with ample depth.

---

[12] This includes high-frequency movements (e.g., 30-miniute window) of short-term futures rates (Federal Fund futures rates and 3-month sterling futures rates) around monetary policy decision meetings.

[13] As a robustness check, we tested instrumental variables used in Nakamura and Steinson (2018), and Rogers, Sack, and Watson (2018) and the results are not qualitatively different. We here use the instrumental variables by Gertler and Karadi (2015) considering the relevancy of the instrumental variables.

Given this limitation, we propose a variety of external instrumental variables for Canada based on the prior theoretical and empirical findings. We classify the instrumental variables by the three groups: (1) short-term interest rates (repo rates, overnight rates, 3-month government bond yields) (classified as "IV1"), (2) changes in expected future short-term rates implied by term-structure model ("IV2"), and (3) residual of central bank policy reaction functions (as in Romer and Romer 2004) ("IV3"). Instrumental variables tested for Canada and the United States are summarized in Table 2.

### 3.4.1. IV1: Daily short-term spot rate changes on monetary policy decision dates

Following Cochrane and Piazessi (2002) and others, we first consider daily movements of short-term interest rates around monetary policy decision announcements, by defining the daily change in the spot rates as a monetary policy surprise. Financial market participants anticipate monetary policy decisions before actual policy announcements, and short-term rates may have already been adjusted beforehand. To the contrary, if the monetary policy announcement is a mere surprise, market rates will adjust only after the announcements.

This approach rests on the following two assumptions. First, asset prices move according to the efficient market hypothesis. In such market conditions, new information including monetary policy decision is immediately reflected on the asset prices as soon as it is released. Second, short-term rates are more sensitive to monetary policy news than long-term rates because central banks typically adjust short-term rates to steer macroeconomic variables. This indicates that news other than monetary policy decision on the dates can be regarded as white noise.

Figure 1 shows the movements of representative short-term rates of the United States and Canada. Short-term rates are not anchored by policy target when the direction and magnitude of shocks are anticipated in advance.

### 3.4.2. IV2: Monetary policy shock implied in term structure model

We calculate the conditional expectation on short-term interest rates using a standard affine term structure model and proxy its changes around monetary policy decision as *monetary policy shocks*. The expectation hypothesis assumes that long-term interest rates consist of the expected path of short-term rates and term premium, as illustrated in Equation (1). Given that current and future path of short-term interest rates are directly linked to the effects of interest rate channel and forward guidance, the changes in the expected future path of short-term interest rates around monetary policy decision will mirror the changes in market participant's expectations on monetary policy stance of central banks.

The affine model we consider is described as below. Prices of zero-coupon bonds are derived from the pricing kernel as in (11):

$$P_t^{\tau} = E_t\left[m_{t+1}P_{t+1}^{\tau-1}\right] \tag{11}$$

where $P_t^{\tau}$ is the zero-coupon bond price with a maturity $\tau$, $m_{t+1}$ is a stochastic discount factor and $E_t$ is a conditional expectation on the information set up to time *t*. We specify the discount factor as (12):

$$m_{t+1} = \exp\left(-r_t - \frac{1}{2}\Lambda_t^{'}\Omega\Lambda_t - \Lambda_t^{'}\nu_{t+1}\right) \tag{12}$$

with the assumption that risk-free short-term rate ($r_t$) and time-varying market prices of risk ($\Lambda_t$) are linear functions of factors:

$$r_t = \delta_0 + \delta_1^{'}X_t \tag{13}$$

$$\text{and} \quad \Lambda_t = \lambda_0 + \lambda_1 X_t$$

where $\delta_0$ is a constant term; $\delta_1$ and $\lambda_0$ are $N \times 1$ vectors; $\lambda_1$ is a $N \times N$ matrix, respectively. We assume that transition equation for state variable $X_t$ follows first-order vector-autoregressive process as in (14):

$$X_t = \mu + \Phi X_{t-1} + \nu_t \tag{14}$$

where factor shocks $\nu_t$ follows i.i.d. normal distribution $N(0,\Omega)$.

Combining equations (11)-(14) yields the bond price and yield for maturity $\tau$ as the following affine functions of the state variables.

$$P_t^\tau = \exp\left[A_\tau + B_\tau X_t\right] \tag{15}$$

$$R_t^\tau \approx -\frac{1}{\tau}\log P_t^\tau = -\frac{1}{\tau}\left(A_\tau + B_\tau X_t\right) \tag{16}$$

where $A_\tau$ and $B_\tau$ are obtained in the recursive equations as in (17) and (18).

$$A_{\tau+1} = A_\tau + B_\tau'\left(\mu - \Omega\lambda_0\right) + \frac{1}{2}B_\tau'\Omega B_\tau - \delta_0 \tag{17}$$

$$B_{\tau+1}' = B_\tau'\left(\Phi - \Omega\lambda_1\right) - \delta_1' \tag{18}$$

In estimating latent factors, we additionally assume that underlying factor is only the short-term interest rates, i.e. $\delta_0 = 0$, $\delta_1 = 1$. In addition, benchmarking Chen and Scott (1993), we assume that there are $K_2$ yields observed without measurement errors. Given a parameter vector $\{\mu, \Phi, \Omega, \delta_0, \delta_1, \lambda_0, \lambda_1\}$, the unobserved factors can be obtained from the chosen yields. Expected *j*-step ahead short-term rate is then obtained as:

$$E_t r_{t+j} = \delta_0 + \delta_1'\left(\bar{\mu} + \Phi^j\left(X_t - \bar{\mu}\right)\right) \tag{19}$$

Finally, we can decompose bond yields with a variety of maturities into the sum of expected short-term rates and term premia. Other things being equal, monetary shocks around policy decision directly cause the changes of future path of short-term interest rate.

We compute the changes in the expected future path of short-term interest rates from zero coupon bonds with the maturities of 3-, 6-, 9-, and 12-month. Data for zero coupon rates are obtained from the Bank of Canada.

### 3.4.3. IV3: Residuals from policy reaction functions

Benchmarking the approach in Romer and Romer (2004), and the extension of the methodology to Canada as in Champagne and Sekkel (2018), we use residuals in forward-looking Taylor rule equation as a proxy variable for Canadian monetary policy shocks (IV3). Main idea is that using internal forecast information in the central bank, we can extract a measure of unanticipated movements in monetary policy target rates (or surprise component) can be extracted which is orthogonal to information about past, current and future economic developments.

We follow Champagne and Sekkel (2018) and take two steps in estimating the Taylor rule equation in Canada. First, using the minutes in monetary policy reports (source: Bank of Canada Monetary Policy Reports), we collect real-time forecasts for output and inflation in Canada. Regarding the CPI inflation forecast, we use both headline and core CPI inflation. Second, we regress changes in monetary policy target rates from the previous monetary policy decision meeting to the current meeting ($\Delta r_m$) on a set of explanatory variables that purge the intended policy rate. The explanatory variables include: (i) levels of policy rates (2 weeks prior to the monetary policy meeting, $r_{t-14}$), (ii) forecasts of real GDP growth ($y^f_{m,j}$) and inflation ($\pi^f_{m,j}$); we here include the 1- and 2-month-ahead forecasts as well as the forecasts at the contemporaneous period and the forecast made one month before the meeting, (iii) changes of the variables selected in (ii) from the previous period, and (iv) other variables that could potentially reflect economic developments between meetings. The terms in (iii) reflect revisions to the forecasts relative to the previous round of forecasts. The last variable (iv) includes real-time rates of unemployment for the previous three months and the levels and changes of US FFR and the logs of the USD/CAD nominal exchange rate two weeks before the meeting. The estimated regression is summarized as (20).

$$\begin{aligned}\Delta r_m = \alpha + \underbrace{\beta_1 r_{t-14}}_{(i)} + \underbrace{\sum_{j=-1}^{2} \beta_{2,j} \hat{y}^f_{m,j} + \sum_{j=-1}^{2} \beta_{3,j} \pi^f_{m,j}}_{(ii)} \\ + \underbrace{\sum_{j=-1}^{2} \beta_{4,j} \left( \hat{y}^f_{m,j} - \hat{y}^f_{m-1,j} \right) + \sum_{j=-1}^{2} \beta_{5,j} \left( \pi^f_{m,j} - \pi^f_{m-1,j} \right)}_{(iii)} + \underbrace{\gamma Z}_{(iv)} + \varepsilon_m \end{aligned} \tag{20}$$

where $\Delta r_m$, changes in policy rates, is measured at the frequency of monetary policy meetings, as indicated by the subscript *m*. The subscript *j* denotes the quarter of the real-time data or forecast relative to the meeting date. Z includes other control variables.

The regression coefficients for equation (10) are summarized in Table 3 (using headline CPI inflation forecast in Panel A and core CPI inflation forecast in Panel B). Consistent with the findings in earlier studies including Champagne and Sekkel (2018), the results indicate that changes in policy rate are significantly and positively associated with levels or changes in forecast of inflation and/or output growth. In addition, the results provide evidence that monetary policy decision in Canada reflects both levels and changes in monetary policy target rates in the United States. Higher real-time unemployment level is associated with decrease in policy rates with less statistical significance after controlling for GDP growth and inflation forecasts. R square of the regressions is over 0.8. This indicates that explanatory variables in the regressions which proxy the intended component of policy changes in Canada explain around 80 percent of variations in monetary policy target rates in Canada.

### 3.4.4. US monetary policy instruments

As explained in Section 3, we use intraday movements of US federal fund futures rates and Eurodollar futures rates for some maturities (as denoted by MP1, FF4, ED2, ED3, and ED4 in Gertler and Karadi 2015) as instrumental variables for US monetary policy shocks.

### 3.4.5. Properties of instrumental variables

Figure 2 depicts the movements of selected instrumental variables over the sample period in each panel. In Panel A, we show the monthly series of changes in representative three short-term rates in Canada, i.e. repo rates, overnight rates and prime rates around monetary policy decision dates (IV1). The series show relatively distinct movements in principle after the dot-come crash in early 2000 and the Global Financial Crisis around 2008-09. However, compared to the other two, the prime rates exhibit relatively less variation around the events. Panel B describes the instrumental variables related to the changes of sum of expected short-term rates for the maturities of 3-, 6-, 9- and 12-month (IV2). All the variables follow a similar path, while the changes for 3-month bond moves with larger variation over time. Panel C exhibits the residuals from the Central Bank's policy reactions functions using headline and core CPI as anchoring price measures (IV3). It is notable that the variables show react comparatively less during the major episodes such as the Global Financial Crisis, indicating that some of the variation in policy rates is already anticipated by the central bank.

Figure 3 summarizes the correlations of the instrumental variables in the format of heatmap in order to have a bird's eye view. We find that the shocks are positively correlated within and across the countries but with different degrees. Instrumental variables are positively correlated with relatively higher correlations among the same IV categories and among the same countries (the US: 0.78, Canada: 0.52, on average). Meanwhile, even though correlations of instrumental variables between the United States and Canada are positive (0.14 on average), they are less correlated than those of within country. Each of the instrumental variables is explained as below.

To test the relevancy of the instrumental variables, we use t-statistics, F-statistics (in the case of multiple instrumental variables), and R square from the first-stage regression of residual of policy indicators projected on the instrumental variables. The relevancy test results are reported in Table 4 for the United States (Panel A) and Canada (Panel B).[14] To the extent that 'F-statistics > 10' is commonly regarded as rule-of-thumb criteria to be safe from weak instrumental-variable problem in practice, the selected instrumental variables of which F-statistics in the first-stage regression exhibit higher than 10 are strongly relevant to the exogenous monetary policy shocks.

## 4. Empirical results

To show how the domestic and international monetary policy transmissions operate in Canada, we here present the impulse responses of financial, capital flow, and macroeconomic variables to domestic monetary policy shocks, and then to US monetary policy shocks.

[14] Staiger and Stock (1997) suggest that the F-statistics of the instrumental variables should be greater than 10 to ensure that the maximum bias in the IV estimators is less than 10%. If we are willing to accept maximum bias in IV estimators of less than 20%, the threshold for the F-statistics would be 5. In the case of single instrumental variable, the F-statistics should be replaced by t-statistics.

### 4.1. Effects of Canadian monetary policy shocks on her economy

Figure 4 displays impulse response of Canadian variables to a positive monetary policy shocks that increases overnight rates in Canada by 100 basis points. Panel A through C in the figure sequentially reports the empirical results using three different types of instrumental variables explained in the previous section. Panel D then shows the results in the case where we employ the three types of instrumental variables altogether. Since the results are quite consistent across different types of instrumental variables, we focus on the results with all types of instrumental variables that report the highest explanatory power in the first-stage regression.

***Market interest rates.*** Interest rate channel of monetary policy operates in Canada; following the contractionary domestic monetary policy shock, Canadian market interest rates respond significantly, although, the magnitude and persistence of the impact weaken with the instruments with longer maturity. Short-term interest rates (3-month T-bill rates) move in tandem with overnight rates, by increasing around 100 basis points on impact and the effects persist until around a year. Long-term rates (5-year bond yields) also increase sizably, around 70 basis points on impact, but the impact dies out quickly, within two-three months after the shock.

The limited degree of response of long-term interest rates, which is at odd with what the conventional New Keynesian framework predicts, may reflect the off-setting effects of various factors that determine the level of long-term interest rates, as illustrated in equation in Section 2. First, the monetary tightening could dampen due to the subsequent exchange rate appreciations and weakened future inflation expectations. In addition, in a country with high level of foreign currency debt, especially in US dollar, currency appreciations against US dollar can enhance the borrowing capacity in Canada, thereby reducing the tail risks associated with currency risk premium (Hofmann et al. 2017). All in all, despite the increase in expected future short-term interest rates, the other three components, expected movements in exchange rates, term premium, and currency risk premium, all contribute to the decrease in long-term rates and, and this finally suppresses the rise in long-term rates.

***Exchange rates.*** Following the contractionary (+100 bp) monetary policy shock, Canadian dollar immediately appreciates by around 7 percent, and then depreciates gradually until it reaches the original level. This is in line with the predictions by the Overshooting theory in Dornbusch (1976), which is based on the uncovered interest rate parity (UIP) condition. As mentioned in the introduction, earlier studies often find that following a contractionary monetary policy shock, domestic currency either depreciates (exchange rate puzzle; see Grilli and Roubini 1995), or, if it appreciates, it does so for a prolonged period of up to three years, thereby exhibiting hump-shaped behavior that violates the UIP condition (delayed overshooting; see Eichenbaum and Evans 1995; Cushman and Zha 1997). Unlike the earlier findings, our results find that the initial appreciation of Canadian currencies following a contractionary monetary shock is not followed by long and persistent appreciation as found in the previous studies.

***Capital flows.*** Net foreign capital inflows to Canada increase immediately following the contractionary domestic monetary policy shock, possibly reflecting the subsequent increase in domestic-foreign interest-rate differentials as well as the appreciation of the domestic currency. This impact quickly dissipates, however, as the domestic currency start to depreciate, and the negative impact of monetary tightening is transmitted to macroeconomic variables over time.

***Credit spreads.*** Credit channel of monetary policy transmission also appears to operate in Canada, notably, through both short- and long-term financing premia. Following the contractionary monetary policy shock, credit spreads, in short-term instruments (3-month CP spreads), increase up to 70 basis points with statistical significance. The credit spread under long-term instruments (3-year mortgage bonds) exhibit a similar magnitude of the response, but the impact persists for a prolonged period, five to six months after the shock.

***Output and prices.*** Following the contractionary monetary policy shock, both output (monthly GDP) and consumer prices in Canada significantly decrease by up to 1 percent. The impacts are maximized around two to three quarters after the shock, but they persist around a year. These results are consistent with New Keynesian theories that highlight the role of financial and credit markets in the monetary policy transmission.[15]The results are

[15] The response of output is weaker than expected and less statistically significant than prices, partly reflecting

also in line with earlier empirical studies on monetary policy transmission in Canada, including Champagne and Sekkel (2018) and Roldos (2006) despite the different sample periods and different identifying assumptions of monetary policy shocks.[16]

### 4.2. Effects of US monetary policy shocks on Canada economy

We now examine the effects of US monetary policy shocks on financial markets and macroeconomic conditions in Canada. In the right side of Figure 4, we plot the impulse responses of the variables to 100bp increase in US federal funds rates. Again, we focus on the results with all types of instrumental variables for Canada monetary policy shocks in Panel D.

***Policy rates in Canada.*** Monetary policy synchronization or coordination seems to exist between United States and Canada. Overnight interest rates in Canada significantly increase following a contractionary US monetary policy shock, and the impact persists longer than a year. The response is comparable in light of the magnitude and persistence to what follows domestic monetary policy shock.

What does this result imply? Does it mean that central bank in Canada does not have a monetary autonomy? Given our results on the effects of domestic monetary policy, as shown in the previous sub-section, the answer will be no. This result may instead reflect the economic dependence of Canada on the United states in trade and financial transactions. One the one hand, the consequences of US monetary policy shocks on her economy, which include negative influences on asset prices and macroeconomic variables, could spill over to Canada. Alternatively, this result can reflect the synchronized monetary policy actions in Canada with the United states, to neutralize the impact of US monetary policy shocks on Canadian financial markets, by reducing the volatility in exchange rates, capital flows, and financial asset prices (Turner 2014).

---

the capital inflow caused by exchange rate appreciations.

[16] As will be seen in Section 5, we provide the empirical results using the identified monetary policy shocks identified by Champagne and Sekkel (2018). The results confirm the significant impact of local monetary policy shocks on Canada macroeconomic variables.

***Market interest rates.*** In line with the uncovered interest-rate parity condition, as illustrated in equation (4) in Section 2, US monetary tightening raise the Canada interest rates with both short and long-term maturities; 100bp increase in Federal funds rates raise 3-month T-Bill rates and 5-year bond yields in Canada by around 50 bp, respectively, consistent with the findings in Ehrmann, Fratzscher and Rigobon (2011). The increase in the Canadian market interest rates can reflect several factors; the increase in US bond rates and correlated movements in Canada bond rates, the depreciation of Canadian currency per US dollar, the consequent increase of currency risk premium in Canada as well as correlated movements in Canada overnight rates are all likely to contribute to the rise in the interest rates.

The above results are different from some earlier findings in the literature, such as Kim (2001), who finds that short-term interest rates in non-US G6 countries do not react strongly to US monetary policy shocks. The difference in the results may partly reflect structural changes over time, including the integration of financial markets. Our results suggest that the endogenous reaction of monetary policy instruments and market interest rates in Canada to US monetary surprises is substantial and lasts longer than the response following domestic monetary shocks, consistently with what is found in Faust et al. (2003), and more recently, in Rey (2015; 2016), Cesa-Bianchi et al. (2016), and Miranda-Agrippino (2016) for the case of United Kingdom and Germany.

***Exchange rates.*** Following the contractionary US monetary policy shock, the Canadian dollar depreciates (i.e. US dollar appreciates per Canadian dollar) depreciates up to 10 percent within 3-4 months, and it appreciates gradually reverting back to the long-term levels. Again, such a response, consistent with what was found on the response of Canadian dollar following domestic monetary policy shocks, is compatible with the predictions by the overshooting hypothesis without any evidence of exchange rate puzzle or delayed overshooting. In line with Bjørnland 2009, Kim and Roubini 2000, and Cushman and Zha 1997, this result suggests that the inappropriate identification of monetary policy shocks may account for the puzzles observed in the prior literature.

***Capital flows.*** Net capital inflows to Canada decrease following the contractionary US monetary policy shocks, revsersing the increase in capital inflows following a contractionary domestic monetary policy shock. Despite the increase in market interest rates in Canada following the US monetary tightening, the depreciation of currency and increase in credit costs in international financial markets could play a negative role in capital inflows to Canada.

***Credit costs.*** Both short- and long-term credit spreads significantly increase around 10 basis points within 2-3 months after the US monetary tightening shock. Indeed, a growing number of studies reports empirical evidence that international credit channel operates significantly, as the dependency of a small open economy on USD-denominated liability is growing rapidly especially after global financial crisis (Rey 2015, Passari and Rey 2015). Credit conditions in Canada are thus expected to be significantly affected by US monetary tightening given that Canadian economy exhibit the high reliance on the United States and considerable portion of foreign debt is raised in US dollar.

***Macroeconomic variables.*** Following the contractionary US monetary shock, output and price levels in Canada significantly *increase* and the impacts persist until two years after the shock Despite its negative impact of US economy and subsequent spillover effects to Canadian economy, this result may reflect fluctuations in terms of trade and external transactions in Canada. Specifically, the depreciation of Canada currency can improve the competitiveness of Canadian goods and services in the international market, thus bring about the positive effects on the output (and finally prices). In addition, the currency depreciation in Canada is passed through to import prices, and finally to consumer prices. This result is consistent with empirical results in Rey (2016), and the predictions by Jones, Mariano Kulish, and Rees (2018) where industrial production and price levels in Canada significantly increase following contractionary monetary policy shocks.[17] On the other hand, there is another group of studies that report a contractionary monetary policy shocks in open economies (see Iacoviello and Gaston Navarro 2017, for instance). The upshot is that the macroeconomic consequence of international spillover effects is highly dependent upon country characteristics as well as sample periods that govern the degree of various channels of transmission.

### 4.3. Summary

[17] Giovanni and Shambaugh (2007) show that high foreign interest rates have a contractionary effect on annual real GDP growth in the domestic economy, but that this effect is centered on countries with fixed exchange rates.

Our results first provide evidence on the significant transmission of domestic monetary policy shocks into financial and macroeconomic conditions in Canada. Our results confirm that the transmission of domestic monetary policy shocks work through various channels of transmission, including interest, exchange rate, and credit channels.

That said, our empirical results find strong and persistent spillover effects from the United States, as explained in a broad set of countries as in Dedolar, Rivolta, and Stracca (2017); Georgiadis (2015); Feldkircher and Huberbin (2014). The effect of foreign (US) interest rates on domestic interest rates is the most likely channel as illustrated in Rey (2015; 2016) and Giovanni and Shambaugh (2007). More interestingly, in response to surprise in US monetary policy, Canadian interest rates at all maturities exhibit significant and persistent response. This international spillover also operates through credit conditions in Canada in both short- and long-term instruments, and capital inflows to domestic financial markets (Dahlhaus and Vasishtha 2014). These results collectively indicate that financial and macroeconomic situation in Canada are quite subject to the impact of monetary policies in the center country, as Rey (2015; 2016) concluded with the possible *Dilemma* central banks in open economies may confront.

All in all, our results provide a different reading of the recent debates on the trilemma. In fact, the cross-border monetary spillover from a financial center country become evident in a financially globalized world. However, domestic monetary policy is still effective in controlling domestic financial and real variables when exchange rates freely float. The Upshot is that monetary policy implementation in Canada can be hampered significantly due to spillover effects from center country, especially when the directions of the monetary policies diverge.

## 5. Robustness exercise

This section achieves several robustness checks to verify the validity of our empirical results. The exercises include using alternative sets of instrumental variables including the Canada monetary policy shocks identified by Champagne and Sekkel (2018), estimation with pre-crisis sample, considering alternative endogenous variables, and using VIX as endogenous variable instead of external control variable. We detail each of these robustness checks next.

### 5.1. Alternative combinations of instrumental variables

In Section 4, we report the impulse response of variables using each of the three types of instrumental variables we proposed. We then estimate the model using the three types of instrumental variables {IV1, IV2, and IV3) altogether to maximize the explanatory power of the instrumental variables as our baseline identification framework. To test sensitivity of the results to the selection of instrumental variables we estimate the VAR model using alternative sets of instrumental variables, {IV1 and IV2}, {IV1 and IV3}, and {IV2 and IV3}.

The corresponding impulse response functions are given in Panel A, B, and C of Figure A1, respectively, which can be compared with the corresponding results in Figure 4. As is evident, impulse response of variables to domestic and US monetary policy shocks are overall consistent between the different sets of instrumental variables.[18]

Moreover, since the Champagne and Sekkel (2018) provide their own identified monetary policy shocks in Canada, we also test these shocks using as an alternative set of instrumental variables. The shocks intrinsically convey the same information as our instrumental variable IV3 except that the study focuses on much longer period of sample (1974-2015). Again, as shown in Panel D of the figure, we do not find any critical differences except that the impulse responses of credit spreads are rather insignificant.

### 5.2. Results with pre-crisis sample

Considering that the United States has implemented unconventional monetary polies since the onset of the Global financial crisis in 2008-09, we here test the robustness of the results using the pre-crisis sample period (i.e. 2000.1 – 2008.8). As shown in Figure A2, overall results are consistent with the full sample results as in Figure 5, although the results with the pre-crisis sample are often less significant as reflected in lower F statistics of the instrumental variables.

### 5.3. Alternative data for endogenous variables

In Figure A3, we test alternative data for endogenous variables to verify the robustness of our baseline results. In Panel A in the figure, we test alternative variable of monthly real GDP with 2012 as base year (instead of chained monthly GDP). As is evident, the results are not sensitive to the change of GDP series. In Panel B of Figure A3, we test an alternative series of exchange rate, i.e.

[18] In addition, we do find significant results for all the variables when these instrumental variables are combined with other types of instrumental variables we propose.

effective exchange rates, in place of bi-lateral exchange rate per USD. The response of the exchange rates is quite consistent with our baseline results and do not report any puzzling movements that deviate from the predictions by Overshooting theory. Finally, we include net exports instead of net capital flows in the VAR system. Following a contractionary (+100bp) domestic monetary policy shock, net exports significantly decrease up to around 2 billion dollar, partly reflecting the appreciation of domestic currency after the shock. Reversely, following a contractionary US monetary policy shock, net export in Canada increases and the impact persists until around a year.

### 5.4. VIX as endogenous variable

As explained in Section 3, we included some external variables including VIX to control for external factors that can simultaneously influence over both the United States and Canada. A group of recent studies including Rey (2014; 2015) suggest that monetary policy shocks in the center country have significant impact on global financial market sentiments, or more generally, global financial cycle, and the changes in the global financial markets are transmitted through financial and macroeconomic condition in other open economies. Considering these findings, we here include VIX as endogenous variable and check the response of the variable as well as overall results on the other variables. As shown in Figure A4, following the contractionary US monetary policy shock, VIX increases within couple of months after the shock, consistent with the findings in the earlier studies. The response of other variables in Canada do not show any notable differences.

## 6. Conclusion

The *Mundell-Fleming's trilemma* has been a central building block in conventional international macroeconomics. However, as global financial markets are increasingly integrated and global factors become crucial drivers of the developments in domestic financial markets, there are extensive debates on the effectiveness of domestic monetary policy in small open economies. In this context, this paper investigates the channels of monetary policy transmission in small open economies *within and across* border, by estimating an open-economy SVAR model with various financial variables as well as macroeconomic variables.

Our empirical findings are summarized as follows. On the one hand, domestic transmission of monetary policy shocks appears to operate through a variety of channels. First, both short-term and long-term rates react significantly to domestic monetary policy shocks, confirming the role of the conventional interest rate channel. Second, foreign exchange rates in this process are seen to respond significantly to monetary policy shocks, as overshooting theory by Dornbusch (1976) predicts. Contrary to the findings in earlier group of studies that report counterevidence for the overshooting hypothesis, we find that an increase in local policy rates causes the nominal exchange rate to appreciate instantaneously and then to depreciate gradually in line with the uncovered interest parity. Third, contractionary monetary policy shocks, both domestic and foreign, generate an increase in credit spreads in Canada. This is consistent with the predictions by the credit and risk-taking channels of monetary policy transmission both in domestic and international perspectives. Reflecting the pass-through of monetary policy shocks into financial and credit markets, macroeconomic conditions (output and price levels) significantly respond to the monetary policy shock as New Keynesian theory predicts.

On the other hand, international spillovers of monetary policy shocks also play an important, if anything stronger, role in financial and macroeconomic conditions in Canada. Following a contractionary US monetary policy shock, market interest rates in Canada, both in short- and long-term maturities significantly increase the impact persist for a prolonged period. More interestingly, overnight rates in Canada, which is monetary policy tool, also respond to the US monetary policy shocks. Following the contractionary US monetary policy shock, credit spreads increase substantially along with an immediate outflow of international capital investments. This is consistent with the predictions by the credit and risk-taking channels of monetary policy transmission both in domestic and international perspectives (Rey 2015; 2016, Hofmann et al. 2017). Finally, the response of macroeconomic variables is across the two types of monetary policy shocks; contractionary US monetary shocks show expansionary and inflationary consequences on the variables in Canada. This may partly reflect the expenditure-switching effects of contractionary US monetary shocks, offsetting negative impacts of tightened financial condition on the real economy in Canada.

Our empirical results indicate that financial and credit conditions, as well as macroeconomic condition, in a small open economy may not react in the way that central banks intend as global financial and credit market get integrated. The results suggest that focusing only on domestic short-term rates can deliver policy errors in achieving macroeconomic stability. The consequences of external shocks, including monetary policy shocks in the center country, should be considered in implementing domestic monetary polies.

## References


Aizenman, J. M. D. Chinn, and H. Ito (2016). Monetary policy spillovers and the trilemma in the new normal: Periphery country sensitivity to core country conditions. *Journal of International Money and Finance* 68:298-330.

Bekaert, G, and A. Mehl (2019). On the Global Financial Market Integration "Swoosh" and the Trilemma. *Journal of International Money and Finance*.

Bernanke, B.S. (2017), Federal Reserve Policy in an International Context. *IMF Economic Review* 65: 1.

Bjørnland, H. C. (2009). Monetary policy and exchange rate overshooting: Dornbusch was right after all. *Journal of International Economics* 79, 64–77.

Bruno, V. and Shin, H. (2014). Cross-border banking and global liquidity. The Review of Economic Studies, 82(2), 535-564.

Bruno, V. and Shin, H. (2015). Capital Flows and the Risk-Taking Channel of Monetary Policy. *Journal of Monetary Economics* 71, 119-132.

Caceres, C., Y. Carrière-Swallow, and B. Gruss (2016). Global Financial Conditions and Monetary Policy Autonomy. IMF WP/16/108.

Carlstroma, C., Fuerst, and T. Paustian, M., (2009). Monetary policy shocks, Choleski identification, and DNK models. *Journal of Monetary Economics* 56, 1014–1021

Cesa-Bianchi, A., Thwaites, G., & Vicondoa, A. (2016). Monetary policy transmission in an open economy: new data and evidence from the United Kingdom. Bank of England Staff Working Paper 615.

Cesa-Bianchi, A., and Sokol, A. (2017). Financial shocks, credit spreads and the international credit channel. Bank of England Staff Working Paper 693.

Champagne, J., and Sekkel, R. (2018). Changes in monetary regimes and the identification of monetary policy shocks: Narrative evidence from Canada. *Journal of Monetary Economics* 99, 72-87.

Chen, R. R., and Scott, L. (1993). Maximum likelihood estimation for a multifactor equilibrium model of the term structure of interest rates. *The Journal of Fixed Income* 3(3), 14-31.

Cochrane, J. H. and M. Piazzesi (2002). The fed and interest rates-a high- frequency identification. *American Economic Review* 92(2), 90–95.

Cushman, D. O. and T. Zha (1997). Identifying monetary policy in a small open economy under flexible exchange rates. *Journal of Monetary Economics* 39, 433-448.

Dedola, L., Rivolta, G., and Stracca, L. (2017). If the Fed sneezes, who catches a cold?. *Journal of International Economics* 108, S23-S41.

Dornbush, R. (1976). Expectations and Exchange Rate Dynamics. *Journal of Political Economy* 84, 1161–1176.

Edwards, S. (2012). The federal reserve, the emerging markets, and capital controls: a high-frequency empirical investigation. *Journal of Money, Credit and Banking* 44 (s2), 151–184.

Eichenbaum, M. and Evans, C. (1995). Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates. *Quarterly Journal of Economics* 110, 975–1010.

Faust J., Rogers, J. H. and Swanson, E. Wright, J. H. (2003). Identifying the Effects of Monetary Policy Shocks on Exchange Rates Using High Frequency Data. *Journal of the European Economic Association*, 1(5), 1031–1057

Gai, P. and Tong, E. (2019) The effects of US monetary policy on inflation-targeting countries. Manuscript.

Georgiadis, G. and A. Mehl (2016). Trilemma, Not Dilemma: Financial Globalisation, and Monetary Policy Effectiveness. Federal Reserve Bank of Dallas, Working Paper 222.

Gertler, M. L. and P. Karadi (2015). Monetary policy surprises, credit costs and economic activity. *American Economic Journal: Marcroeconomics* 7(1), 44-76

Grilli, V. and Roubini, N. (1995). Liquidity models in open economies: theory and empirical evidence. NBER working paper 5313.

Gürkaynak, R. S., B. Sack, and E. T. Swanson (2005). Do actions speak louder than words? the response of asset prices to monetary policy actions and statements. *International Journal of Central Banking*.

Hamilton, J. D. (1994). Time Series Analysis, Princeton University Press, Princeton, NJ.

Hofmann, B., Shim, I., and Shin, H. S. (2016). Sovereign yields and the risk-taking channel of currency appreciation. BIS Working Papers 538.

Jarocinski, M. and Karadi, P. (2018) Deconstructing monetary policy surprises: the role of information shocks. ECB Working paper series 2133.

Kim, S. (2001). International transmission of U.S. monetary policy shocks: Evidence from VAR. *Journal of Monetary Economics* 48, 339–372.

Kim, S. and N. Roubini (2000). Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach. *Journal of Monetary Economics* 45, 561-586.

Klein, M. W., J. C. Shambaugh, (2015). Rounding the Corners of the Policy Trilemma: Sources of Monetary Policy Autonomy. *American Economic Journal: Macroeconomics* 7 (4), 33-66.

Kuttner, K. N. (2001). Monetary policy surprises and interest rates: Evidence from the Fed funds futures market. *Journal of monetary economics* 47(3), 523-544.

Mertens, K. and M. O. Ravn (2013). The dynamic e□ects of personal and corporate income tax changes in the United States. *American Economic Review* 103(4), 1212–47.

Miranda-Agrippino, S. (2016). Unsurprising shocks: information, premia, and the monetary transmission. Bank of England Staff Working Paper No. 626

Nakamura, E., and Steinsson, J. (2018). High-frequency identification of monetary non-neutrality: The information effect. *The Quarterly Journal of Economics* 133(3), 1283-1330.

Obstfeld, M. (2015). Trilemmas and trade-offs: living with financial globalization. BIS Working Papers 480.

Obstfeld, M, J. C. Shambaugh and A. M. Taylor (2005). The trilemma in history: tradeoffs among exchange rates, monetary policies, and capital mobility. *Review of Economics and Statistics* 87:3, 423–38.

Obstfeld, M., J. D. Ostry and M. S. Qureshi (2017), "A Tie That Binds: Revisiting the Trilemma in Emerging Market Economies," IMF Working Papers 130.

Ehrmann, M., Fratzscher M., and Rigobon, R. (2011). Stocks, Bonds, Money Markets and Exchange Rates : Measuring International Financial Transmission. *Journal of Applied Econometrics* 26, 948–974.

Passari, E. and Rey, H. (2015). Financial Flows and the International Monetary System. *The Economic Journal* 125:584, 675-698.

Rey, H. (2015). Dilemma not trilemma: the global financial cycle and monetary policy independence. NBER Working Paper 21162.

Rey, H. (2016). International channels of transmission of monetary policy and the Mundellian trilemma. *IMF Economic Review* 64(1), 6-35.

Rogers, J. H., Scotti, C., and Wright, J. H. (2018). Unconventional monetary policy and international risk premia. *Journal of Money, Credit and Banking* 50(8), 1827-1850.

Romer, C. D., and Romer, D. H. (2004). A new measure of monetary shocks: Derivation and implications. *American Economic Review* 94(4), 1055-1084.

Rudebusch, G. D. (1998). Do Measures of Monetary Policy in a VAR Make Sense?, *International Economic Review* 39, 907–931.

Shambaugh, J. C. (2004). The Effect of Fixed Exchange Rates on Monetary Policy. *Quarterly Journal of Economics* 119(1): 301-352.

Staiger, D. and Stock, J. H. (1997). Instrumental Variables Regression with Weak Instruments. *Econometrica* 65:3, 557-586.

Stock, J. H. and M. W. Watson (2012). Disentangling the channels of the 2007–09 recession. Brookings Papers on Economic Activity 2012(1), 81–135.

Turner, P. (2013). Benign neglect of the long-term interest rate. BIS Working Papers 403.

**Tables and Figures**

**Table 1 List of Data**

| Category | Variables |
|---|---|
| **US** | MP*: Effective FFR |
| **Canada** | Y: Industrial production (S.A.)<br>P: Consumer Price Index<br>MP: Money market financing rates<br>R3m: TB (3-month) yields<br>R3y: TB (10-year) yields<br>CS3m: CP rate – TB rate (3-month),<br>CS3y: Mortgage rate – TB rate (3-year),<br>CF: Capital inflow to CA<br>FX: Nominal foreign exchange rate per USD |
| **Control variables** | Commodity price index; US dollar index; CBOE VIX<br>Crisis dummy variable with 1 for the period between Sep 2008-June 2009, |

**Table 2 Instrumental variables for Canada**

| Country | Category | Description |
|---|---|---|
| Canada | **Market-based IV (IV1)** | MP surprise = daily change in the short-term spot rates on MP decision date (Cochrane and Piazessi 2002) |
| | **Model-based IV (IV2)** | Change of expected short-term rate path (Affine term structure model) |
| | **Survey-based IV (IV3)** | Market participant's anticipation ≠ Central Bank's expectation (Romer and Romer (2004)'s method) |
| United States | **MP1** | Changes in the expectations of current-month Federal Funds Futures Rates (FFFRs) |
| | **FF4** | Changes in 3-month-ahead FFFRs |
| | **ED2** | Changes in 6-month-ahead Euro-dollar futures rates (EDs) |
| | **ED3** | Changes in 9-month-ahead EDs |
| | **ED4** | Changes in 12-month-ahead EDs |

## Table 3 Regression of monetary policy rates on explanatory variables

### Panel A. Regression with headline CPI inflation forecast

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Initial policy rates in Canada | -0.192649 | 0.025934 | -7.428585 | 0.0000 |
| Policy rates in United States (FFR) | | | | |
| level | 0.130563 | 0.018160 | 7.189584 | 0.0000 |
| changes | 0.080705 | 0.027262 | 2.960315 | 0.0040 |
| CAD/USD rates | | | | |
| level | -0.359447 | 0.224150 | -1.603596 | 0.1126 |
| changes | -0.006184 | 0.007134 | -0.866821 | 0.3886 |
| Unemployment in Canada | | | | |
| 1-month before | -0.036782 | 0.072621 | -0.506500 | 0.6139 |
| 2-month before | -0.017720 | 0.088072 | -0.201202 | 0.8410 |
| 3-month before | 0.055735 | 0.068163 | 0.817667 | 0.4159 |
| Forecasted output growth | | | | |
| 1-quarter before | 0.026783 | 0.023968 | 1.117476 | 0.2671 |
| Contemporaneous | 0.045471 | 0.037112 | 1.225258 | 0.2240 |
| 1-quarter ahead | -0.078720 | 0.037803 | -2.082393 | 0.0404 |
| 2-quarter ahead | 0.053297 | 0.032669 | 1.631396 | 0.1066 |
| Changes in forecasted output growth | | | | |
| 1-quarter before | -0.149773 | 0.055176 | -2.714472 | 0.0081 |
| Contemporaneous | 0.138268 | 0.068509 | 2.018241 | 0.0468 |
| 1-quarter ahead | 0.093050 | 0.062863 | 1.480194 | 0.1427 |
| 2-quarter ahead | -0.118515 | 0.049754 | -2.382031 | 0.0195 |
| Forecasted headline CPI inflation | | | | |
| 1-quarter before | -0.037131 | 0.021934 | -1.692859 | 0.0943 |
| Contemporaneous | 0.063968 | 0.036908 | 1.733167 | 0.0868 |
| 1-quarter ahead | -0.026049 | 0.046645 | -0.558449 | 0.5781 |
| 2-quarter ahead | 0.012939 | 0.048568 | 0.266408 | 0.7906 |
| Changes in forecasted headline CPI inflation | | | | |
| 1-quarter before | 0.009725 | 0.047910 | 0.202982 | 0.8397 |
| Contemporaneous | 0.021266 | 0.059126 | 0.359676 | 0.7200 |
| 1-quarter ahead | 0.101772 | 0.056881 | 1.789221 | 0.0773 |
| 2-quarter ahead | -0.111498 | 0.060318 | -1.848507 | 0.0681 |
| Constant | 0.082699 | 0.187800 | 0.440359 | 0.6608 |
| R-squared: 0.83 | | | | |

Note: This tables report regression coefficients of changes in Canada policy rates from previous MPC meeting on various independent variables.

**Panel B. Regression with core CPI inflation forecast**

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| Initial policy rates in Canada | -0.216874 | 0.028234 | -7.681386 | 0.0000 |
| Policy rates in United States (FFR) | | | | |
| level | 0.143442 | 0.018892 | 7.592562 | 0.0000 |
| changes | 0.074782 | 0.029562 | 2.529716 | 0.0134 |
| CAD/USD rates | | | | |
| level | -0.372791 | 0.254851 | -1.462779 | 0.1474 |
| changes | -0.013598 | 0.007710 | -1.763746 | 0.0816 |
| Unemployment in Canada | | | | |
| 1-month before | -0.045798 | 0.079264 | -0.577797 | 0.5650 |
| 2-month before | -0.021667 | 0.099087 | -0.218662 | 0.8275 |
| 3-month before | 0.045895 | 0.074536 | 0.615746 | 0.5398 |
| Forecasted output growth | | | | |
| 1-quarter before | 0.033699 | 0.024338 | 1.384632 | 0.1700 |
| Contemporaneous | 0.024772 | 0.045668 | 0.542433 | 0.5890 |
| 1-quarter ahead | -0.053297 | 0.045478 | -1.171920 | 0.2447 |
| 2-quarter ahead | 0.037525 | 0.037580 | 0.998537 | 0.3210 |
| Changes in forecasted output growth | | | | |
| 1-quarter before | -0.118785 | 0.053430 | -2.223193 | 0.0290 |
| Contemporaneous | 0.048662 | 0.068908 | 0.706182 | 0.4821 |
| 1-quarter ahead | 0.143130 | 0.072578 | 1.972092 | 0.0521 |
| 2-quarter ahead | -0.115595 | 0.055572 | -2.080078 | 0.0407 |
| Forecasted core CPI inflation | | | | |
| 1-quarter before | -0.020315 | 0.072921 | -0.278593 | 0.7813 |
| Contemporaneous | -0.186997 | 0.103439 | -1.807809 | 0.0744 |
| 1-quarter ahead | 0.137614 | 0.162703 | 0.845800 | 0.4002 |
| 2-quarter ahead | -0.052282 | 0.128875 | -0.405682 | 0.6861 |
| Changes in forecasted core CPI inflation | | | | |
| 1-quarter before | -0.044718 | 0.120096 | -0.372351 | 0.7106 |
| Contemporaneous | 0.316570 | 0.198366 | 1.595888 | 0.1145 |
| 1-quarter ahead | -0.286173 | 0.227397 | -1.258475 | 0.2119 |
| 2-quarter ahead | 0.230942 | 0.155710 | 1.483155 | 0.1420 |
| Constant | 0.518576 | 0.329914 | 1.571852 | 0.1199 |
| R-squared: 0.81 | | | | |

Note: This tables report regression coefficients of changes in Canada policy rates from previous MPC meeting on various independent variables.

## Table 4 Relevancy test results

### A. US IV

| *F*-value | $R^2$ | *t*-value | | | | |
|---|---|---|---|---|---|---|
| | | *MP1* | *FF4* | *ED2* | *ED3* | *ED4* |
| 12.39 | 0.25 | 5.31 | -1.96 | -1.29 | 2.07 | -1.94 |

### B. CA IV1

| | *F*-value | $R^2$ | *t*-value | | |
|---|---|---|---|---|---|
| | | | *overnight* | *repo* | *prime* |
| $IV_{CA,1}$ = | | | | | |
| $\{overnight\}$ | 50.44 | 0.21 | 7.10 | - | - |
| $\{repo\}$ | 47.58 | 0.20 | - | 6.90 | - |
| $\{\boldsymbol{overnight}, \boldsymbol{repo}\}$ | **25.64** | **0.22** | **1.77** | **-0.93** | **-** |
| $\{overnight, repo, prime\}$ | 18.01 | 0.23 | 1.82 | -1.08 | 1.54 |

### C. CA IV2

| | *F*-value | $R^2$ | *t*-value | | | |
|---|---|---|---|---|---|---|
| | | | $EH_{3m}$ | $EH_{6m}$ | $EH_{9m}$ | $EH_{12m}$ |
| $IV_{CA,2}$ = | | | | | | |
| $\{EH_{3m}\}$ | 74.37 | 0.28 | 8.62 | - | - | - |
| $\{EH_{6m}\}$ | 59.96 | 0.24 | - | 7.74 | - | - |
| $\{\boldsymbol{EH_{3m}}, \boldsymbol{EH_{6m}}\}$ | **38.39** | **0.29** | **3.61** | **-1.42** | **-** | **-** |
| $\{EH_{3m}, EH_{6m}, EH_{9m}, EH_{12m}\}$ | 19.36 | 0.30 | 0.60 | 0.71 | -0.64 | 0.49 |

### D. CA IV3

| | *F*-value | $R^2$ | *t*-value | | | |
|---|---|---|---|---|---|---|
| | | | $RR_{hcpi}$ | $RR_{ccpi}$ | $CS_{new}$ | $CS_{full}$ |
| $IV_{CA,3}$ = | | | | | | |
| $\{RR_{hcpi}\}$ | 70.51 | 0.27 | 8.40 | - | - | |
| $\{RR_{ccpi}\}$ | 82.53 | 0.31 | 9.08 | - | - | |
| $\{CS_{new}\}$ | 19.33 | 0.09 | - | - | 4.40 | |
| $\{CS_{full}\}$ | **27.70** | **0.13** | **-** | - | - | 5.26 |
| $\{\boldsymbol{RR_{hcpi}}, \boldsymbol{RR_{ccpi}}\}$ | **41.11** | **0.31** | **0.29** | **2.96** | **-** | **-** |
| $\{RR_{hcpi}, RR_{ccpi}, CS_{new}, CS_{full}\}$ | 22.60 | 0.33 | 0.01 | 2.86 | 0.06 | 2.09 |

Notes: 1) *t*-values and $R^2$ (parentheses) of each instrumental variable through the first-stage regression of the VAR residual for MP and each IV.

2) '-' indicates that selected instrumental variable is not available for a given sample period

3) Bold parts are the finally chosen IV sets for each category.

**Figure 1. Policy rate and short-term spot rate movements**

**A. United States** **B. Canada**

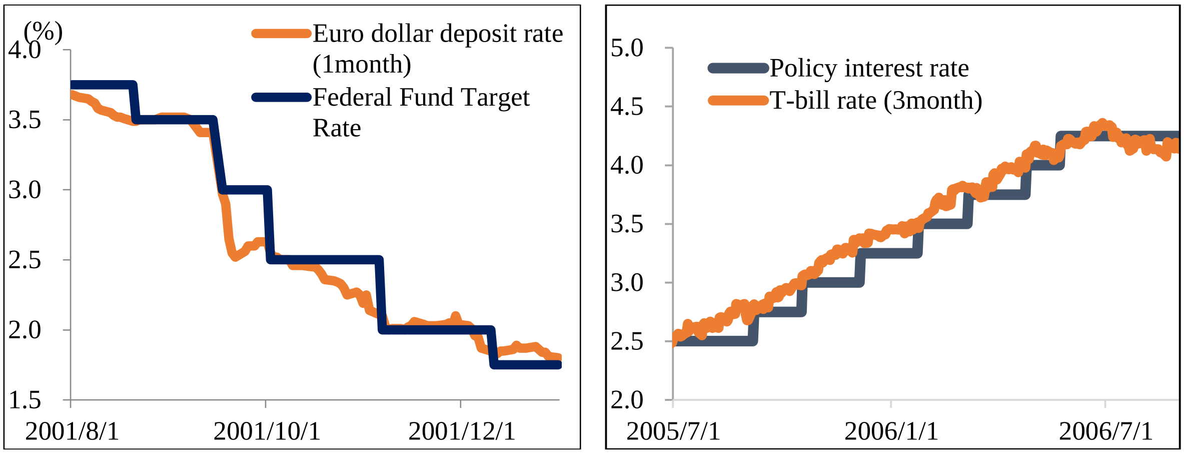
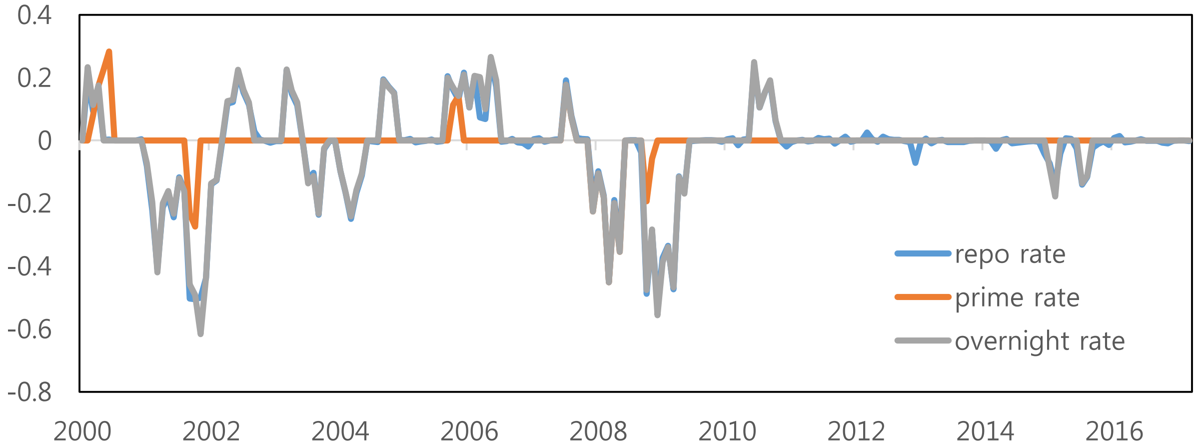
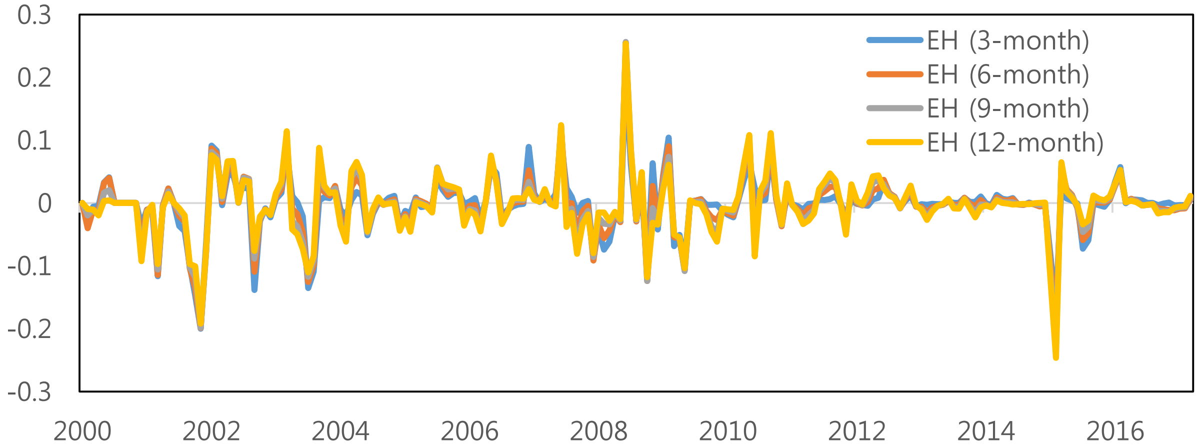


**Figure 2. Selected IVs for Canadian monetary policy shocks**

**Panel A. market-based instrument variable (IV1)**




**Panel B. model-based instrument variable (IV2)**




**Panel C. Survey-based instrument variable (IV3)**

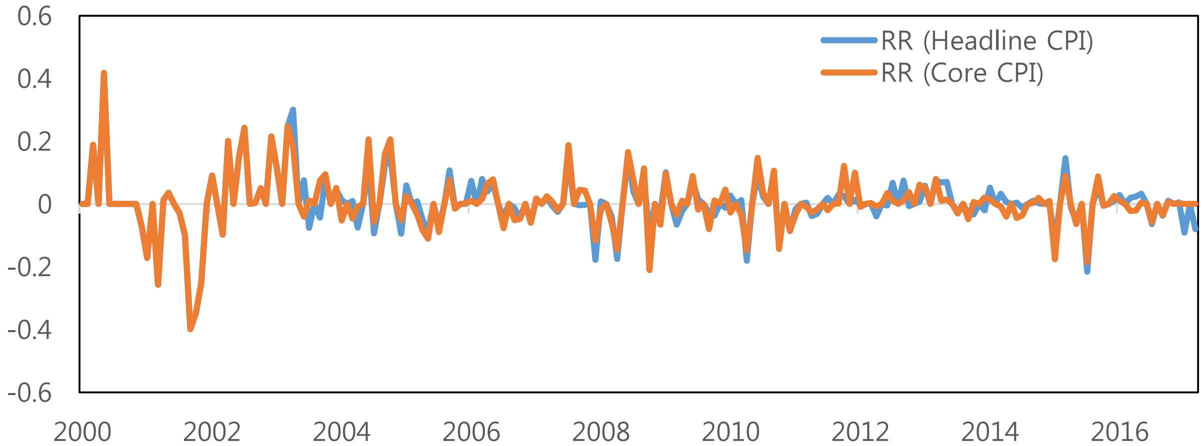
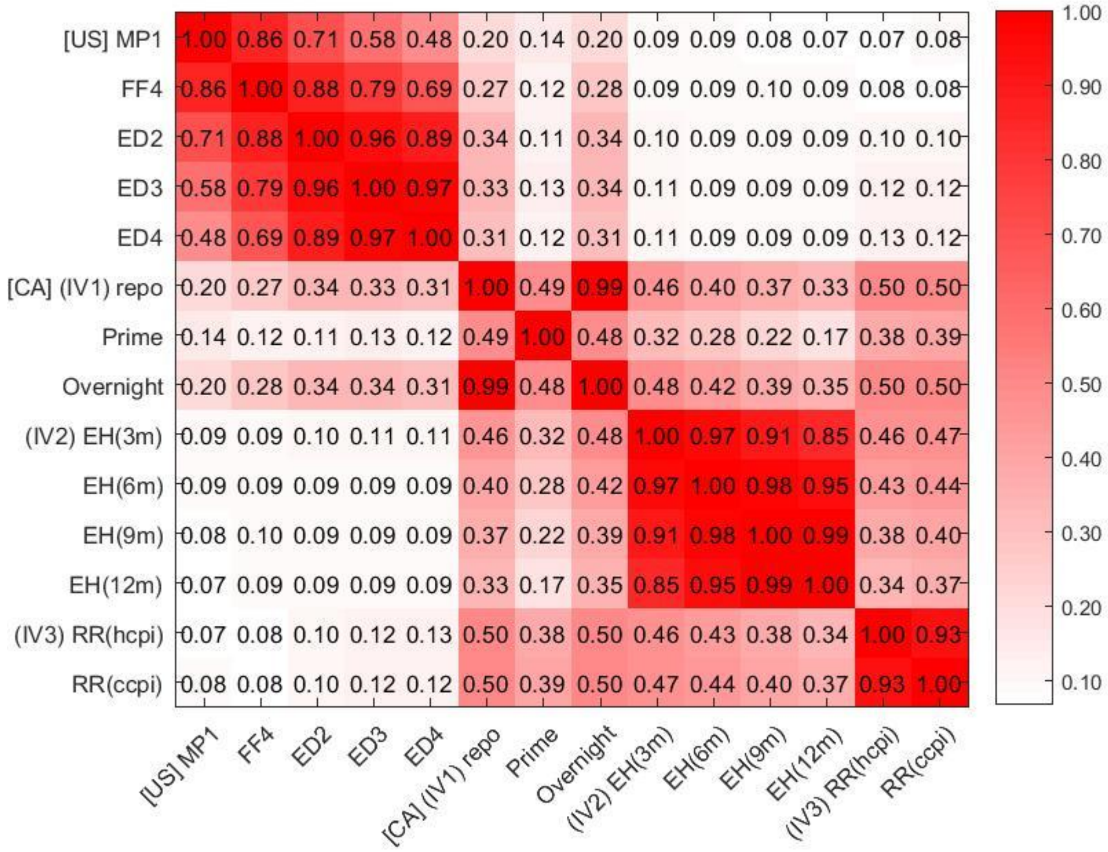


**Figure 3. Correlation Heatmap for the instrumental variables**

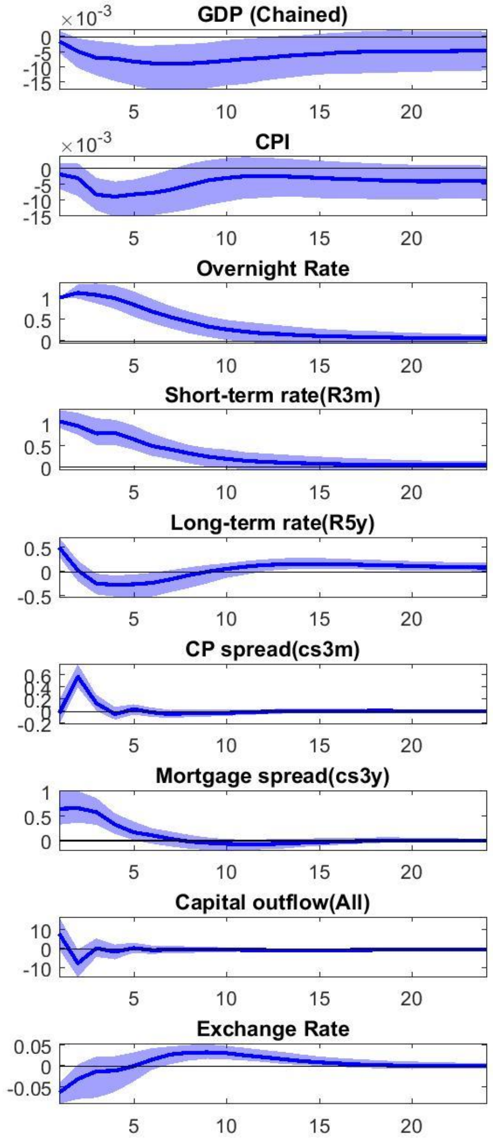


## Figure 4. Impulse response of Canada variables to monetary shocks

### Panel A. market-based instrument variable

**IRF following CA monetary policy shocks**

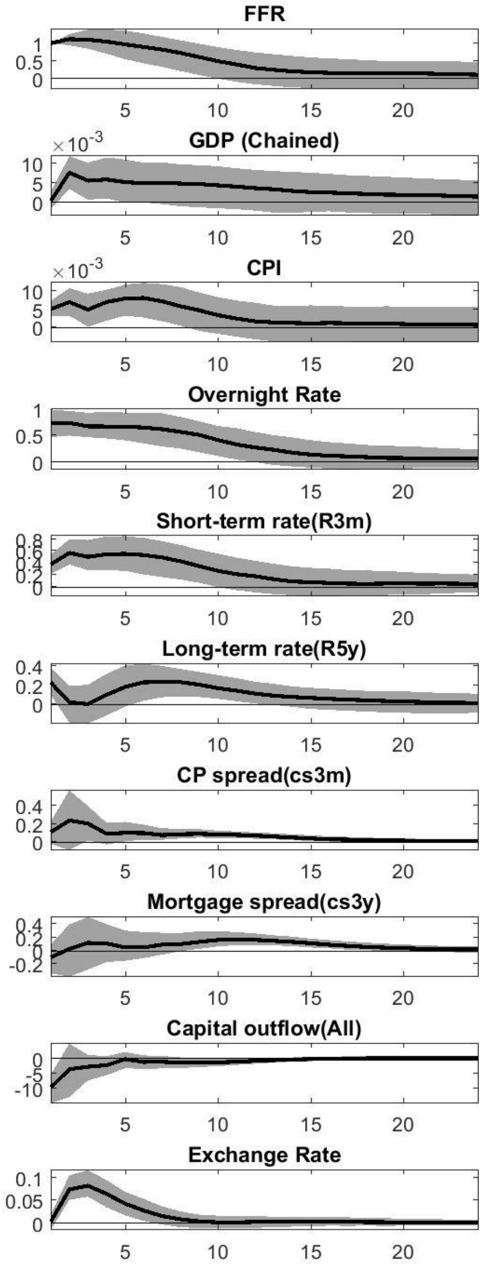
$IV_{CA,1} = \{overnight, repo\}$




**F = 25.64**

**IRF following US monetary policy shocks**

$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$

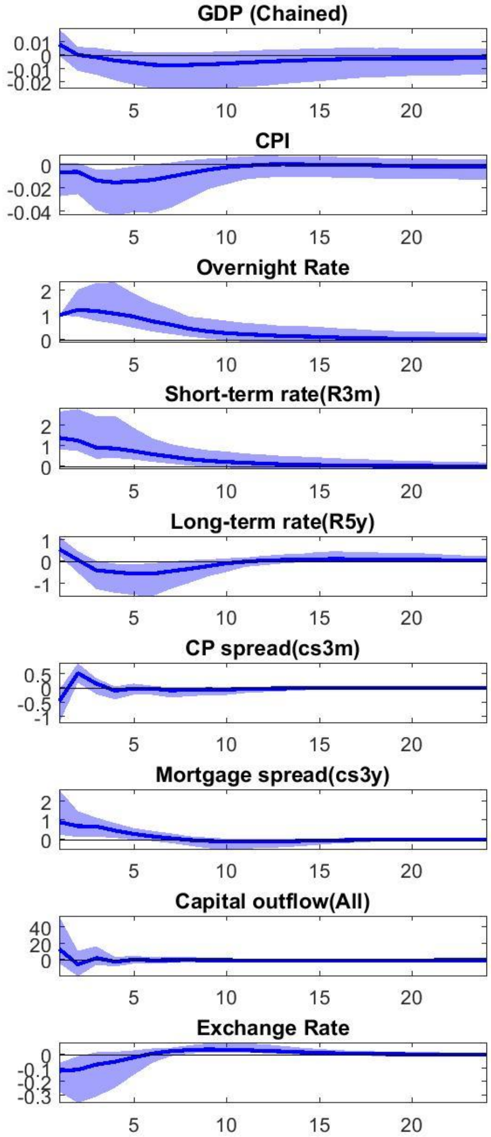



**F = 12.39**

## Panel B. model-based instrument variable

**IRF following CA monetary policy shocks**

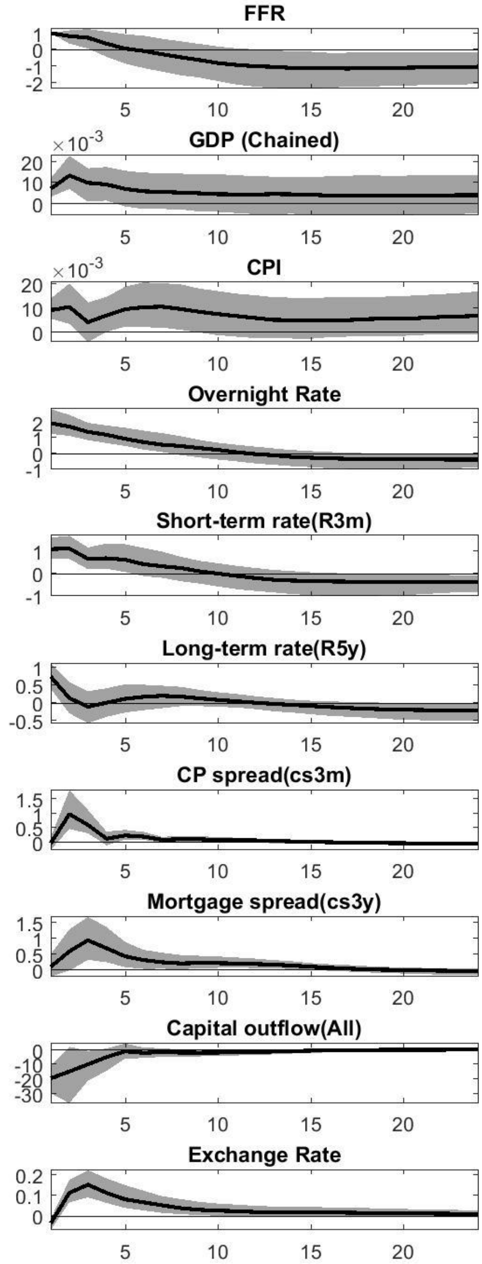
$IV_{CA,2} = \{EH_{3m}, EH_{6m}\}$




**F = 38.39**

**IRF following US monetary policy shocks**

$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$

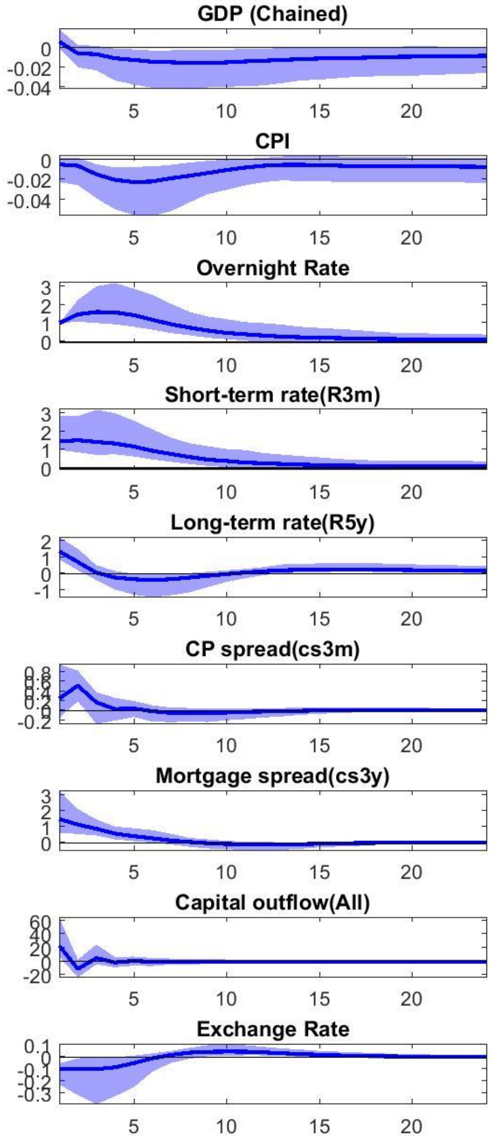



**F = 12.39**

## Panel C. Survey-based instrument variable (IV3)

**IRF following CA monetary policy shocks**

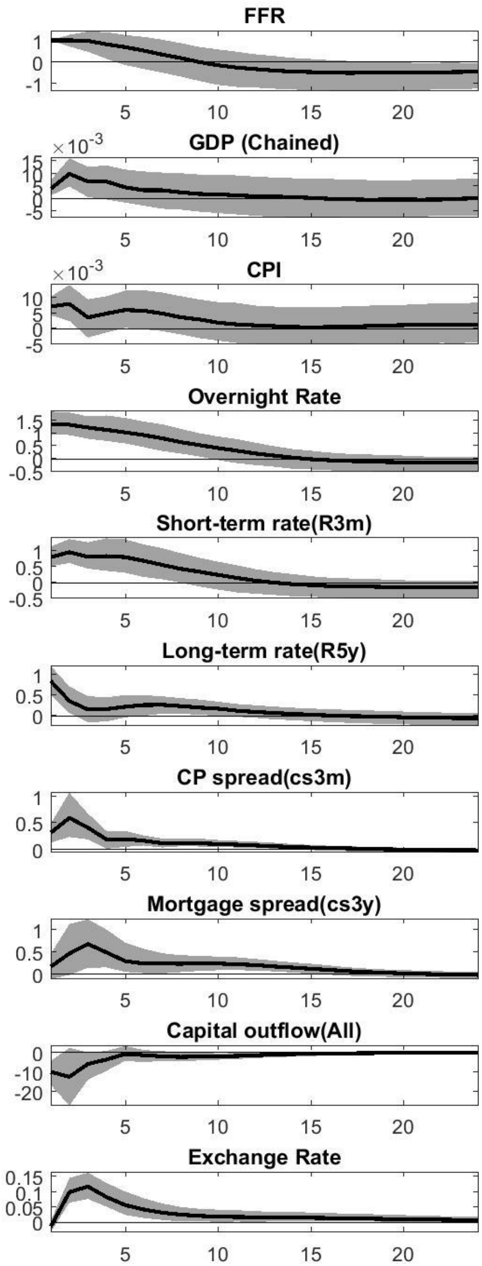
$IV_{CA,3} = \{RR_{hcpi}, RR_{ccpi}\}$




**F = 41.11**

**IRF following US monetary policy shocks**

$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$




**F = 12.39**

Notes: 1. Y axis indicates %(%p). X axis indicates months after shock.

2. Based on contractionary (100p) Canada monetary policy shocks.

3. Shaded area are the 16% and 84% quantiles of the empirical distribution based on 5,000 draws.

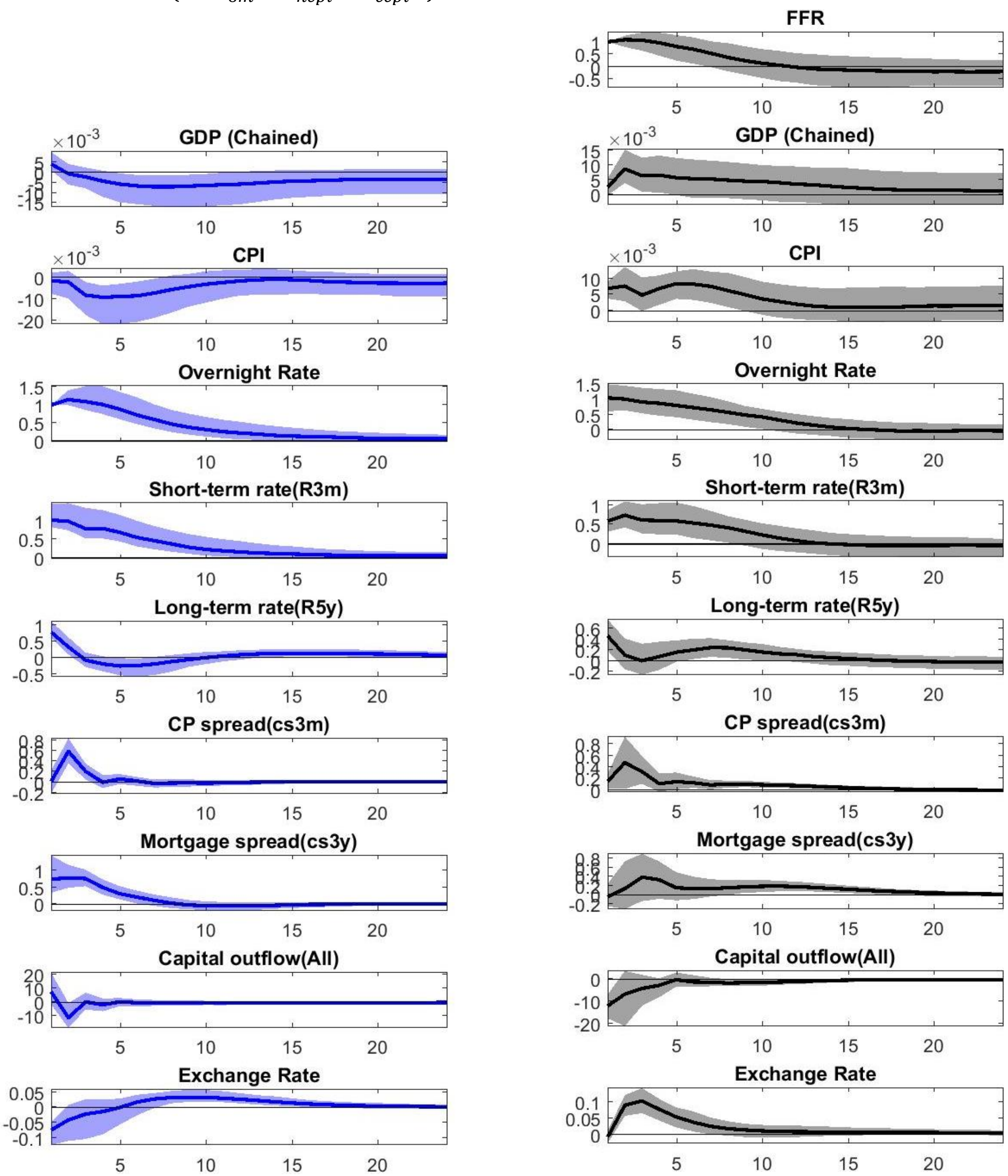
**Figure 5. Impulse response of Canada variables to monetary shocks**

**IRF following CA monetary policy shocks**

$$IV_{CA,all} = \begin{Bmatrix} overnight, repo, EH_{3m}, \\ EH_{6m}, RR_{hcpi}, RR_{ccpi} \end{Bmatrix}$$

**IRF following US monetary policy shocks**

$$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$$




**F = 22.02** **F = 12.39**

Notes: 1. Y axis indicates %(%p). X axis indicates months after shock.

2. Based on contractionary (100p) Canada monetary policy shocks.

3. Shaded area are the 16% and 84% quantiles of the empirical distribution based on 5,000 draws.

## Appendix

### External Instrument Identification Scheme

The relationship between residuals of reduced-form VAR ($e_t$) and structural shocks ($\varepsilon_t$) in equation (7) can be rearranged as (20):

$$\begin{bmatrix} e_t^p \\ e_t^q \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^q \end{bmatrix} = \begin{bmatrix} s_{11}\varepsilon_t^p + s_{12}\varepsilon_t^q \\ s_{21}\varepsilon_t^p + s_{22}\varepsilon_t^q \end{bmatrix} \qquad (20)$$

where $s_{11}$ represents the response of the residuals of the MP instrument to its own shock and $s_{21}$ represents the responses of residual series of the other variables to the structural MP shock. Since we are interested in how variables respond to MP shocks, $s_{11}$ and $s_{21}$ are the only two parts of the impact matrix (*S*) to be identified.

Next, VAR residuals $e_t^p$ and $e_t^q$ can be expressed by the other reduced-form residuals and structural shocks $\varepsilon_t^p$ or $\varepsilon_t^q$ because those are composites of structural shocks:

$$e_t^p = \eta e_t^q + C_1 \varepsilon_t^p \qquad (21)$$

$$e_t^q = \theta e_t^p + C_2 \varepsilon_t^q \qquad (22)$$

where $\eta = s_{12}s_{22}^{-1}$, $\theta = s_{21}s_{11}^{-1}$, $C_1 = s_{11} - s_{12}s_{22}^{-1}s_{21}$, and $C_2 = s_{22} - s_{21}s_{11}^{-1}s_{12}$. In particular, the $2 \times 2$ matrix $C_1$ represents variance–covariance between two structural MP shocks, and it has the following relationship with $s_{11}$ and $s_{21}$:[19]

$$\begin{bmatrix} s_{11} \\ s_{21} \end{bmatrix} = \begin{bmatrix} \left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)^{-1} \\ s_{21}s_{11}^{-1}\left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)^{-1} \end{bmatrix} C_1 \qquad (23)$$

$$C_1C_1' = \left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)s_{11}s_{11}'\left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)' \qquad (24)$$

---

[19] $C_1$ can be rearranged as $C_1 = s_{11} - s_{12}s_{22}^{-1}s_{21} = \left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)s_{11}$ and thus $s_{11}C_1^{-1} = \left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)^{-1}$. Similarly, $C_2$ can be expressed in terms of partitions of *S* matrix as the following form: $s_{21}C_1^{-1} = s_{21}s_{11}^{-1}s_{11}C_1^{-1}$ $= s_{21}s_{11}^{-1}\left(I - s_{12}s_{22}^{-1}s_{21}s_{11}^{-1}\right)^{-1}$.

Thus, obtaining $s_{11}$ and $s_{21}$ requires identification of two parts: One is $s_{21}s_{11}^{-1}(=\theta)$, which can be estimated by two-stage least squares (2SLS) estimation, and the others are $s_{11}s_{11}^{'}$ and $s_{12}s_{22}^{-1}$, which can be calculated by restrictions from the covariance matrix.

**(Restriction from 2SLS estimation: $s_{21}s_{11}^{-1}(=\theta)$)**

Consider first the regression of equation (12). Since the reduced-form residual for MP instrument ($e_t^p(=s_{11}\varepsilon_t^p+s_{12}\varepsilon_t^q)$) is correlated with $C_2\varepsilon_t^q$, denoting it as $u_t$ hereafter, we can obtain consistent estimates of $\theta$ of regression $e^q$ on $e^p$ from 2SLS, employing appropriate instrumental variables that satisfy the following moment conditions:

$$E\left[Z_t u_t\right]=0 \quad \text{or} \quad E\left[Z_t\varepsilon_t^q\right]=0 \qquad (25)$$

$$E\left[Z_t e_t^p\right]=\pi \quad (\pi\neq 0) \quad \text{or} \quad E\left[Z_t\varepsilon_t^p\right]=\phi \quad (\phi\neq 0) \qquad (26)$$

**(Restriction from covariance matrix: $s_{11}s_{11}^{'}$ and $s_{12}s_{22}^{-1}$)**

In addition to the restrictions derived from IV estimation, identification of $s_{11}$ and $s_{21}$ requires the additional restrictions from the covariance matrix. Consider the following reduced form variance-covariance and its partitioning:

$$\Sigma=E[SS'] \;\Rightarrow\; \begin{bmatrix}\Sigma_{11} & \Sigma_{12}\\ \Sigma_{21} & \Sigma_{22}\end{bmatrix}=\begin{bmatrix}s_{11}s_{11}^{'}+s_{12}s_{12}^{'} & s_{11}s_{21}^{'}+s_{12}s_{22}^{'}\\ s_{21}s_{11}^{'}+s_{22}s_{12}^{'} & s_{21}s_{21}^{'}+s_{22}s_{22}^{'}\end{bmatrix} \qquad (27)$$

Then, $s_{11}s_{11}^{'}, s_{12}s_{22}^{-1}$ is obtained by the following closed-form solution:

$$s_{11}s_{11}^{'}=\Sigma_{11}-s_{12}s_{12}^{'} \qquad (28)$$

$$s_{12}s_{22}^{-1}=\left(s_{12}s_{12}^{'}\theta'+(\Sigma_{21}-\theta\Sigma_{11})'\right)\left(s_{22}s_{22}^{'}\right)^{-1} \qquad (19)$$

where $s_{12}s_{12}^{'}=\left(\Sigma_{21}-\theta\Sigma_{11}\right)'Q^{-1}\left(\Sigma_{21}-\theta\Sigma_{11}\right)$ , $s_{22}s_{22}^{'}=\Sigma_{22}+s_{21}s_{11}^{-1}\left(s_{12}s_{12}^{'}-\Sigma_{11}\right)\left(s_{21}s_{11}^{-1}\right)^{'}$ and $Q=\Sigma_{22}-(\Sigma_{21}\theta'+\theta\Sigma_{21})+\theta\Sigma_{11}\theta'$.[20]

---

[20] Consider first the fact that $\Sigma_{21}-\theta\Sigma_{11}=C_2s_{12}^{'}$ because $\Sigma_{21}-\theta\Sigma_{11}=s_{21}s_{11}^{'}+s_{22}s_{12}^{'}-s_{21}s_{11}^{-1}(s_{11}s_{11}^{'}+s_{12}s_{12}^{'})$ $=s_{22}s_{12}^{'}-s_{21}s_{11}^{-1}s_{12}s_{12}^{'}=\left(s_{22}-s_{21}s_{11}^{-1}s_{12}\right)s_{12}^{'}$.

These restrictions from 2SLS and VAR residual covariance allow for the identification of $C_1C_1^{'}$ and the covariance of $C_1\varepsilon_t^p$. If structural shocks to domestic MP are uncorrelated with foreign MP shocks and vice versa, $C_1$ is a diagonal and can be directly identified up to a sign convention from equation (18).[21] However, if we cannot impose zero cross-correlations between structural shocks, we must make an arbitrary assumption regarding how domestic MP shocks respond contemporaneously to unanticipated movements in foreign monetary policy instruments and vice versa in order to disentangle the causal effects of shocks on both MP shocks. To the extent that the model considers two countries, the US and a small open economy, Cholesky decomposition of $C_1C_1^{'}$, supposing that the foreign MP shock is ordered before the domestic MP shock, permits economically meaningful results in this analysis. Finally, by plugging the identified $C_1$ back into (13), $s_{11}$ and $s_{21}$ are uniquely pinned down.

---

The derivation of $s_{12}s_{22}^{-1}$ is straightforward, noticing that $s_{12}s_{22}^{'} = s_{12}s_{12}^{'}\theta' + (\Sigma_{21} - \theta\Sigma_{11})'$.

$Q = Q'$ because $Q$ is symmetric, and it is same as $u_tu_t^{'}$ or $C_2C_2^{'}$. Using this fact, $s_{12}s_{12}^{'}$ can be obtained by the following form:

$$s_{12}s_{12}^{'} = s_{12}C_2^{'}C_2^{'-1}C_2^{-1}C_2s_{12}^{'} = s_{12}C_2^{'}Q^{-1}C_2s_{12}^{'} = (\Sigma_{21} - \theta\Sigma_{11})'Q^{-1}(\Sigma_{21} - \theta\Sigma_{11})$$

And from the covariance matrix, $s_{22}s_{22}^{'} = \Sigma_{22} - s_{21}s_{21}^{'}$ ,and it can be expressed as the above because $s_{21}s_{21}^{'} = s_{21}\left(s_{11}^{-1}s_{11}s_{11}^{'}s_{11}^{-1'}\right)s_{21}^{'} = \left(s_{21}s_{11}^{-1}\right)\left(\Sigma_{11} - s_{12}s_{12}^{'}\right)\left(s_{11}^{-1'}s_{21}^{'}\right)$.

[21] If so, a simpler identification approach, such as Gertler and Karadi (2014) employ, can be directly applied to identify $s_{11}$ and $s_{21}$ $C_1$.

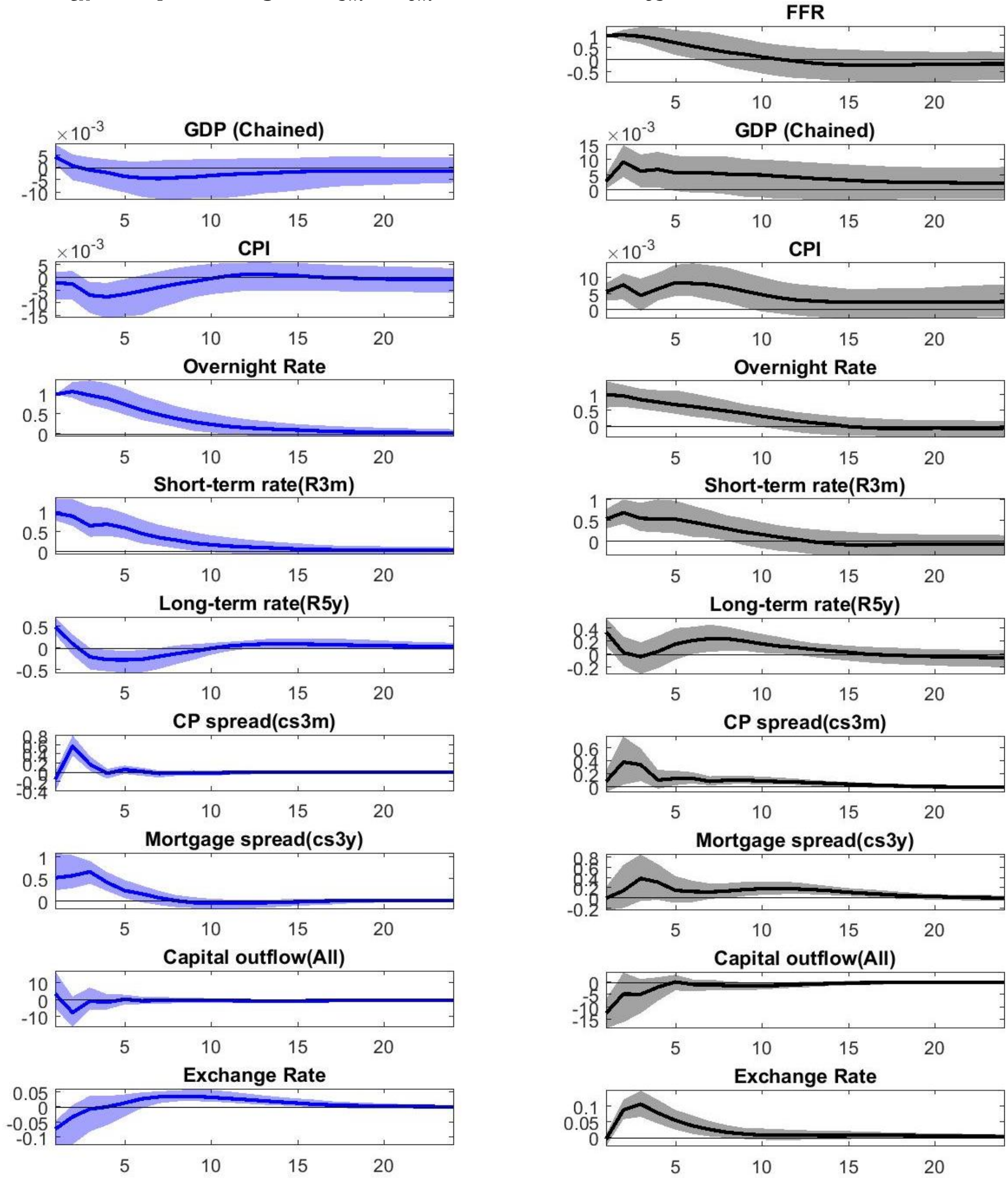
## Appendix 2

### Robustness exercise

**Figure A1. IRFs with different Canadian IV sets**

**A. IV1 & IV2 sets**

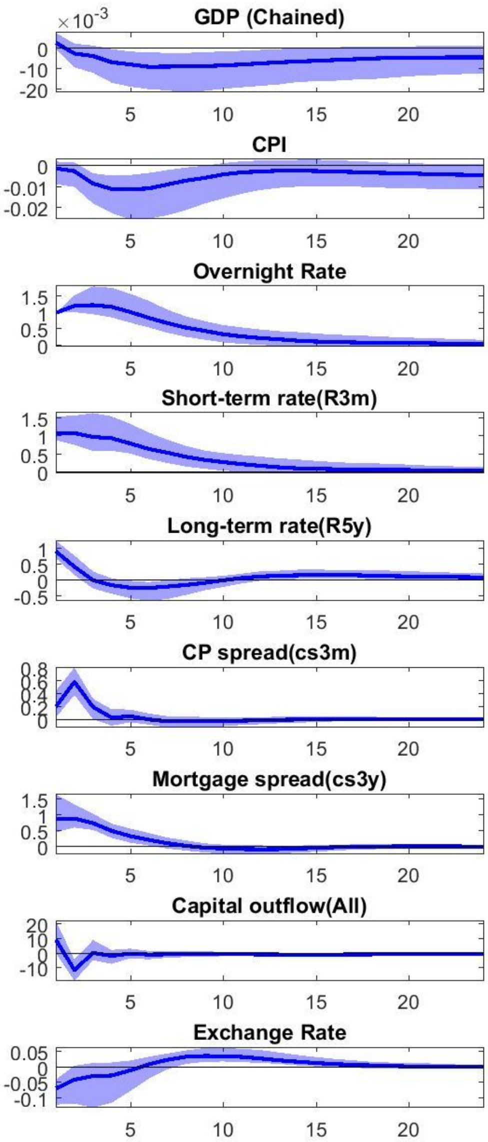
| **IRF following CA monetary policy shocks** | **IRF following US monetary policy shocks** |
|---|---|
| $IV_{CA} = \{\text{repo}, \text{overnight}, EH_{3m}, EH_{6m}\}$ | $IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$ |



**B. IV1 & IV3 sets**

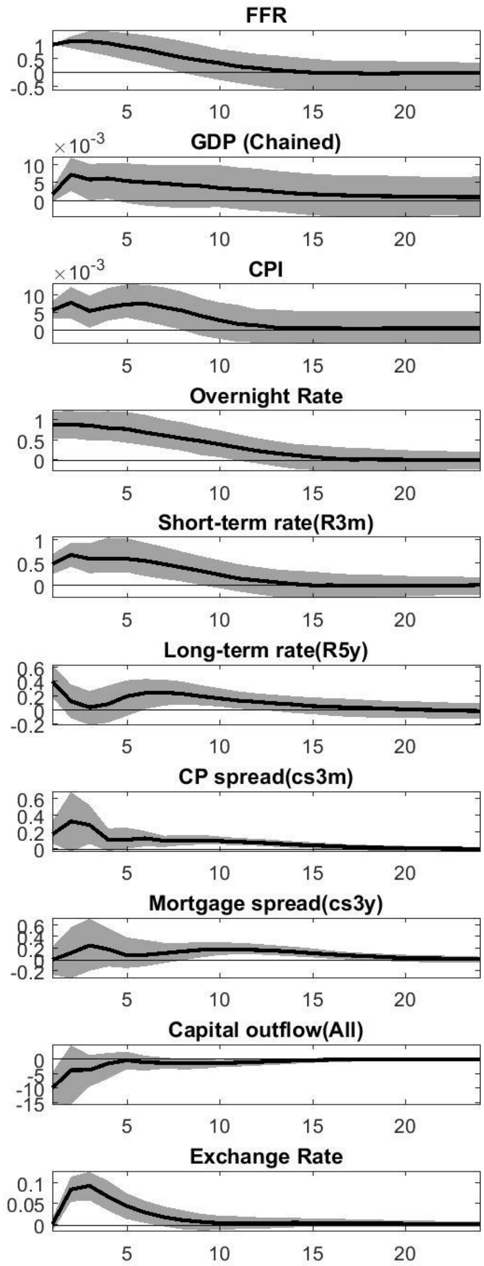
**IRF following CA monetary policy shocks**

$IV_{CA} = \{\text{repo, overnight}, RR_{hcpi}, RR_{hcpi}\}$




**IRF following US monetary policy shocks**

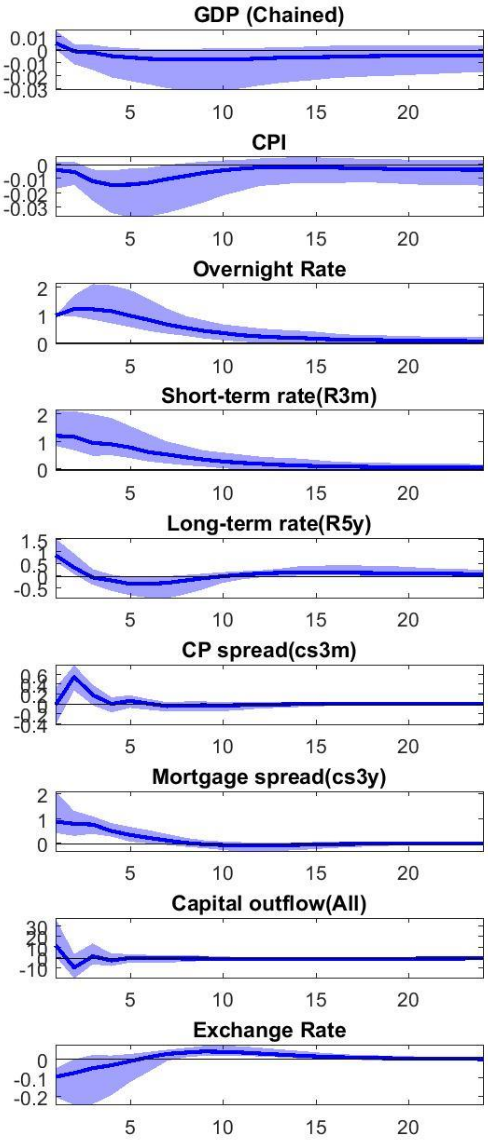
$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$



## C. IV2 & IV3 sets

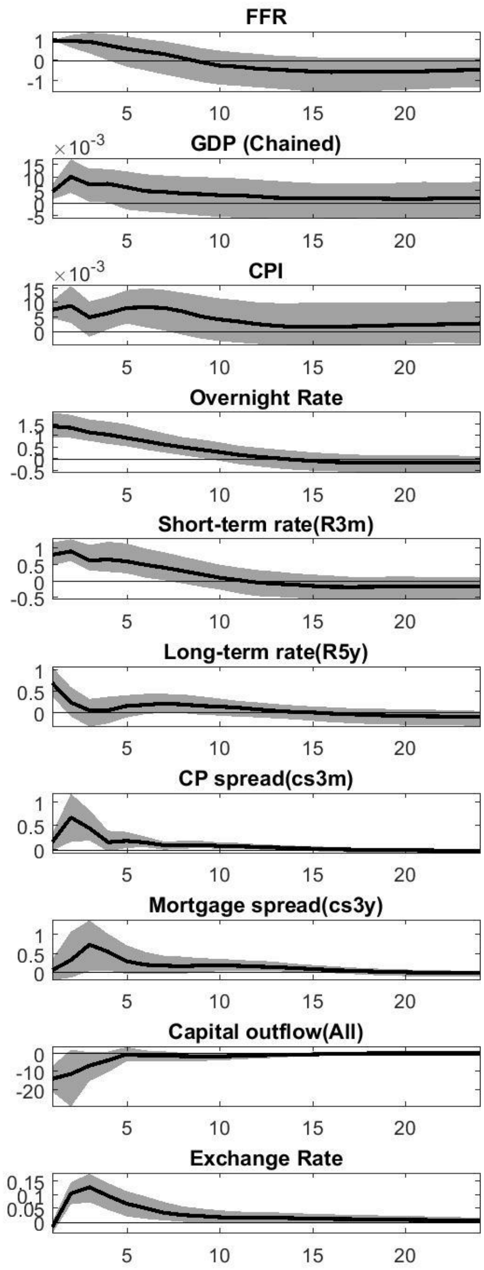
**IRF following CA monetary policy shocks**

$IV_{CA} = \{\text{EH3m}, \text{EH6m}, \text{RR\_hcpi}, \text{RR\_ccpi}\}$




**IRF following US monetary policy shocks**

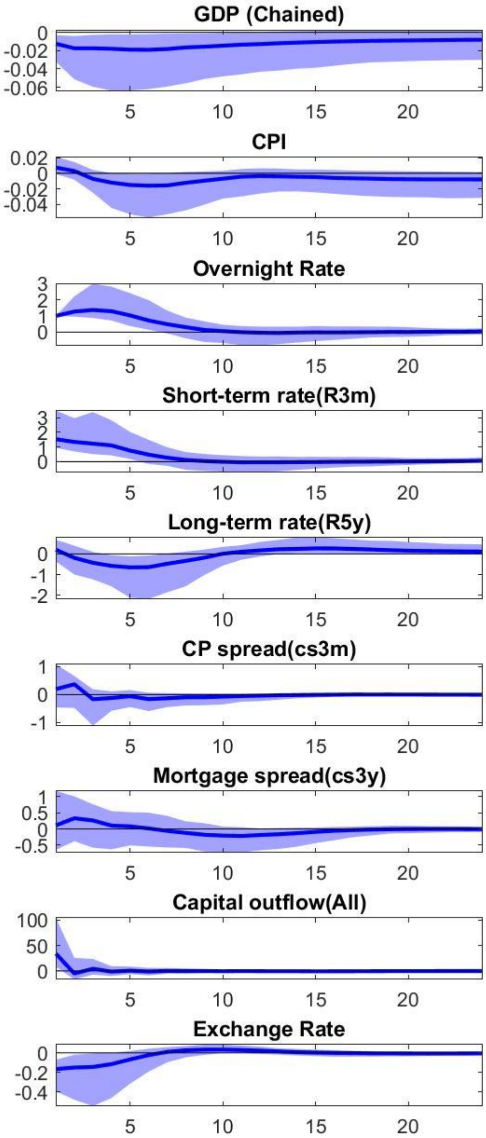
$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$



## D. Alternative IV3: Monetary policy shocks in Champagne and Sekkel (2019)

**IRF following CA monetary policy shocks**

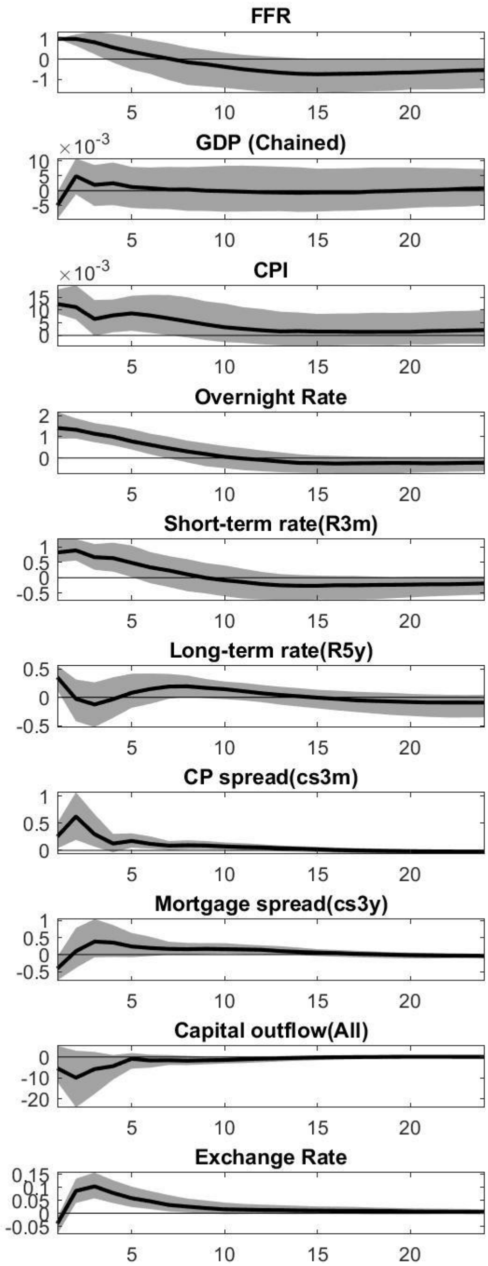
$IV_{CA,all} = \{CS_{new}, CS_{full}\}$




F = 15.23

**IRF following US monetary policy shocks**

$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$

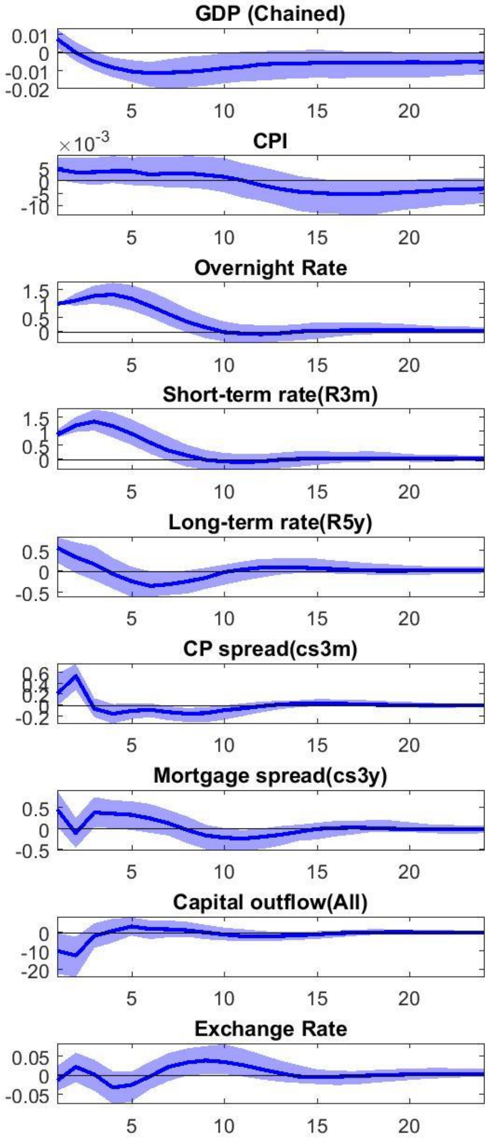



F = 12.39

## Figure A2. IRFs with pre-crisis sample (00.1-08.8)

**IRF following CA monetary policy shocks**

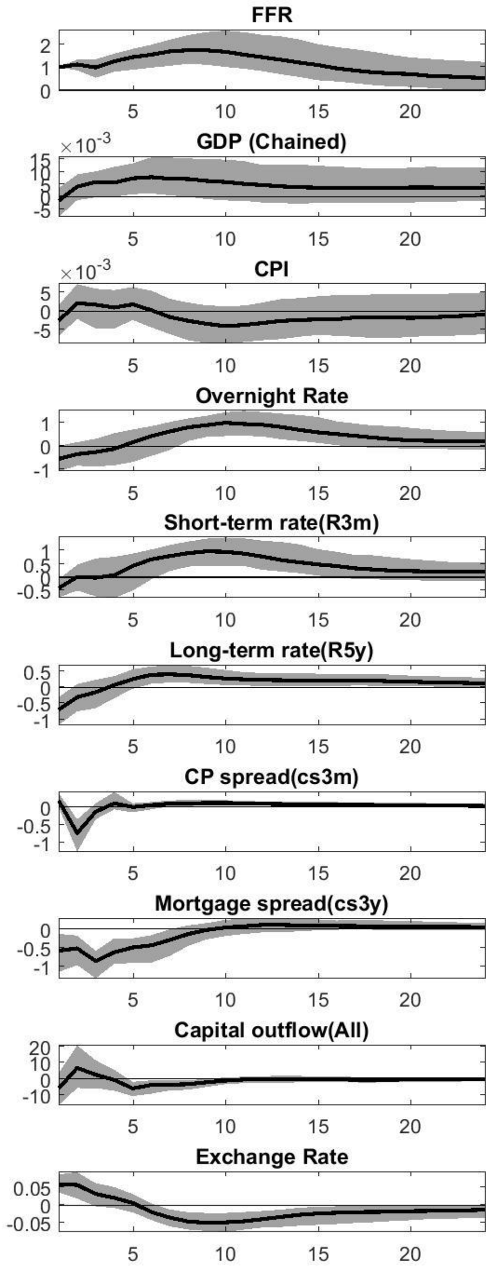
$$IV_{CA,all} = \begin{Bmatrix} overnight, repo, EH_{3m}, \\ EH_{6m}, RR_{hcpi}, RR_{ccpi} \end{Bmatrix}$$




F = 6.17

**IRF following US monetary policy shocks**

$$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$$



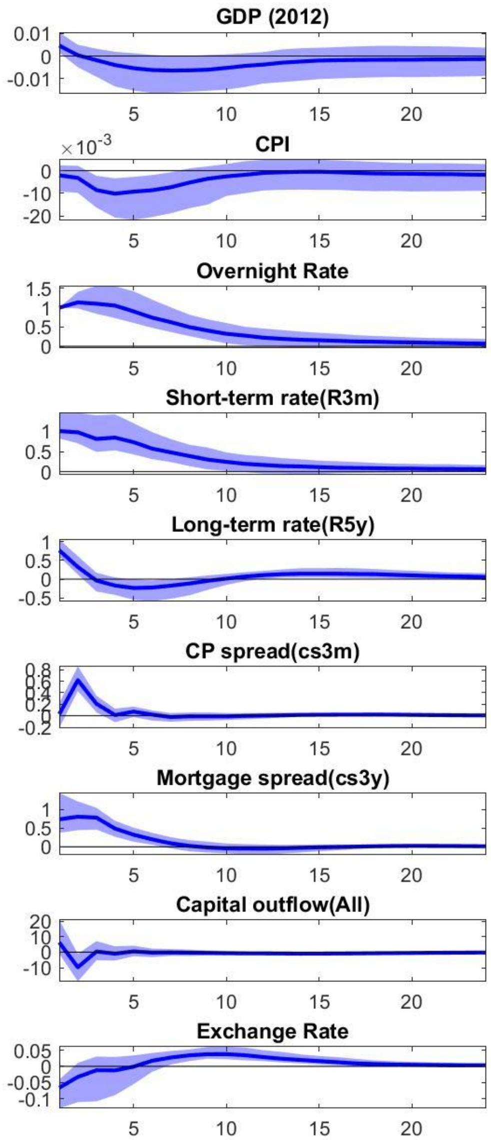

F = 5.49

**Figure A3. IRFs with alternative endoenous variables**

**A. Different output variables**

**IRF following CA monetary policy shocks**

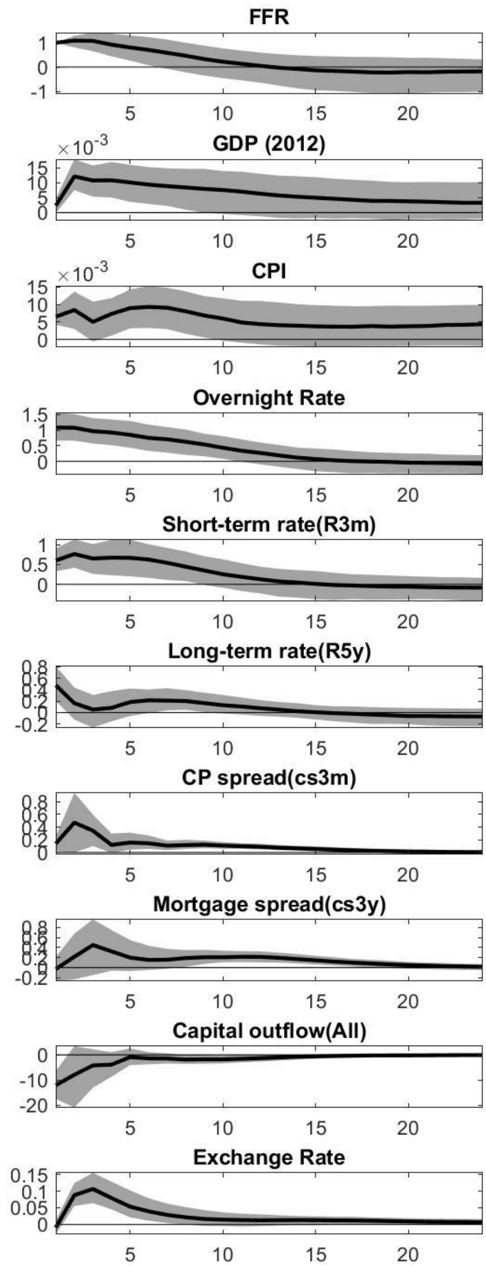
$$IV_{CA,all} = \left\{ \begin{matrix} overnight, repo, EH_{3m}, \\ EH_{6m}, RR_{hcpi}, RR_{ccpi} \end{matrix} \right\}$$




F = 21.93

**IRF following US monetary policy shocks**

$$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$$

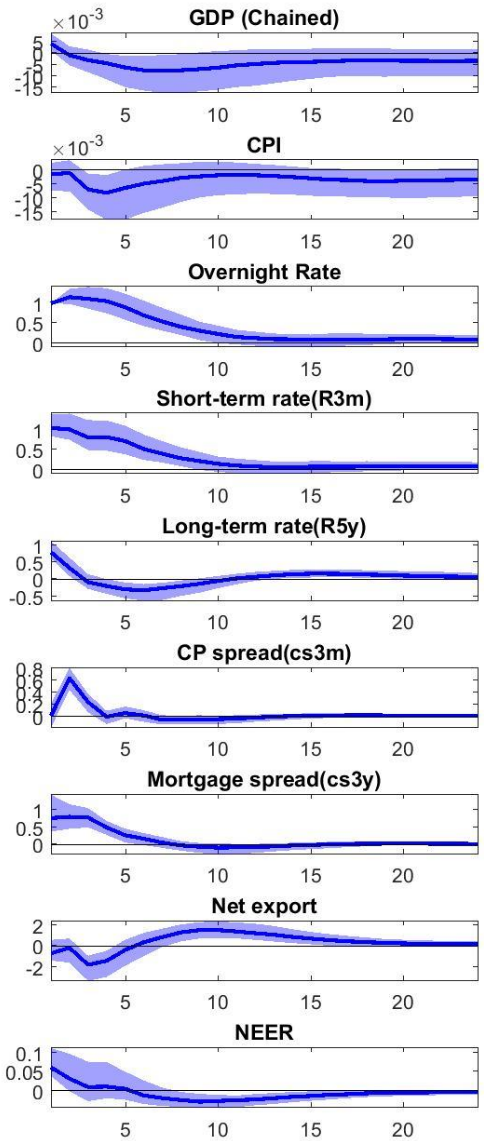



F = 12.52

## B. Alternative exchange rates and trade variables

**IRF following CA monetary policy shocks**

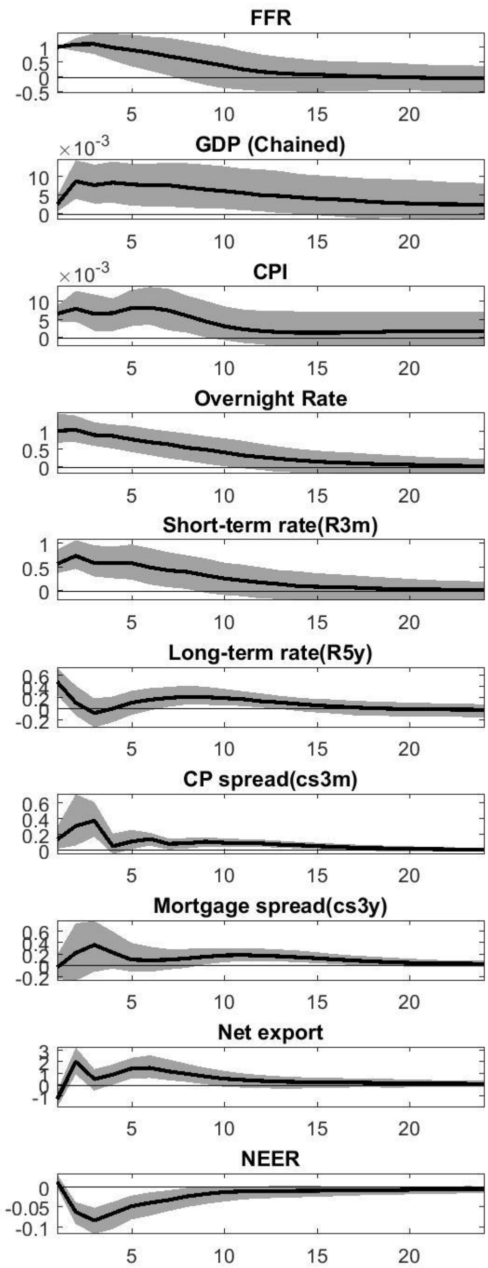
$$IV_{CA,all} = \begin{Bmatrix} overnight, repo, EH_{3m}, \\ EH_{6m}, RR_{hcpi}, RR_{ccpi} \end{Bmatrix}$$




F = 22.58

**IRF following US monetary policy shocks**

$$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$$

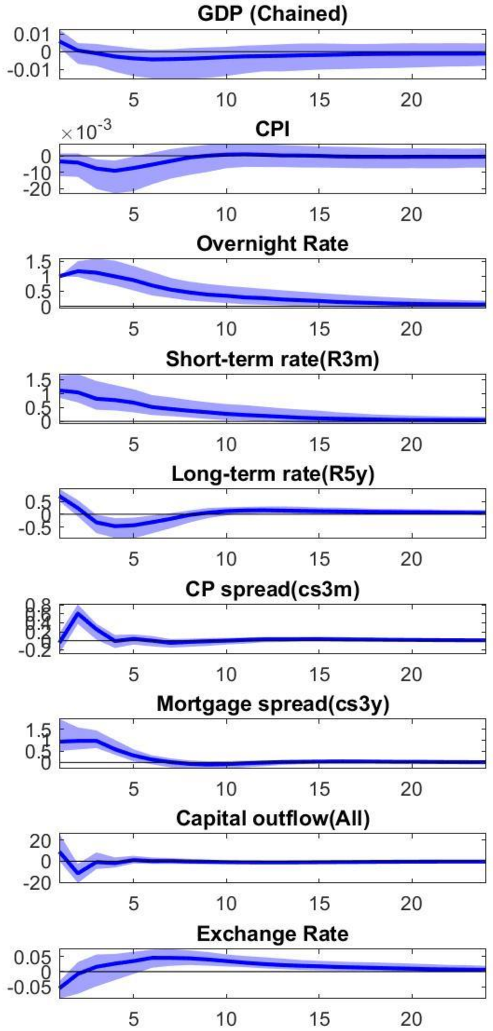



F = 12.55

**Figure 4 VIX index included as an endogenous variable**

**IRF following CA monetary policy shocks**

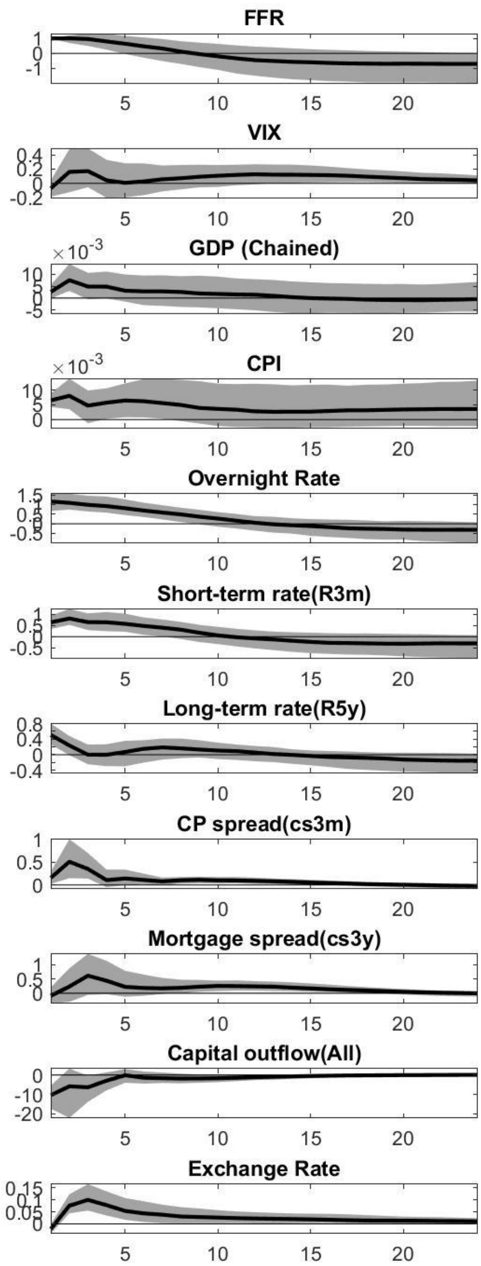
$$IV_{CA,all} = \begin{Bmatrix} overnight, repo, EH_{3m}, \\ EH_{6m}, RR_{hcpi}, RR_{ccpi} \end{Bmatrix}$$




F = 21.36

**IRF following US monetary policy shocks**

$$IV_{US} = \{MP1, FF4, ED2, ED3, ED4\}$$




F = 12.66