

## WORKING PAPER SERIES 6

Michal Franta, Jan Libich and Petr Stehlík:  
Tracking Monetary-Fiscal Interactions Across Time and Space



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# Tracking Monetary-Fiscal Interactions Across Time and Space

Michal Franta, Jan Libich and Petr Stehlík\*

## Abstract

The fiscal position of many countries is worrying – and getting worse. Should formally independent central bankers be concerned about observed fiscal excesses spilling over to monetary policy and jeopardizing price stability? To provide some insights, this paper tracks the interactions between fiscal and monetary policies in the data across time and space. It makes three main contributions. The first one is methodological: we combine two recent econometric procedures – time-varying parameter vector autoregression with sign restrictions identification – and discuss the advantages of this approach. The second contribution is positive: we show how monetary-fiscal interactions and other macroeconomic variables have changed over time in six industrial countries (Australia, Canada, Japan, Switzerland, the UK, and the U.S.). The third contribution is normative: the paper highlights the role of the institutional design of each policy on the outcomes of both policies. Specifically, it first offers some evidence that an explicit long-term commitment of monetary policy (a legislated numerical target for average inflation) gives the central bank stronger grounds for not accommodating debt-financed fiscal shocks. Our second set of (albeit weaker) results then indicates that this threat of a policy tug-of-war may improve the government's incentives and fiscal outcomes – reducing the probability of both a fiscal crisis and unpleasant monetarist arithmetic.

**JEL Codes:** C10, E61.

**Keywords:** Fiscal gap, monetary-fiscal interactions, sign restrictions, time-varying parameters VAR, unpleasant monetarist arithmetic.

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## **Nontechnical Summary**

In the aftermath of the global financial crisis, several high-income countries have faced a substantial amount of fiscal stress. Most others are likely to follow in their footsteps within a decade or two, primarily due to the demographic trends of aging populations and ballooning per capita health care costs.

That such a fiscal trend is undesirable and threatens economic prosperity is uncontroversial. For example, the 2011 Global Risks Barometer by the World Economic Forum ranks ‘fiscal crises’ as the number 1 risk in terms of the perceived financial losses (out of 37 economic, geopolitical, societal, environmental, and technological risks), perceived as ‘very likely to occur in the next ten years.’

It is, however, an open question whether such fiscal stress may affect the outcomes of monetary policy, and if so, how. The unpleasant monetarist arithmetic first warned of the possible inflationary consequences of fiscal excesses. The fiscal theory of the price level identified a slightly different channel through which fiscal stress can spill over to monetary policy and jeopardize the goal of price stability.

To contribute to the debate, this paper tracks the interactions between fiscal and monetary policies in the data across time and space, namely, from 1980 in six advanced countries: Australia, Canada, Japan, Switzerland, the UK, and the U.S. We do so using a novel empirical approach based on a combination of two recent econometric procedures – time-varying parameter vector autoregression with sign restrictions identification.

Our analysis highlights the role of the institutional design of monetary policy on the behavior of the central bank when faced with excessive fiscal policy. Specifically, we demonstrate that legislating a strong monetary commitment in the form of a numerical inflation target substantially changed the bank’s interest rate responses to debt-financed government spending shocks. These shocks were no longer accommodated, and in fact they were offset by higher interest rates. Intuitively, a committed central bank engaged in a tug-of-war with the government in its pursuit of low inflation. Importantly, we show that this altered the government’s incentives, as marked improvements in fiscal policy towards sustainability were observed 1–3 years after the adoption of explicit inflation targeting.

The implied policy conclusion is therefore that a strong commitment of monetary policy in the long term, reduced the threat of undesirably high inflation as well as increased the chances of the necessary fiscal reform.

## 1. Introduction

Many countries have been experiencing substantial fiscal stress. The responses to the global financial crisis combined with a large structural gap between government expenditures and revenues have led to rapidly growing debt-to-GDP ratios, which are forecasted to deteriorate much further due to aging populations.<sup>1</sup>

These cyclical and structural fiscal policy developments have given rise to a new wave of discussions on whether such fiscal stress affects the conduct of monetary policy, and if so, how. Does it (eventually) spill over and lead to sub-optimally high inflation as many observers fear? Or is formal central bank independence sufficient to shelter monetary policy from such fiscal spillovers? To provide some answers, this paper uses a novel empirical framework to track fiscal-monetary interactions over time in six major countries.

The fact that monetary and fiscal policies are inter-related is widely accepted. Both policies jointly affect a number of economic variables, including private agents' expectations, and these in turn affect the payoffs of central bankers and government officials. In addition to the obvious channels (such as the crowding-out effect or inflationary pressures arising from excessive government spending), the seminal work of Sargent and Wallace (1981) and Leeper (1991) identified two avenues through which fiscal excesses may spill over to monetary policy. When fiscal policymakers are unable or unwilling to balance their budgets, both the unpleasant monetarist arithmetic and the fiscal theory of the price level eventually imply undesirable departures from price stability.

Our game theoretic work Libich et al. (2012) analyzed such strategic monetary-fiscal interactions (the policy game of chicken) and identified two main institutional variables at play. The likelihood of inflationary fiscal spillovers into monetary policy was found to decrease with the degree of long-term monetary commitment (the explicitness of the inflation target) and to increase with the degree of fiscal rigidity (the size of the fiscal gap). These variables are graphically depicted for high-income countries in Figure A1 of Appendix A, which is accompanied by a discussion of the underlying intuition. The likelihood of unpleasant monetary arithmetic was found to diminish with the monetary commitment to fiscal rigidity ratio, i.e., it is lowest in Australia and New Zealand, and highest in the United States and Japan.

The presented paper attempts to assess these theoretic predictions using a novel econometric approach. We use vector autoregressions (VARs) with time-varying parameters (TVP) as introduced in Primiceri (2005) and Cogley and Sargent (2005).<sup>2</sup> The flexibility of this approach

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<sup>1</sup> See, for example, IMF (2009), which reports the net present value of the impact of aging-related spending on fiscal deficits to be in the order of hundreds of percent of GDP for advanced countries (and on average over the G20 countries about ten times higher than the effect of the global financial crisis). Specifically for the United States, Batini, Callegari, and Guerreiro (2011) provide a recent estimate of the 'fiscal gap' (unfunded liabilities) arguing that: 'a full elimination of the fiscal and generational imbalances would require all taxes to go up and all transfers to be cut immediately and permanently by 35 percent' (*italics in the original*).

<sup>2</sup> TVP-VARs have been used by many studies, mainly to analyze monetary policy transmission (e.g. Canova et al., 2007; Benati and Surico, 2008). But there have also been applications to fiscal policy (Kirchner et al., 2010; Pereira and Lopes, 2010), financial issues (Eickmeier et al., 2011), exchange rate dynamics (Mumtaz and Sunder-Plassmann, 2010), oil price shock transmission (e.g. Baumeister and Peersman, 2008), and yield curve dynamics (Bianchi et al., 2009).

enables us to examine medium to long-term *changes* in policy behavior over and above the short-run stabilization issues explored in fixed-parameter VARs. Given the dire long-term fiscal projections, we believe that this broadened focus is warranted. It must, however, be acknowledged that the use of TVP-VARs requires a reduced number of endogenous variables and lags to keep the set of parameters manageable.

In comparison with standard approaches featuring structural breaks, the TVP-VAR framework allows for structural policy changes to be gradual and differ in their timing across the two policies. As such, an analysis based on TVP-VARs can be superior to an analysis based on data sub-samples.<sup>3</sup> We use the framework to contrast the differences in monetary policy responses to debt-financed government spending shocks in three early inflation-targeting countries (Australia, Canada, and the United Kingdom) before and after adoption of the regime, and compare them to those in countries without a legislated numerical inflation target (Japan, Switzerland, and the United States).

The methodological contribution of this paper, discussed in detail in the next section, is an extension of the TVP-VAR framework using an identification of fiscal shocks based on a combination of sign, magnitude, and contemporaneous restrictions.

So far, only Kirchner et al. (2010) and Pereira and Lopes (2010) have employed the TVP-VAR framework to assess the effect of fiscal policy shocks. Kirchner et al. (2010) focus on the euro area using the traditional recursive assumption (e.g. as in Fatás and Mihov, 2001) to identify government spending shocks. Pereira and Lopes (2010) examine the United States and identify the tax-net-of-transfers shock and the spending shock along the lines of Blanchard and Perotti (2002), who exploit institutional information on taxes and transfers to separate automatic movements of fiscal variables from fiscal shocks.

While the identification approach in Kirchner et al. (2010) and Pereira and Lopes (2010) based on the assumption of lagged reactions among endogenous variables is suitable in some contexts, it may be too restrictive for the analysis of monetary-fiscal interactions. This is because it implies that either the monetary authority does not react contemporaneously to fiscal shocks, or the fiscal authority neglects contemporary movements in monetary policy. Intuitively, such specification may implicitly impose unrealistic timing assumptions about the interaction between the monetary and fiscal authorities. As the game theoretic examination of monetary-fiscal interactions dating back to Sargent and Wallace (1981) suggests, the exact timing of policy moves is a crucial determinant of the outcomes of both policies. Similarly, Caldara and Kamps (2008) show that different identification approaches can lead to qualitatively different results in terms of monetary policy responses to government spending shocks.

Therefore, an additional advantage of using the sign restrictions framework in the policy context is that no timing assumptions on the monetary-fiscal interaction need to be imposed. On the other hand, sign restrictions are a weak identification approach in terms of there being many structural models that correspond to the estimated reduced-form model and satisfy the signs imposed on the

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<sup>3</sup> It is well established that many advanced countries have experienced structural breaks in monetary and fiscal policy, with their policy regimes changing over time – see, for example, Davig and Leeper (2010) and Clarida, Gali, and Gertler (1998). Fiscal policy analyses based on sub-samples can be found in Pappa (2010), Perotti (2007), and Blanchard and Perotti (2002).



impulse responses (Fry and Pagan, 2011). We mitigate this potential problem by adding a set of contemporaneous and magnitude restrictions.

Our analysis offers several insights regarding the monetary-fiscal interaction: how it changed over time, how it differed across countries, and how the institutional design of the policies may explain the changes and differences. In particular, it is shown that in the inflation-targeting countries considered, the degree of monetary policy accommodation of debt-financed fiscal shocks indeed decreased after the adoption of a numerical inflation target. In contrast, in the ‘non-targeters’ the degree of accommodation over the same period did not change much, or, most notably in the United States, increased.

Importantly, the inflation-targeting countries have not only improved their monetary outcomes. With a delay of 1–3 years after the adoption of the regime, their fiscal outcomes started improving as well, and remained in good shape until at least the recent crisis. These findings are consistent with the game theoretic predictions of Libich et al. (2012) that a long-term monetary commitment may help the central bank discipline governments (induce fiscal reforms) through a credible threat of a policy tug-of-war. This may explain the negative correlation in Figure A1: institutional reforms increasing long-term monetary commitment (moving a country to the right) may also induce a reduction in fiscal rigidity (a movement down). However, one needs to be careful in drawing conclusions about causality between stronger monetary commitment and improved fiscal outcomes – our evidence is limited to *correlation*.

The tentative policy recommendation is therefore as follows: to get an upper hand in the policy game of chicken, central banks should try to commit as explicitly as possible to their long-term inflation objective.<sup>4</sup> The fact that the Federal Open Market Committee has subscribed more explicitly to the 2% long-term inflation target is consistent with our recommendation. The committee’s justification also seems to point to the channels examined in our paper: ‘Communicating this inflation goal clearly to the public helps keep longer-term inflation expectations firmly anchored.’

Our analysis offers additional results, most importantly regarding the size of output and private consumption multipliers and how these evolved over time. Due to space constraints we will cover these results in detail in a separate paper.

## 2. Identification

Three approaches to the identification of fiscal policy shocks have been established in the literature. First, the event-study approach (Ramey and Shapiro, 1998) focuses on describing the effects of an unexpected increase in government defense spending. Second, the structural VAR approach (Blanchard and Perotti, 2002) draws on the assumption of a lagged reaction of fiscal variables to changes in economic conditions. Third, the identification scheme based on sign restrictions, developed originally for the analysis of monetary policy shocks, has been applied to fiscal policy (Mountford and Uhlig, 2009; Pappa, 2009; Canova and Pappa, 2007). Recently, the

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<sup>4</sup> It should be stressed, however, that since the target is specified as a long-term objective achievable on average over the business cycle, it does not seem to reduce short-run policy stabilization flexibility: for recent evidence see e.g. Kuttner and Posen (2011) and for theoretic modeling see Libich (2011).

sign restrictions identification approach has been enriched by additional identifying assumptions based on, for example, cointegration (Dungey and Fry, 2009) and magnitude restrictions (Hur, 2011).

Our identification procedure complements sign restrictions with magnitude and contemporaneous restrictions, building on Franta (2011). Our focus is on the identification of a debt-financed government spending shock. Government spending is defined as government consumption and investment, i.e., total expenditures excluding government transfers.

Similarly to Canova and Pappa (2007), Pappa (2009), and Dungey and Fry (2009) we assume that a positive debt-financed government spending shock increases: (i) government spending for four quarters, (ii) government debt for four quarters, and (iii) output for two quarters. The length of the imposed sign restrictions is related to some aspects of the data, which we discuss in Section 4. As shown in Pappa (2009) such restrictions, at least on impact, are consistent with standard structural models of both the real business cycle and the New Keynesian tradition, and they do not result from productivity, labor supply or monetary shocks.<sup>5</sup>

A rise in output and government debt can, however, also be brought about by a tax cut and/or an increase in transfers. Therefore, to filter out the effects of government transfer and tax shocks, we impose a magnitude restriction that an identified debt-financed spending shock does not increase government debt by more than the amount of government spending.<sup>6</sup> The situation where tax cuts imply an increase of tax revenues cannot be distinguished from a government spending shock within our identification framework, but such a scenario is arguably unlikely.

Next, to capture the fact that government purchases do not react much to the business cycle, we impose a zero contemporaneous restriction on the effect of a business cycle shock on government spending. This is reminiscent of the recursive identification of shocks when government spending is ordered before GDP. Nevertheless, we do not restrict the contemporaneous feedback between government debt and output to allow for the effect of automatic stabilizers on the fiscal variables (taxes/debt). The contemporaneous restriction on the relationship between output and government spending enables us to distinguish between a generic business cycle shock (Mountford and Uhlig, 2009) and fiscal shocks. As shown by Wouters (2005) a higher number of shocks identified implies greater reliability of the sign identification procedure.

Finally, let us stress that we do not impose any restriction on the interest rate because it is our main variable of interest, summarizing the responses of monetary policy to debt-financed spending shocks. Furthermore, no restriction on private consumption is imposed because of the

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<sup>5</sup> Leeper et al. (2010) show within a neoclassical growth model fit to U.S. postwar data that government investment implementation delays can even lead to a slight decline of output in the short run. We discuss the anticipation effects of fiscal shocks in Section 6.

<sup>6</sup> In focusing on monetary-fiscal interactions we need to distinguish a debt-financed government spending shock from a tax-cut shock and government transfers shock. This is because the real economy behaves differently after different types of fiscal shocks (e.g. private investment is usually crowded out in the case of excessive government spending, but not in the case of a tax cut), which would warrant a different response from the central bank. To distinguish between spending and tax-cut shocks, Pappa (2010) assumes a zero or small correlation of the identified shock and tax revenues. The difference of our identification approach is driven by our set of endogenous variables, which includes government debt instead of tax revenues.

opposite predictions of the traditional Keynesian and real business cycle models: the former predicts an increase whereas the latter predicts a decrease in private consumption following a debt-financed government spending shock.

### 3. The Econometric Model

The reduced-form TVP-VAR follows Cogley and Sargent (2005) and Primiceri (2005):

$$y_t = X_t \beta_t + A_t^{-1} \Sigma_t \varepsilon_t \quad t = p+1, \dots, T, \quad (1)$$

where  $y_t$  is an  $M \times 1$  vector of endogenous variables,  $X_t = I_M \otimes (1, y'_{t-1}, \dots, y'_{t-p})$  is a Kronecker product of the identity matrix with a constant and lagged vectors of endogenous variables,  $p$  denotes the number of lags, and  $\varepsilon_t$  denotes the vector of i.i.d. structural shocks. An  $M(Mp+1) \times 1$  vector  $\beta_t$  stacks reduced-form coefficients, the matrix  $A_t$  is a lower triangular matrix capturing contemporaneous relations:

$$A_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \alpha_{21,t} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{M1,t} & \cdots & \alpha_{M,M-1,t} & 1 \end{bmatrix},$$

and the matrix of standard deviations of structural shocks,  $\Sigma_t$ , is diagonal:

$$\Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{M,t} \end{bmatrix}.$$

The TVPs follow random walks and a geometric random walk:

$$\beta_{i,t} = \beta_{i,t-1} + u_t^i \quad i = 1, \dots, M^2 p + M, \quad (2)$$

$$\alpha_{i,t} = \alpha_{i,t-1} + v_t^i \quad i = 1, \dots, (M^2 - M)/2, \quad (3)$$

$$\log(\sigma_{i,t}) = \log(\sigma_{i,t-1}) + w_t^i \quad i = 1, \dots, M. \quad (4)$$

Model innovations are assumed to be jointly normally distributed:

$$\begin{bmatrix} \varepsilon_t \\ u_t \\ v_t \\ w_t \end{bmatrix} \sim N \left( 0, \begin{bmatrix} I_M & 0 & 0 & 0 \\ 0 & U & 0 & 0 \\ 0 & 0 & V & 0 \\ 0 & 0 & 0 & W \end{bmatrix} \right), \quad (5)$$

where the vectors  $u_t, v_t$  and  $w_t$  consist of innovations as introduced in (2)–(4). The matrices  $U, V$ , and  $W$  are positive definite. Moreover,  $V$  is assumed to be a block diagonal matrix, with blocks constituted by the coefficient innovations from a particular equation, i.e., we assume that innovations to contemporaneous effects are uncorrelated across equations. Finally, we follow Cogley and Sargent (2005) and assume the matrix  $W$  to be diagonal. As noted in Kirchner et al. (2010) the reason is that fiscal TVP-VARs usually consist of more variables than VARs for monetary policy analysis and thus we need to reduce the number of parameters.

The simulation of the system (2)–(5) employs a Gibbs sampler. A sample from the joint posterior distribution of the parameter set is obtained from blocks that provide samples from conditional distributions. Thus, draws from the VAR coefficients  $\beta_{i,t}$ , contemporaneous relations  $\alpha_{i,t}$ , volatility states  $\sigma_{i,t}$ , and the hyperparameters  $U, V$ , and  $W$  are produced by the sampler in turn. A detailed description of the sampler and priors used can be found in Appendix B. The Gibbs sampler generates 20,000 draws after a burn-in period of 20,000. Only every fifth draw is kept to avoid autocorrelation of draws. Convergence diagnostics are presented in Appendix C.

The identification of structural shocks boils down to finding a linear combination of structural shocks  $\varepsilon_t$  that yields the reduced-form residuals  $z_t$ . The relationship between the two is modeled in (1) as follows:

$$z_t = A_t^{-1} \Sigma_t \varepsilon_t.$$

The sign restrictions identification approach draws on the fact that for any orthonormal matrix  $Q$ , i.e., the matrix such that  $Q'Q = I_M$ , it holds that:

$$z_t = A_t^{-1} \Sigma_t Q' Q \varepsilon_t.$$

In such way the new set of uncorrelated structural shocks,  $\tilde{\varepsilon}_t = Q \varepsilon_t$ , is produced and the new linear combination,  $z_t = A_t^{-1} \Sigma_t Q' \tilde{\varepsilon}_t$ , no longer determines the system of structural shocks recursively. However, the covariance matrix of the reduced-form residuals does not change.<sup>7</sup> The implementation of the identification restrictions is based on Givens rotations, i.e., orthonormal matrices of the form:

$$Q_{ij}(\theta) = \begin{pmatrix} 1 & \cdots & 0 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots & & \vdots \\ 0 & \cdots & \cos(\theta) & \cdots & -\sin(\theta) & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & \sin(\theta) & \cdots & \cos(\theta) & \cdots & 0 \\ \vdots & & \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & 0 & \cdots & 1 \end{pmatrix},$$

<sup>7</sup> In contrast to Kirchner et al. (2010) and Pereira and Lopes (2010), the identification is not an integral part of the estimation procedure. In their case, the estimated matrices of the contemporaneous effects already embed the identification scheme.

where the rotation angle  $\theta \in [0, \pi]$  and respective goniometric functions occupy the  $i$ -th and  $j$ -th columns and the  $i$ -th and  $j$ -th rows of the matrix. For 5x5 matrices, any rotation can be constructed as a product of 10 possible Givens rotations:

$$Q(\theta) = \prod_{\substack{i,j=1 \\ i < j}}^5 Q_{ij}(\theta).$$

In order to impose no impact of output on government spending in a given period, we use only nine Givens rotations to guarantee zero at the respective position (the first row and the second column) in the matrix  $Q$ . Hence we have:

$$Q(\Theta) = Q_{24}(\theta_1) Q_{23}(\theta_2) Q_{14}(\theta_3) Q_{35}(\theta_4) Q_{34}(\theta_5) Q_{25}(\theta_6) Q_{45}(\theta_7) Q_{15}(\theta_8) Q_{13}(\theta_9).$$

For each rotation we check the sign and magnitude restrictions. The sign restrictions are described in the first row of Table 1. Pappa (2009) shows that a crucial feature of the spending shock identification – distinguishing it from other types of shocks – is that unexpected spending raises output and the government deficit on impact. In terms of our framework this means that a government debt-financed spending shock increases output and government debt. In addition, the second and third rows of Table 1 present the reactions of endogenous variables to a generic business cycle shock (e.g. a technology or labor supply shock) and a monetary policy shock. The important feature of the shocks is that either they do not affect government spending contemporaneously, or they affect output and government debt in opposite directions.

**Table 1. Sign Restrictions**

		Output		Private consumption		Interest rate		Government spending		Government debt	
		impact	2 lags	impact	lag	impact	lag	impact	4 lags	impact	4 lags
Debt-financed gov. spending shock		+	+	none	none	none	none	+	+	+	+
Monetary shock	policy	0	-	0	-	+	+	0	+/-	+	+
Generic cycle shock	business	+/-	+/-	+/-	+/-	+/-	+/-	0	+/-	-	-

In addition, magnitude restrictions are imposed such that the effect of a shock on government spending is not lower than the effect of the shock on government debt in the next four quarters. If it is lower it means that other components of the government budget constraint must have been affected by the shock (e.g. lower tax revenues). Note that the magnitude restrictions are applied on a particular draw of the rotation matrix, i.e., on a particular structural model. For a given draw of

the model parameters, at most forty rotations are tested to find the ones that satisfy the sign and magnitude restrictions.

#### 4. Data

An analysis of this type is constrained by the unavailability of fiscal data affecting decisions on the variables and countries included. Our set of endogenous variables  $y_t$  consists of five variables, namely, output, private consumption, the short-term interest rate, government spending (consumption and investment), and government debt.<sup>8</sup> All variables except the interest rate are in logs of real per capita terms. The data are quarterly, except for government debt, which is yearly. Using a simple univariate interpolation (Boot-Fiebes-Lisman) method we disaggregated the yearly debt data into quarters.<sup>9</sup> The data enter our analysis in levels like in Kirchner et al. (2010) – but unlike in Pereira and Lopes (2010), who detrend the data. This is for three reasons. First, trends can reveal valuable information about monetary-fiscal interactions and how these have changed over time. Second, this approach avoids the possibility of incorrectly imposing cointegration relationships; see Sims et al. (1990). Third, within the Bayesian estimation strategy it is not necessary to stationarize time series, as the presence of unit root does not affect the likelihood function. The lag length is set equal to two.<sup>10</sup> The data sources are described in Appendix G.

<sup>8</sup> This adds government debt to the four endogenous variable analyses of Kirchner et al. (2010) and Pereira and Lopes (2010) (the latter paper uses taxes net of transfers instead of private consumption). This choice is very close to the set of endogenous variables usually employed in VAR studies dealing with fiscal policy issues. VARs for monetary policy analysis use mainly output, inflation, the interest rate, and the exchange rate. It would be our preferred choice to also include the latter two variables in our estimation and thus better capture the monetary policy rule and open economy features, but this is not computationally feasible due to the large number of estimated parameters in the TVP-VAR framework.

<sup>9</sup> This is one of the reasons for imposing sign restrictions on the response of debt to four quarters: a change in government debt that occurs anytime during the year is reflected by the debt data in all four quarters. Similarly, this is true for the magnitude restrictions.

<sup>10</sup> The choice of the lag length is driven by both the number of parameters to estimate and an attempt to best capture the dynamics of endogenous variables. Two lags imply more than 10,000 parameters to estimate, and three lags almost 20,000. Exact determination of the lag length based on the marginal likelihood is beyond the scope of this paper. Nevertheless, some guidance can be taken from the sample autocorrelations presented in the following table for two and three lags. Even for two lags, the table does not indicate any problems with residual autocorrelation.

#### *Autocorrelation of Reduced-Form Residuals*

lags	p=2					p=3				
	t-1	t-2	t-3	t-4	t-5	t-1	t-2	t-3	t-4	t-5
var1	0,15	0,03	0,20	0,08	0,05	0,10	0,02	0,11	0,01	0,03
var2	0,07	0,15	0,06	0,01	-0,02	0,10	0,07	0,08	0,04	0,01
var3	0,07	0,03	0,16	-0,08	0,04	0,11	0,06	0,11	-0,06	0,04
var4	0,13	0,10	0,20	-0,04	0,10	0,17	0,09	0,10	0,02	0,04
var5	0,12	-0,05	0,08	0,07	0,06	0,09	-0,03	0,09	0,07	0,07

We estimate the model for Australia, Canada, Japan, Switzerland, the UK, and the U.S. The country choice is driven by our interest in comparing countries with and without a legislated inflation target. As there are only three advanced countries in the latter category (Japan, Switzerland, and the U.S.), we pick an equal number of early targeters. Their choice follows the justification of Dotsey (2006), most importantly the fact that ‘their inflation rates were fairly well contained before they adopted inflation targeting.’

The data set covers the period 1980Q1–2008Q2 (the UK data set begins in 1981Q1). We do not include data on the recent financial crisis in our benchmark analysis for three main reasons. First, it is well documented that this period reflected an environment of increased risk following the collapse of Lehman Brothers and the subsequent credit crunch. As we are interested in monetary-fiscal interactions, we would like the interest rate to represent the behavior of monetary policy alone, rather than risk. Second, during the crisis central banks affected the economy through additional channels, e.g. by directly subsidizing commercial banks. Third, our priors are based on OLS estimates of the model on the whole sample, so extreme observations can alter the estimates in a way unrepresentative of the medium to long-term developments.<sup>11</sup> Nevertheless, as a demonstration we report the estimates on the dataset ending with 2010Q4 for the U.S. in Appendix F. It shows that while our benchmark results are robust, including the recent crisis leads to some loss of insight.

Two points in relation to data choices are worth emphasizing. First, to analyze monetary-fiscal interactions an appropriate short-term interest rate must be chosen, one that reflects the monetary policy stance for the whole period. This means that we do not automatically use the currently announced instrument of the central bank, as it may not be informative of monetary policy behavior under older style money growth targeting performed at the start of our sample. Therefore, for robustness we mainly use the Treasury bill rate. Second, government spending data are usually available for the general level of government (except the UK). However, the government debt data relate to central government only. Assuming that the change in general government debt is no smaller than the change in central government debt, the magnitude restrictions imposed imply that the change in general government spending does not exceed the change in general government debt.

## 5. Two Conjectures

Our game theoretic work Libich et al. (2012) implies two conjectures regarding monetary-fiscal interactions (Appendix A sketches the theory and intuition behind them):

**Conjecture 1:** A central bank with a numerical target for average inflation is less prone to accommodate a debt-financed government spending shock than a central bank without such an explicit long-term monetary commitment.

**Conjecture 2:** Legislating a long-term monetary commitment (and the subsequent change in monetary policy responses described in Conjecture 1) alters the incentives of governments by

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<sup>11</sup> As Canova (2007) suggested, in the case of short samples it is preferable not to use a training sample that would be discarded.

reducing their payoff from debt-financed spending, and therefore leads to an improvement in the fiscal balance.

In summary, we are interested in both directions of the policy interactions: from fiscal to monetary, and from monetary to fiscal. Tracking how these have changed over time can provide some clues about the possible outcomes of both policies in the future. Specifically, it is of high importance to anticipate to what extent the observed and predicted structural fiscal shortfalls can threaten the outcomes of monetary policy, and whether any institutional arrangements can play a positive role in this respect.

Such interest drives our empirical analysis. We estimate the impulse response functions (IRFs) of the endogenous variables to a positive debt-financed government spending shock. As shown by Fry and Pagan (2011) sign restrictions can recover correct impulse responses to an *unknown* one standard deviation shock, i.e., one cannot distinguish between the shock itself and the contemporaneous effect of the shock on a variable.<sup>12</sup> Therefore, the impulse responses are normalized with respect to the impact of the shock on government spending. Since the sign of the impact is driven by the sign of the contemporaneous effect, the signs of the IRFs provide accurate information. It should be acknowledged that the same cannot be claimed with certainty about the magnitudes of the IRFs, which are of interest for comparison between periods. However, assuming that the variance in the impacts is driven mainly by shocks – that is basically our prior belief on hyperparameters implying variation of coefficients in comparison with the prior on the variation of volatility – conclusions can be also made with respect to changes in magnitude.

Finally, in order to get the interpretation of impulse responses as multipliers, the size of the shock equals one percent of GDP and all endogenous variables except the interest rate are also expressed as a percentage of GDP. The interest rate, which is the main variable of interest, is considered in percentage points. To maintain the focus on monetary-fiscal interactions, in the main text we will only report the impulse responses of the interest rate to the debt-financed fiscal shock. For an illustration of the rest of the results, the responses on impact and in the 3<sup>rd</sup> quarter are available in Appendix D for all variables and countries.

## 6. Results Regarding Conjecture 1

If Conjecture 1 is correct, we should see no monetary accommodation of fiscal shocks (lowering of interest rates) after a numerical inflation target is legislated, or even observe the central bank offsetting such shocks by raising interest rates. In contrast, Conjecture 1 predicts no change or possibly more monetary accommodation in countries without a legislated inflation objective.

### 6.1 Estimated Impulse Responses

Figure 1 reports the estimated responses of the interest rate to the fiscal shock for all the countries considered. It plots the medians of the posterior distributions. Figure 2 presents the *average*

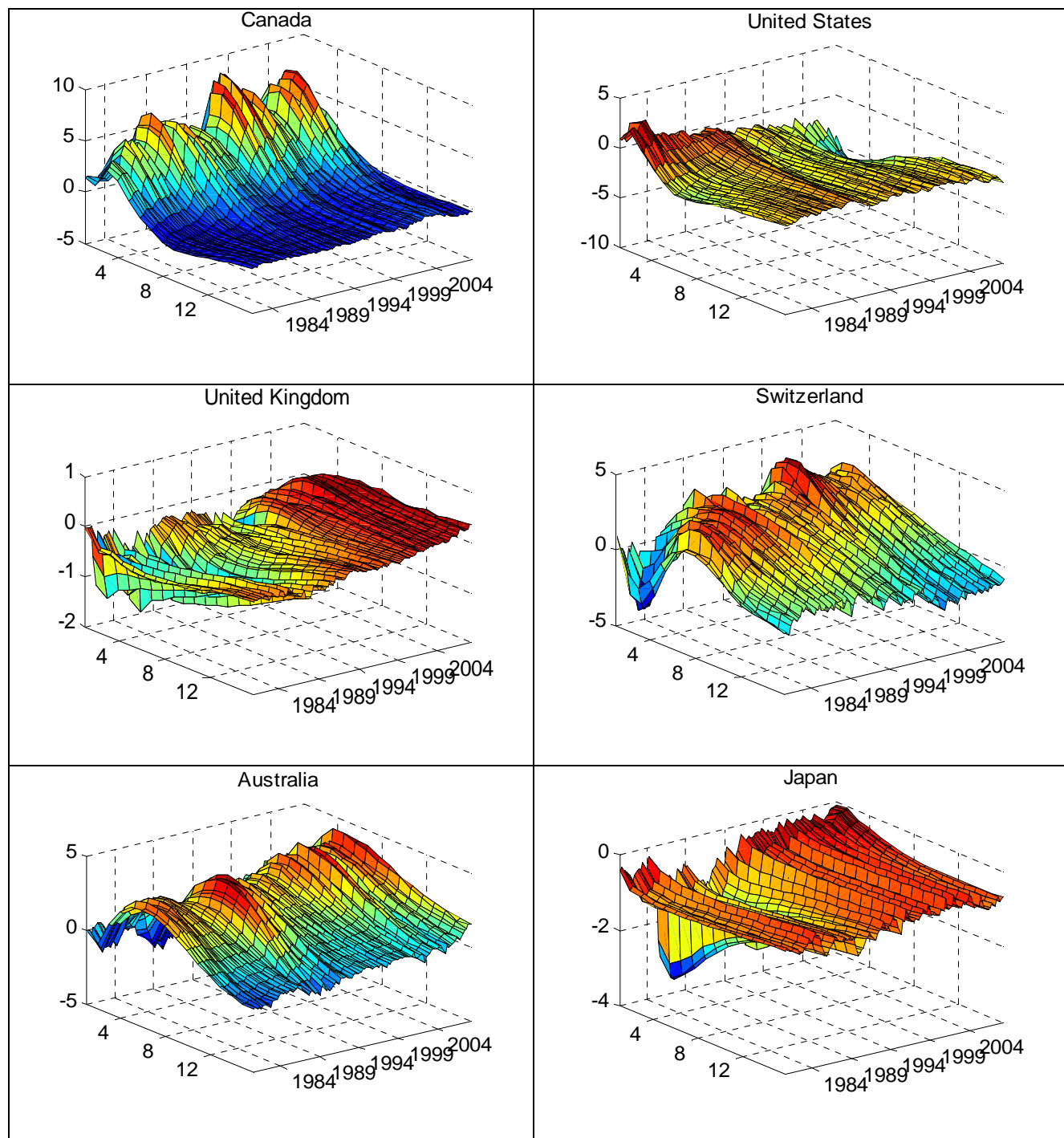
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<sup>12</sup> Primiceri (2005) avoids this problem by assuming recursive identification and estimating the matrix of standard deviations  $\Sigma_t$  and the matrix of contemporaneous effects  $A_t$  separately. We adjust the matrices with the rotations and hence lose the possibility of distinguishing them.



responses for two sub-samples in order to better contrast monetary policy behavior before and after the introduction of an explicit numerical inflation target.<sup>13</sup>

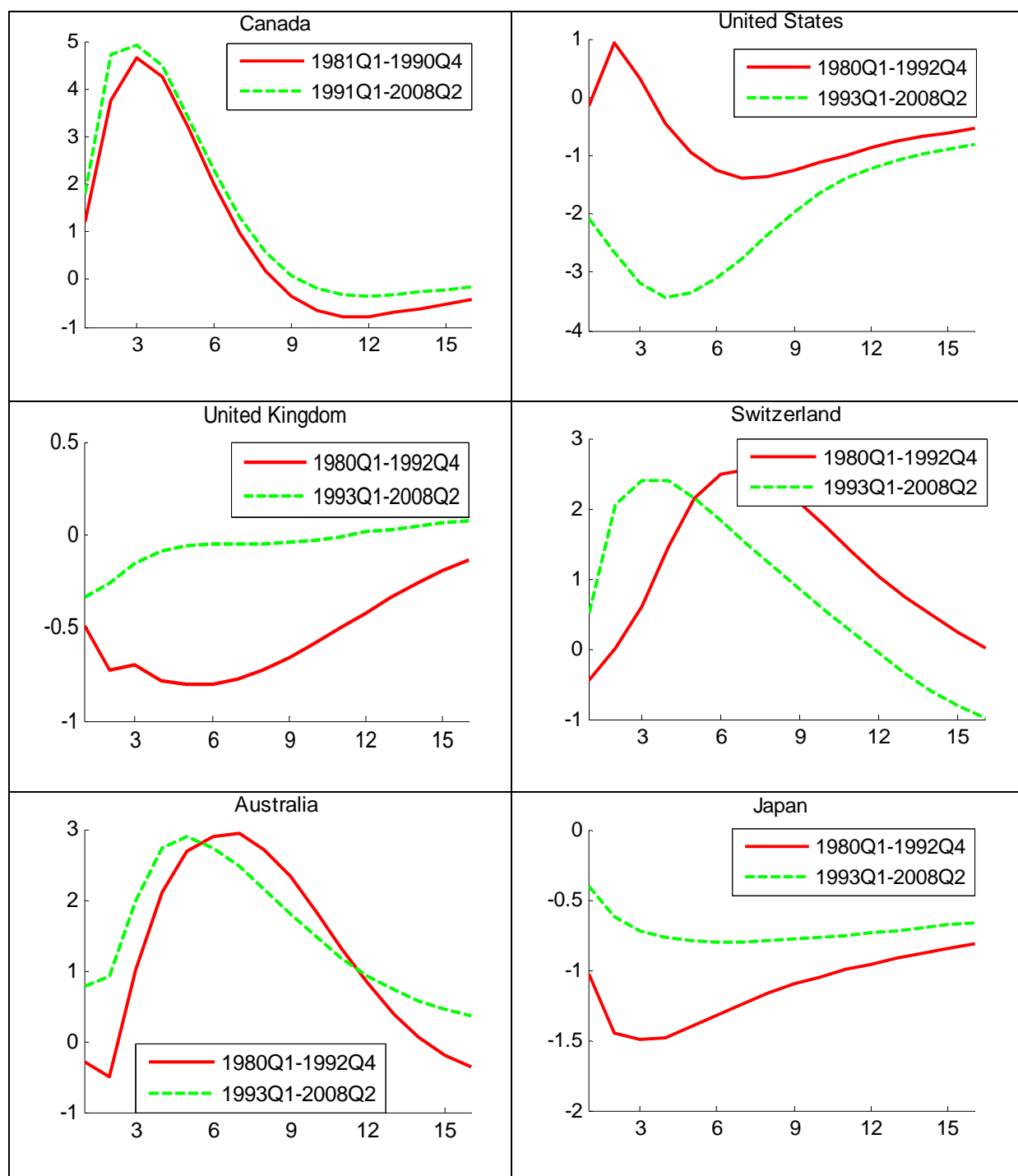
**Figure 1: IRF of the Interest Rate for Explicit Inflation Targeters (the Left Column) and Non- targeters (the Right Column)**



<sup>13</sup> Note that for countries without a legislated inflation target the switch period for the computation of the average responses is set to 1992/1993 following Dotsey (2006).

The results in Figures 1–2 are largely consistent with Conjecture 1. The estimates suggest that after legislating a numerical inflation target the central banks' response to unexpected debt-financed government spending has changed in all three countries considered in the predicted direction of less accommodation or more offsetting.<sup>14</sup>

**Figure 2: Average IRFs of the Interest Rate for a Horizon of 16 Quarters**



<sup>14</sup> This is in line with the results of Kirchner et al. (2010) and Cimadomo (2010) for the euro area.

## 6.2 Discussion of Explicit Inflation Targeters

The left columns of Figures 1 and 2 show the following changes after the formal adoption of the inflation-targeting regime. The Bank of Canada now tends to offset fiscal shocks slightly more aggressively on impact as well as over longer horizons (where it seems to have switched from accommodating to no reaction). Specifically, after an episode of M1 growth targeting (ending in November 1982) and a short period without a specific anchor for monetary policy, in 1988 the Bank of Canada announced price stability to be its new monetary policy goal. This announcement corresponds to the first peak of monetary offsetting of fiscal shocks in Figure 1. Such offsetting further increased in the 1990s after the formal adoption of inflation targeting. This is especially visible around 1998 (the horizon of the second inflation target announced in 1993).

As for the UK, the degree of fiscal shock accommodation by the Bank of England has decreased substantially over time, as Figure 2 shows. Figure 1 then reveals a more nuanced view of what happened. The monetary accommodation of debt-financed government spending shocks observed in the 1980s largely disappeared around the introduction of an explicit inflation target in 1992. Interestingly, this arrangement was not sufficient and accommodation resurfaced until the Bank of England was granted formal independence from the government in 1997. This seems to confirm what many have argued: formal central bank independence is a pre-requisite for an inflation-targeting regime to function effectively (see e.g. Masson et al., 1997).

Turning to Australia, in the 1980s the Reserve Bank of Australia tended to accommodate fiscal shocks on impact and then, after about one year (arguably when the inflationary effects became apparent), the bank would reverse this accommodation by tightening monetary policy. Such (non-forward-looking) responses led to a much greater volatility of the interest rate instrument and were inconsistent with the notion of interest rate smoothing (Woodford, 1999). Figures 1 and 2 show that after the adoption of a numerical inflation target in 1993 there is no more monetary accommodation of debt-financed fiscal shocks on impact. The bank raises rates immediately and keeps increasing them further for another four quarters to offset the effect of such shocks.

## 6.3 Discussion of Non-targeters

In contrast to full-fledged inflation targeters, the central banks in the three considered countries without a legislated inflation commitment (the right column of Figure 1) accommodated on impact both before and after 1992. Since 1992 they have either not changed their responses to debt-financed spending shocks in a major way (Japan and Switzerland), or their policy response has become more accommodative (the United States).

In the U.S., Figure 1 shows that the degree of monetary accommodation of debt-financed fiscal shocks has been increasing through time over all horizons. It is interesting to note the strong monetary offsetting of such shocks in the early 1980s. This reflects the tug-of-war between Chairman Volcker's disinflation efforts and the expansionary fiscal policies of the Reagan administration. This finding is in line with the estimates of Davig and Leeper (2011), who identify this period as an active fiscal and active monetary regime in which debt is on an explosive path. Our estimated U.S. monetary policy responses for other periods also match Davig and Leeper (2011). For example, the period from the early 2000s on can be characterized as passive monetary policy accommodating active fiscal policy.

In the case of Japan, we see monetary accommodation over all horizons throughout the sample. Naturally, its magnitude since the early 1990s has been constrained by the zero lower bound on interest rates, which is reflected in our results even though we did not explicitly account for this bound.

As regards Switzerland, the Swiss National Bank is arguably closer to being an explicit inflation targeter, with an upper bound on medium-term inflation (similar to that of the European Central Bank). This can be seen in our estimates, in that monetary accommodation on impact is smaller (or non-existent) in the second part of the sample, largely due to strong monetary offsetting of fiscal shocks in the period since 1999, in which the bank re-iterated price stability as being an important part of its monetary policy framework. Nevertheless, the impulse responses reveal that the bank has started accommodating shocks in the medium run, suggesting its monetary commitment may be insufficiently explicit.

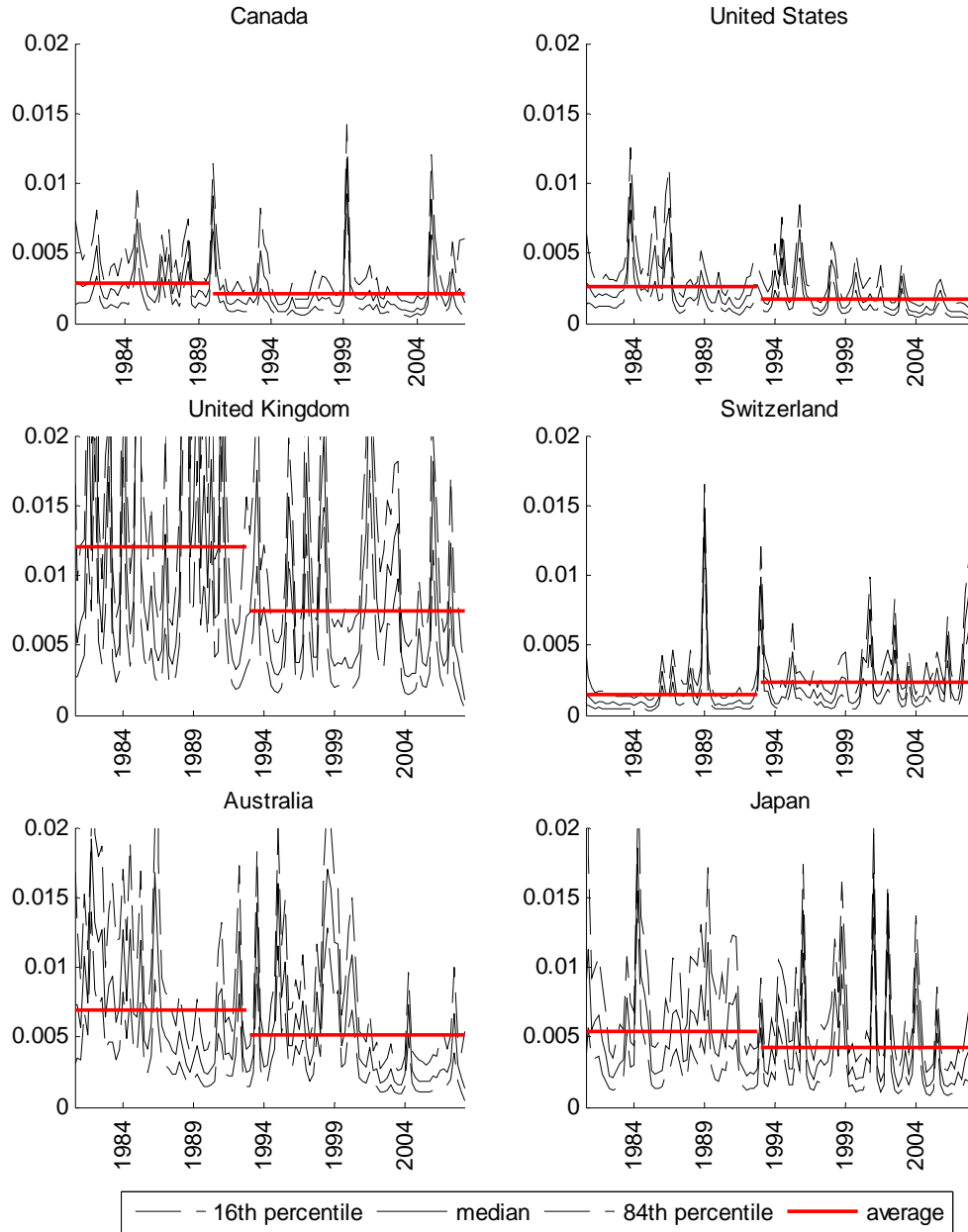
Let us stress that the presented results should be taken as only indicative, not conclusive. As already discussed, the TVP-VARs contain a large number of parameters, and an additional piece of information in the form of priors will not necessarily lead to a substantial decrease in uncertainty. Moreover, the identification based on sign restrictions adds uncertainty related to the structural model underlying the reduced-form VAR. For illustration, Figures E1 and E2 in Appendix E present the effects of a debt-financed spending shock on impact together with the centered 68 percent of the posterior distribution of the response. In general, the posterior distributions for the two periods overlap to a large extent. Nevertheless, for some countries and horizons, the centered 68 percent of the posterior distribution lies above/below the horizontal axis, which suggests changes in the responses. Figure E3 shows credible intervals for the posterior distribution of all IRFs for a given sub-period.

## **7. Results Regarding Conjecture 2**

Conjecture 2 implies that the estimated standard deviations of debt-financed government spending shocks should decrease after a numerical inflation target is legislated. The fact that government spending does not react contemporaneously to the business cycle shocks in our identification approach is an advantage, as it means that the reduced-form residuals in the equation for government spending do *not* capture immediate reactions of government spending to the state of the real economy. Nevertheless, they can represent both an unexpected fiscal shock and an immediate reaction to an unexpected monetary policy shock. Therefore, a decrease in the standard deviation of the reduced-form residuals could be caused not only by a reduction in the frequency/size of debt-financed government spending shocks, but also by a reduction in the response of the fiscal authority to monetary policy actions.

Figure 3 shows the standard deviation of the reduced-form residuals for spending, with the red line indicating the average of the standard deviations median for the two sub-periods. The figure shows – in line with Conjecture 2 – that the standard deviation decreased after the adoption of formal inflation targeting. Nevertheless, reductions in the volatility of spending are present for some of the non-targeters as well, so no clear-cut conclusions can be drawn. Figure E4 in Appendix E captures credible intervals for the posterior distribution of the reduced-form residuals in the equation for government spending over a given sub-period.

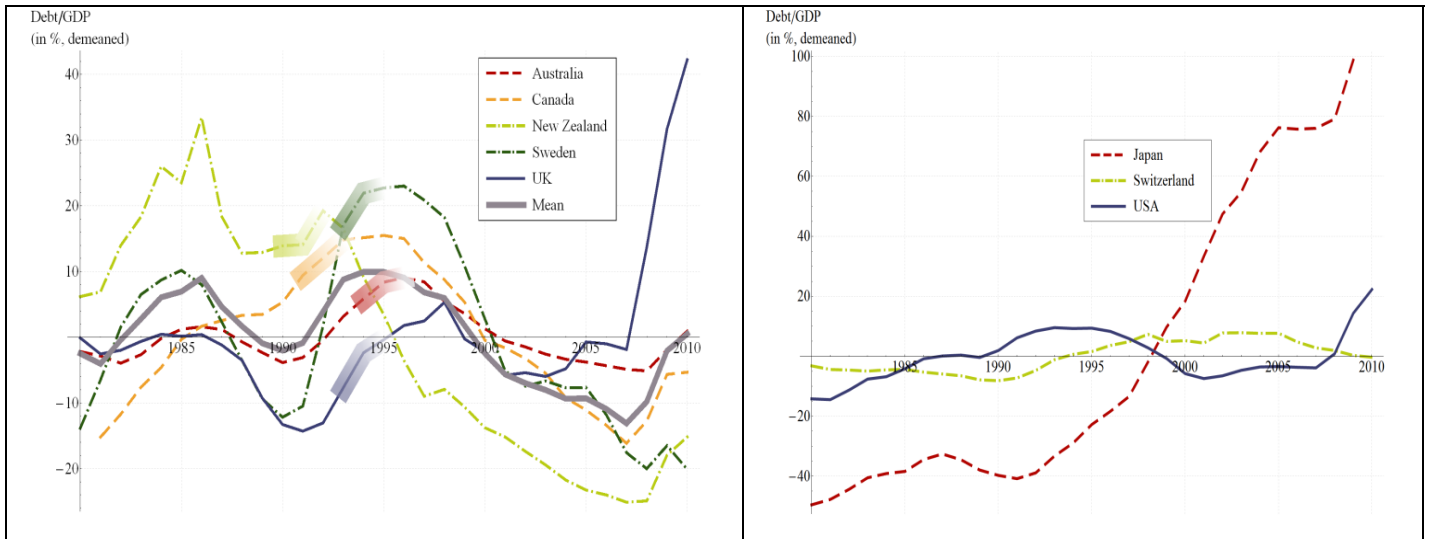
**Figure 3: Estimated Standard Deviations of the Reduced-form Residuals for Government Spending**



Therefore, in order to get an indication of whether the reductions in the volatility of fiscal shocks are linked to the commitment effect of an explicit inflation target, Figure 4 plots the central government debt to GDP ratio separately for five early inflation targeters and non-targeters (to better see the trends the series are de-meaned). In all five early targeters, we can see a decrease in government debt starting about 1–3 years after the formal adoption of an explicit inflation target (in the case of the UK after the subsequent granting of central bank instrument independence discussed above). These improvements are sustained at least until the global financial crisis. In

contrast, such improvements in the fiscal balance are not present for the non-targeters. A similar picture emerges if we plot the (primary) deficit to GDP ratio.

**Figure 4: Central Government Debt (De-meaned) to GDP for Explicit Inflation Targeters (the Left Panel, where the Start of the Regime Is Indicated by the Shaded Region) and Non-targeters (the Right Panel)**



It should be emphasized, however, that this and the negative correlation of monetary commitment and fiscal rigidity reported in Figure A1 do not constitute evidence of causality. It is plausible that both the introduction of inflation targeting and the improvement of fiscal policy were driven by a common factor. Narrative evidence shows this to be the case for Canada, where fiscal sustainability became the number one policy issue for the public at the time see Mauro (2011). But the New Zealand experience tells a different story. As the former governor of the Reserve Bank of New Zealand Don Brash (2011) argues: ‘I have not the slightest doubt that having legislation which requires government and central bank to formally agree, and disclose to the public, the inflation rate which the central bank must target has a most useful role in creating strong incentives for good fiscal policy.’<sup>15</sup>

Importantly, the fact that fiscal outcomes *continued* to be well behaved in the inflation-targeting countries considered long after the original fiscally responsible governments left office provides some anecdotal evidence for the ‘disciplining effect’ of an explicit monetary commitment over fiscal policy.

## 8. Notes on Anticipation Effects and Some Robustness Issues

In this section we briefly discuss the anticipation effects of fiscal policy shocks in relation to our modeling approach and then touch on several robustness issues of the estimation. Government spending shocks are often anticipated by agents because of implementation and legislative lags.

<sup>15</sup> For additional real world examples see the discussion in Brash (2011b).

Anticipation effects can be related to the timing of a spending shock (Ramey, 2011), or the way future fiscal adjustment will be carried out (Leeper et al., 2010).

The identification approach used in this paper can deal with the first type of anticipation effects similarly to Mountford and Uhlig (2009), who account for ‘announcement effects’ by imposing a positive sign on a fiscal variable after four quarters. For the first four quarters, the fiscal variable is assumed to be inert and the prescribed signs of other responses do not change. Using U.S. data, Martens and Ravn (2010) demonstrate that the anticipation effects of spending shocks do not affect the sign of the output reaction. Therefore, our identification approach is not affected by the presence of such anticipation effects.

The latter type of anticipation effects – agents’ expectations of the way current fiscal shortfalls are reversed by the future fiscal-monetary mix – could possibly be an issue for our identification strategy. This would be the case if different expected ways of fiscal adjustment affected the real economy differently and satisfied the same set of identification restrictions. Nevertheless, in our analysis the problem is partially mitigated by the fact that our focus is strictly on debt-financed spending. An additional insight in this regard can be taken from the robustness exercise on the length of the imposed magnitude restrictions. For the U.S., a change in the number of quarters for which the magnitude restriction is imposed affects the magnitude and profile of the impulse responses only marginally.

Another robustness exercise suggests that the length of the sign restrictions to some extent affects the magnitudes of the responses. Similarly to Primiceri (2005) we find the results to be robust to the choice of priors for the variance of initial states. We also find that our prior belief for the parameter  $U$ , which drives how much coefficients can differ between adjacent periods, significantly influences the posterior variation of the coefficients and thus the resulting impulse responses. Nevertheless, our prior belief reflected by the parameter is that changes in the economy/coefficients are gradual.

## 9. Summary and Conclusions

It is uncontroversial that monetary and fiscal policies are inter-related even if the central bank is formally independent of the government. This is because the actions of each policy affect many important economic variables (including private expectations of the future), and these variables in turn affect the actions of both policies. That the institutional design of each policy affects the incentives and outcomes of that policy is also uncontroversial. But could it be that the design affects the behavior and outcomes of the *other* policy in a major way? If so, how?

This paper attempts to track monetary-fiscal interactions over time and across several advanced countries in order to contribute to our understanding of the inter-relation of the two policies and offer some tentative answers to these questions. It does so using a novel empirical framework that combines time-varying parameter vector autoregression with the sign restrictions identification procedure.

Having first discussed the advantages of this framework vis-à-vis the standard fixed parameter VARs and/or the recursive identification method, we then report how monetary policy responses

to debt-financed government spending shocks have changed in countries that legislated a commitment to a numerical target for average inflation. Specifically, inflation-targeting central banks generally stopped accommodative monetary policy and started offsetting debt-financed fiscal shocks by raising interest rates. No comparable change can be found in the non-targeters.

Interestingly, we find some (albeit weak and indirect) evidence that the disciplining effects of a legislated monetary commitment may have spilled over to fiscal policy too. The adoption of inflation targeting was associated with a decrease in the variability of fiscal shocks, and, with a 1–3 year lag, is followed by a general improvement in the fiscal position (sustained debt reductions). This could be because the threat of a tug-of-war with a committed central bank reduced the government's incentives to pursue excessive fiscal policy and avoid necessary fiscal reforms.

While our empirical results should be taken as only suggestive rather than conclusive, they indicate that an institutional reform of *each* policy may perhaps have positive effects on the outcomes of *both* policies. More research is required to shed light on the robustness of our findings and the many specific channels through which monetary and fiscal policies affect each other. This is of particular importance in the current situation of high economic uncertainty following the Great Recession and of a large fiscal gap facing advanced countries.



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## Appendix A: The Theory Behind Strategic Monetary-Fiscal Interactions

The seminal analyses of Sargent and Wallace (1981) and Leeper (1991) point in the direction of *strategic* interactions between monetary and fiscal policy. Using game theoretic methods, their gist can be presented in the payoff matrix below. Let us stress that this represents a structural (i.e., cycle-free) situation: the economy is performing at potential, it is *not* at a cyclical swing requiring specific (stimulatory) actions.

		Fiscal policymaker	
		Debt-financed Spending (active)	Tax-financed Spending (passive)
Monetary policymaker	Not Accommodate (active)	$a, w$	$b, x$
	Accommodate (passive)	$c, y$	$d, z$

The variables  $\{a, b, c, d, w, x, y, z\}$  denote the policymakers' payoffs, which are functions of the structure of the economy, policy preferences, the behavior of expectations, etc. Roughly speaking, Leeper's (1991) passive policies adjust to balance the intertemporal budget constraint of the government. Specifically, an increase in government spending is accompanied by an increase in (current or future) taxes under passive fiscal policy, and higher (current or future) inflation – via lower interest rates and debt monetization – under passive monetary policy. In contrast, active policies largely ignore the budget constraint to focus on other policy goals. Spending is financed by debt creation under active fiscal policy, whereas active monetary policy focuses on achieving low inflation.

The payoff matrix makes it transparent that, unless  $a=c$ , the central bank's (intended/actual) responses affect the payoffs of the government and hence potentially its decision regarding the medium-run fiscal stance. A number of papers, starting with Sargent and Wallace (1981), imply that in the presence of a fiscal gap the policy interaction can best be modeled as a game of chicken where the payoffs satisfy:  $a > d > \max\{b, c\}$  and  $z > w > \max\{x, y\}$ .<sup>16</sup> In such case the game has two pure strategy Nash equilibria: (active monetary, passive fiscal) and (passive monetary, active fiscal), alternatively called the Ricardian and non-Ricardian regimes. The fact that the former is preferred by the central bank and the latter by the government implies that there is a policy conflict. In addition, the fact that both pure Nash equilibria are Pareto superior to the mixed Nash equilibrium implies a coordination problem between the policies.

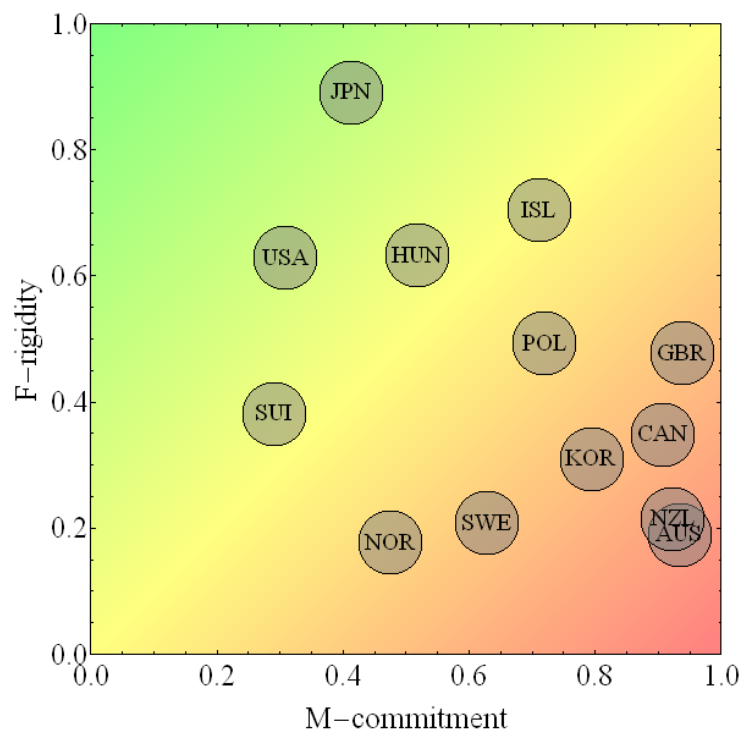
Given that neither standard nor evolutionary game theory can select between pure Nash equilibria, researchers have commonly applied Stackelberg leadership to the game. The leader in the game (the dominant policy) ensures its preferred pure Nash by being able to force the follower to coordinate. Libich et al. (2012) generalize the timing of the policy moves to allow for arbitrary (stochastic or deterministic) policy revisions that can capture institutional features such as monetary commitment and fiscal rigidity. Effectively, their framework converts the standard

<sup>16</sup> Let us stress again that the payoff relationships, and hence the class of game, would be different in a cyclical downturn such as the global financial crisis, in which stimulatory actions (passive monetary and or active fiscal policy) are likely to be required.

Stackelberg leadership concept from static to dynamic. Their analysis refines the standard conclusion that the leader in the game always ensures its preferred Nash equilibrium by showing that this depends on a number of economic and policy variables. Nevertheless, the result that under reasonable circumstances the central bank's commitment reduces monetary accommodation of fiscal shocks and the government's incentive to accumulate debt and avoid fiscal reforms still obtains.

The paper then uses twelve existing measures in the literature to quantify indices of long-term monetary commitment and fiscal rigidity for high-income countries, see Figure A1.<sup>17</sup>

**Figure A1: Long-term Monetary Commitment Versus Fiscal Rigidity Indices from Libich et al. (2012)**



The probability of inflationary fiscal spillovers decreases as countries move from the top left corner to the bottom right corner of Figure A1.

## Appendix B: Gibbs Sampler

The specification of the sampling algorithm and the parameters of the prior distributions mostly follows Primiceri (2005), Cogley and Sargent (2005), Kirchner et al. (2010), and Pereira and Lopes (2010).

<sup>17</sup> The paper does not provide monetary commitment values for the euro area countries as they do not have autonomous monetary policy.

## B1. Priors

The prior distribution of the initial states  $(\alpha_{i,0}, \beta_{i,0}, \log(\sigma_{i,0}))$  is normal with means given by corresponding OLS estimates on the whole data sample. The assumed prior variances are proportional to the estimated OLS variances for the coefficients and to the identity matrix for the volatility states:

$$\beta_{i,0} \sim N(\beta_{i,0}^{OLS}, 4\text{Var}(\beta_i^{OLS})),$$

$$\alpha_{i,0} \sim N(\alpha_{i,0}^{OLS}, 4\text{Var}(\alpha_i^{OLS})),$$

$$\log(\sigma_{i,0}) \sim N(\log(\sigma_i^{OLS}), 10I_5).$$

The hyperparameter  $U$  and blocks of  $V$  are distributed as an inverse-Wishart distribution:

$$U \sim IW(k_Q^2 \tau \text{Var}(\beta^{OLS}), \tau),$$

$$V_{bl} \sim IW(k_V^2 (1 + \dim(V_{bl})) \text{Var}(A_{bl}^{OLS}), 1 + \dim(V_{bl})), \quad bl = 1, \dots, 4,$$

where  $k_Q = 0.01$  and  $k_V = 0.1$ . These parameters represent our prior belief on the proportion of uncertainty of the OLS estimate attributed to time-variation of the VAR coefficients and elements of the matrix  $A$ . The degrees of freedom parameter  $\tau$  is 50. The diagonal elements of  $W$  are distributed as inverse-Gamma (Kirchner et al., 2010):

$$W_i = IG\left(\frac{k_w^2}{2}, \frac{1}{2}\right), \quad \text{where } k_w = 0.01.$$

## B2. Estimation Procedure

The Gibbs sampler exploits the fact that draws from the conditional distributions of subsets of the model parameters (given the rest of the parameter set) represent a sample from the joint posterior distribution. So, the sampler can be described in several steps:

The vector of coefficient states  $\beta$  is estimated using the Carter and Kohn (1994) algorithm. For the given data and history of the covariance and volatility states, equation (1) and (2) represent a linear Gaussian system with a known covariance matrix.

The covariance states stacked in matrix  $A_t$  are also estimated employing the algorithm of Carter and Kohn (1994). Equation (1) implies that

$$\hat{y}_t = A_t(y_t - X_t \beta_t) = \Sigma_t \varepsilon_t, \quad (\text{A1})$$

i.e., given the data and the history of the coefficient and volatility states we again obtain a linear Gaussian system. The algorithm is applied equation by equation i.e., it yields draws of the covariance states stacked below the diagonal of  $A_t$  in turns.

To draw the volatility states we follow Cogley and Sargent (2005). Given the data and the history of the coefficient and covariance states, the RHS of (A1) is observable. Assuming diagonality of the hyperparameter  $W$ , the volatility states can be drawn as in Jacquier et al. (1994), i.e., a univariate algorithm is applied on the orthogonalized residuals element by element. Jacquier et al. (1994) describe a Metropolis step that produces a draw (if accepted) from the conditional posterior distribution for a volatility state.

Finally, given the data, coefficient states, and covariance and volatility states, innovations in (2)–(4) are observable. The priors on the hyperparameters are distributed as inverse-Wishart (inverse-Gamma), thus posterior distributions take the same type of distribution and drawing of the hyperparameters is straightforward.

## Appendix C: Convergence Diagnostics

The convergence of the sequence of draws to a posterior distribution is assessed by two measures based on the autocorrelation of draws and by the diagnostics suggested by Raftery and Lewis (1992).<sup>18</sup> The first measure is a simple autocorrelation of draws from conditional posterior distributions at a lag equal to 10. Low autocorrelation suggests efficiency of the sampling algorithm. A more sophisticated measure based on sample autocorrelations takes into account autocorrelations at all possible lags. It is defined as

$$1 + 2 \sum_{k=1}^{\infty} \rho_k ,$$

with  $\rho_k$  denoting the  $k$ -th autocorrelation of the chain of draws and denoted as an inefficiency factor. Primiceri (2005) suggests that values of the inefficiency factor below 20 can be viewed as satisfactory. Finally, Raftery and Lewis (1992) introduced a statistic that provides the number of draws ensuring a certain level of precision.<sup>19</sup>

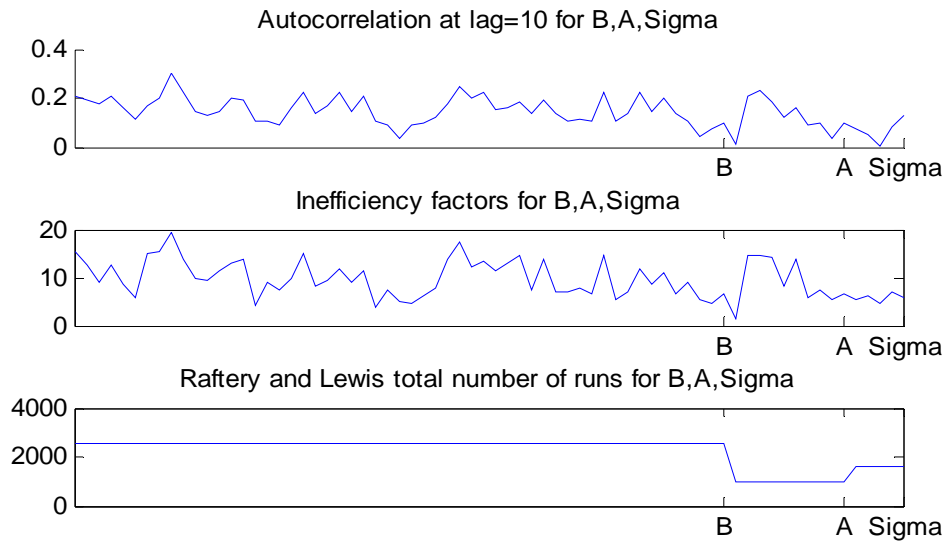
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<sup>18</sup> The same convergence diagnostics as in Primiceri (2005) are presented. The implementation in Matlab draws on Econometric Toolbox discussed in LeSage (1999).

<sup>19</sup> Here, for the 0.025 and 0.975 quantiles of the marginal posterior distributions, the desired accuracy of 0.025 is required to be achieved with probability 0.95.



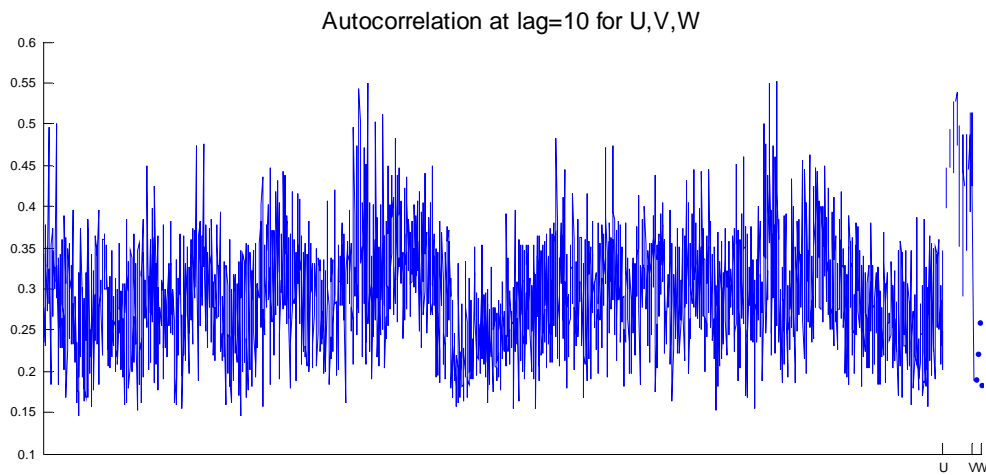
**Figure C1: Autocorrelation, Inefficiency Factors, and the Raftery and Lewis Statistic for the Model Parameters in the Period 1985Q1**

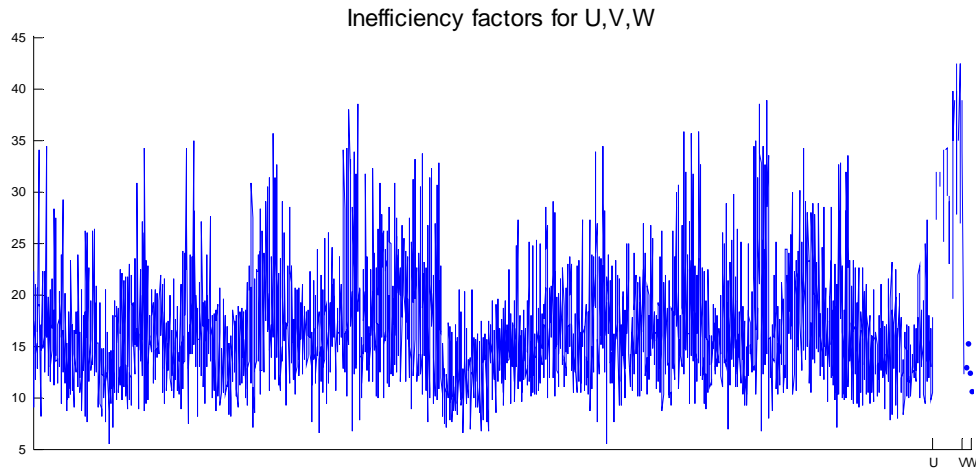
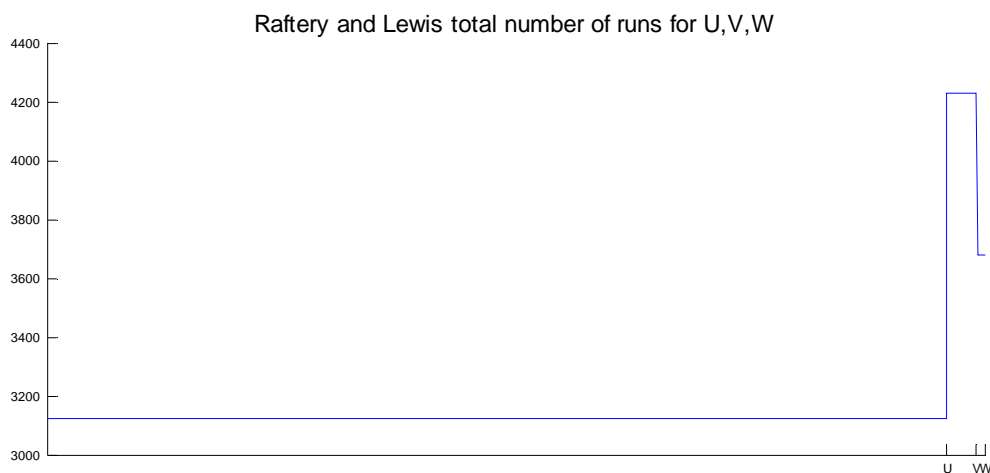


Due to a high number of parameters we present in Figure C1 the convergence diagnostics only for Australia, and only for coefficients related to an arbitrarily chosen period 1985Q1. The statistics presented in Figure C1 suggest sufficient convergence of the Markov chain Monte Carlo algorithm for the parameters: the autocorrelation of the chain is low, the inefficiency factors take values below 20, and the suggested number of runs is lower than 4,000. For other countries the convergence statistics look very similar.

The hyperparameters are reported in Figures C2–C4. The diagnostics for some elements of the hyperparameter vector suggest possible convergence problems. Our primary interest, however, lies in the parameters and thus we do not elaborate on these convergence diagnostics.

**Figure C2: Autocorrelation of the Chain for the Hyperparameters  $U$ ,  $V$ ,  $W$**



**Figure C3: Inefficiency factors for the hyperparameters  $U$ ,  $V$ ,  $W$** **Figure C4: Raftery and Lewis Statistics for the Hyperparameters  $U$ ,  $V$ ,  $W$** 

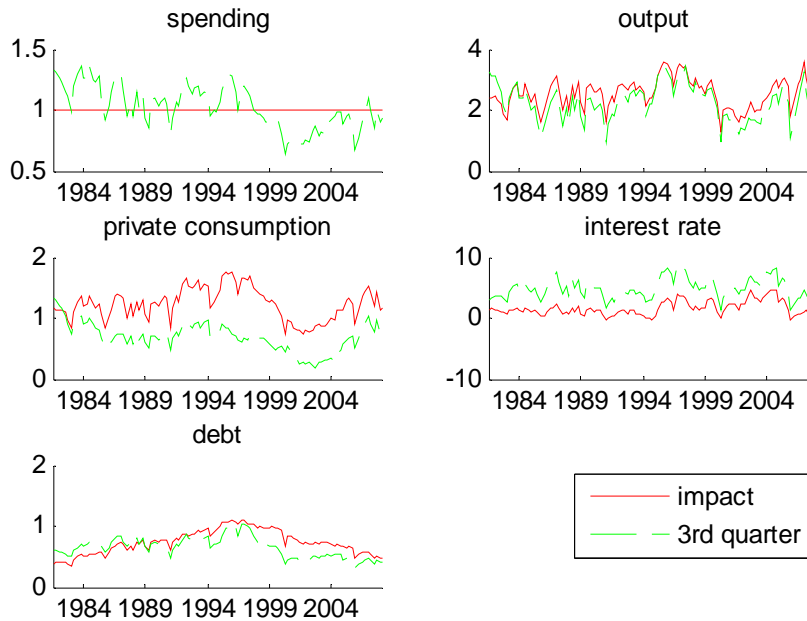
## Appendix D: IRFs for a Debt-financed Government Spending Shock for All Countries and Variables at Two Horizons

As explained above we will leave an in-depth discussion of results not relating to monetary-fiscal policy interactions, primarily the estimated fiscal multipliers, to a separate paper. A selection of the results – namely the impulse responses on impact and in the 3<sup>rd</sup> quarter – appears in Figures D1–D6.

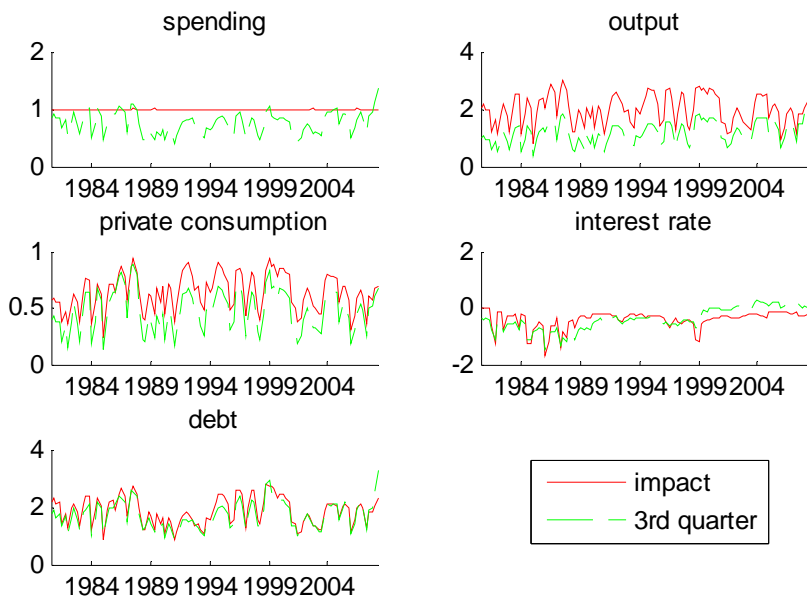
Let us just mention in passing that our output and private consumption multipliers are high compared to the literature (for a survey see e.g. Hall, 2009). This is because existing studies examine the effects of shocks to general government purchases, while we focus on a subset of

such shocks: those financed by debt. It is well established that government spending financed by higher taxes can affect output and private consumption in a different way than spending financed by debt, depending on whether the assumptions underlying Ricardian equivalence hold. In particular, if economic agents are myopic and/or credit constrained, debt-financed spending tends to have a larger stimulatory effect than tax-financed spending.

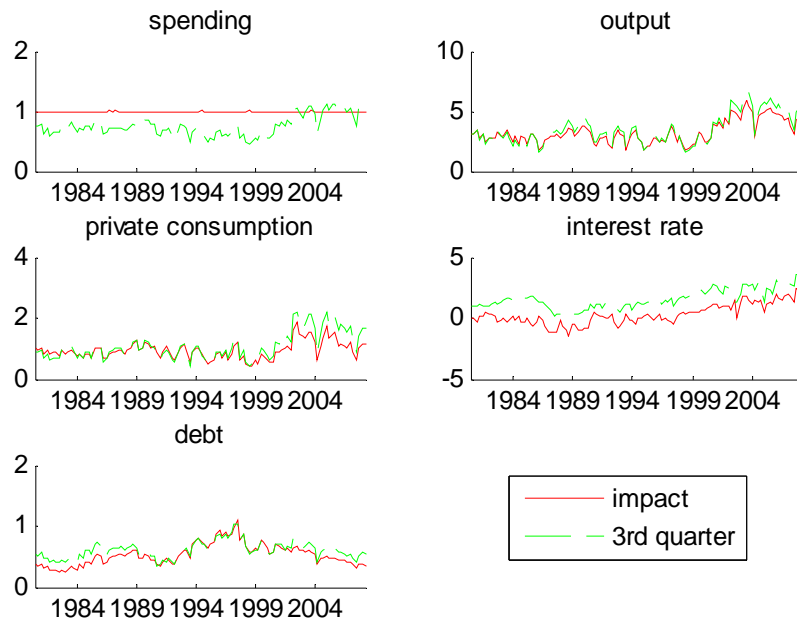
**Figure D1: Canada: IRF on Impact and in the 3<sup>rd</sup> Quarter**



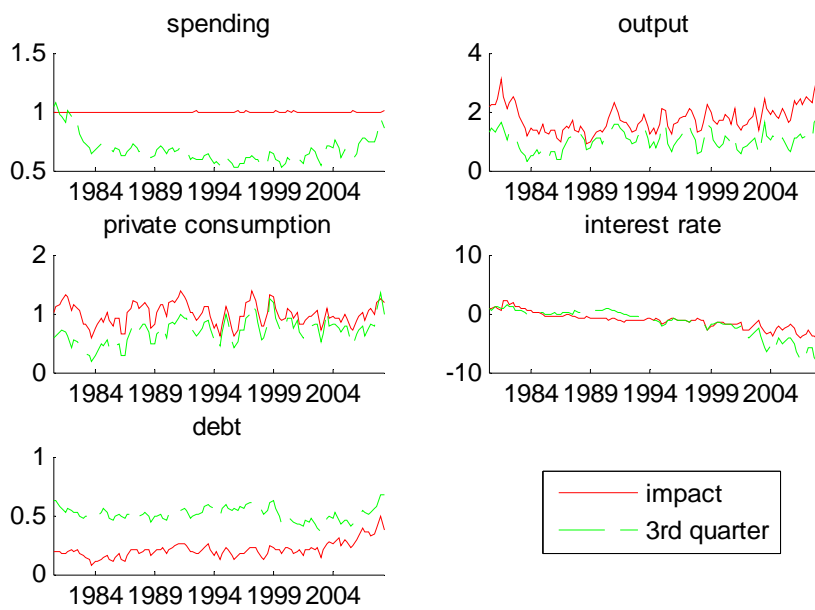
**Figure D2: The UK: IRF on Impact and in the 3rd Quarter**

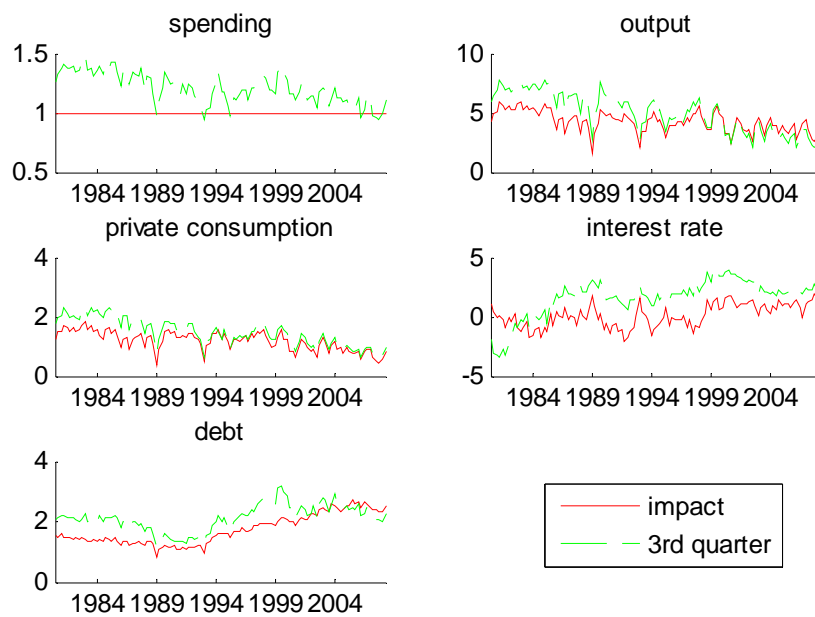
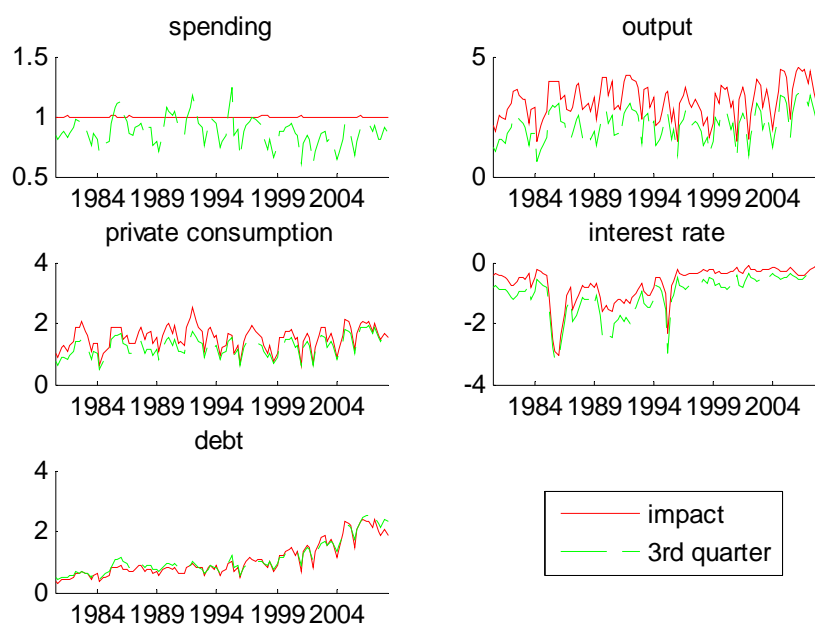


**Figure D3: Australia: IRF on Impact and in the 3rd Quarter**



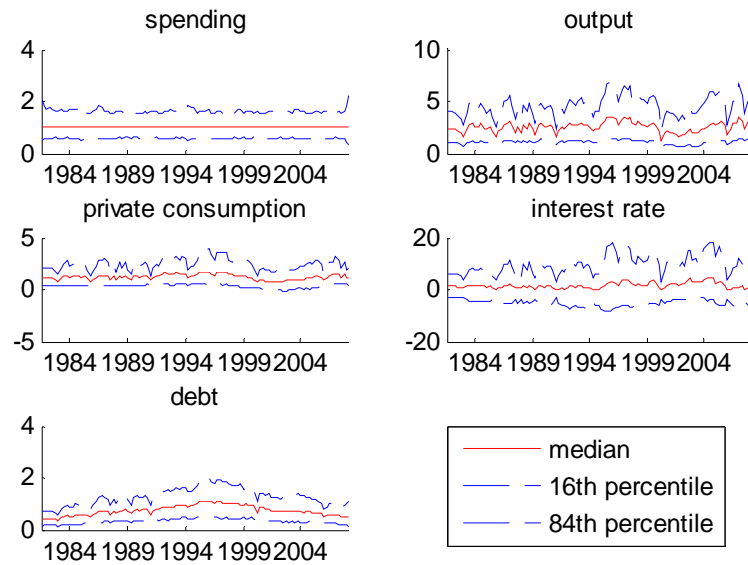
**Figure D4: The U.S.: IRF on Impact and in the 3<sup>rd</sup> Quarter**



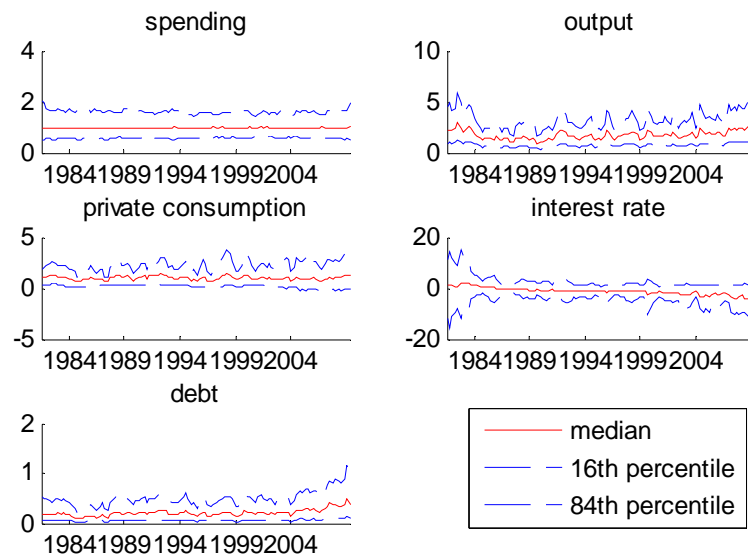
**Figure D5: Switzerland: IRF on Impact and in the 3rd Quarter****Figure D6: Japan: IRF on Impact and in the 3rd Quarter**

## Appendix E: Illustration of the Estimates' 'Uncertainty'

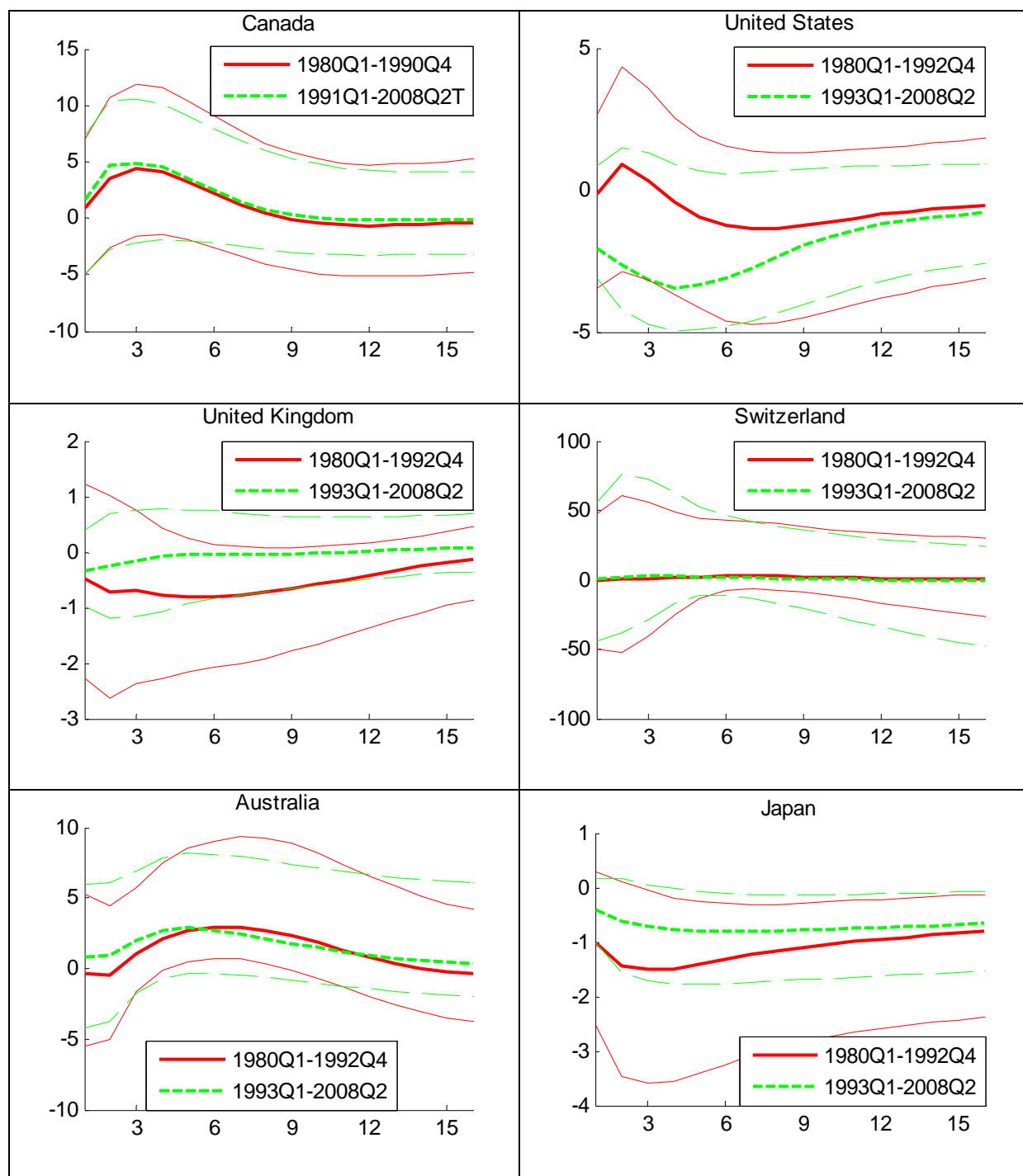
*Figure E1: Canada: IRF on Impact with the Centered 68 Percent of the Posterior Distribution*



*Figure E2: The U.S.: IRF on Impact with the Centered 68 Percent of the Posterior Distribution*



**Figure E3: Median IRFs of the Interest Rate over a Horizon of 16 Quarters with the Centered 68 Percent of the Posterior Distribution of All IRFs in a Given Sub-period**



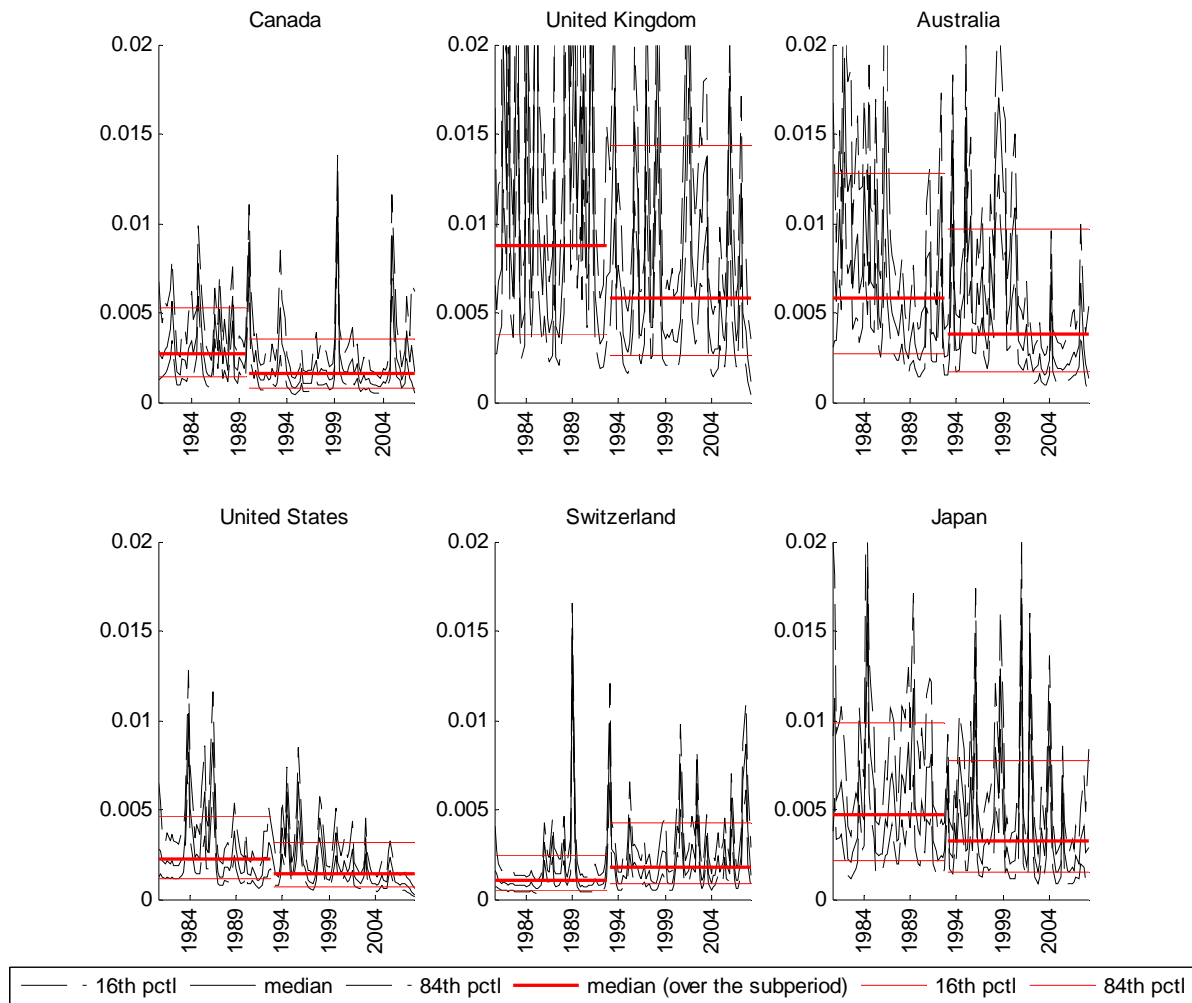
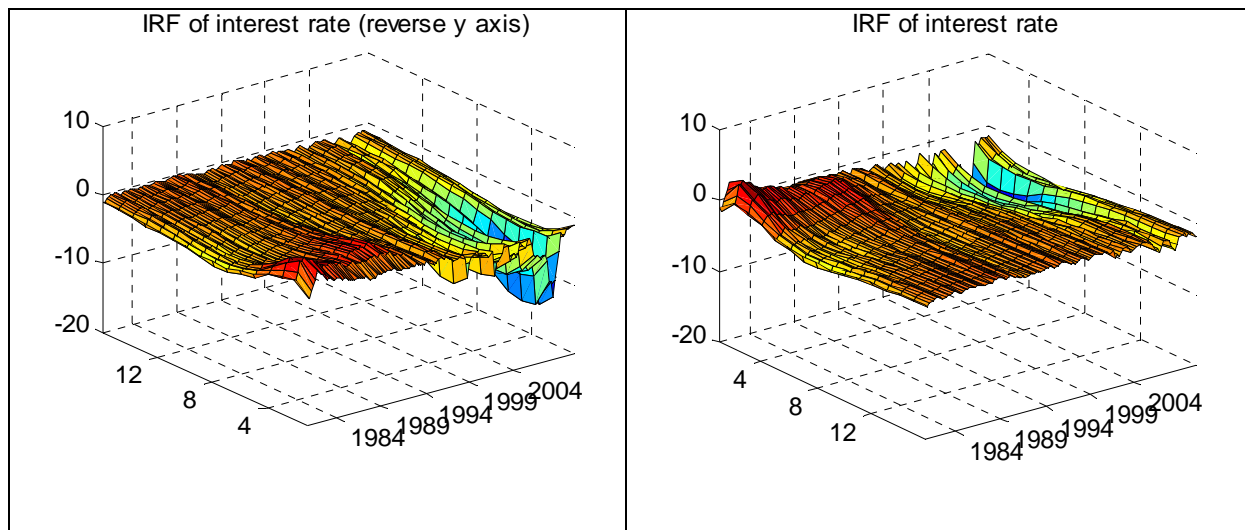
**Figure E4: Estimated Standard Deviations of the Reduced-form Residuals for Government Spending****Appendix F: Inclusion of the Global Financial Crisis**

Figure F1 presents estimation results for the U.S. based on an extended dataset (1980Q1–2010Q4) for reasons discussed in the main text. Comparing it with the benchmark results in Figure 1, especially the scale on the vertical axis, makes clear that the inclusion of the recent financial crisis is costly in terms of loss of insight. Nevertheless, while this large shock overshadows some of the phenomena discussed in the main text, the fact that U.S. monetary policy has become more accommodative of debt-financed fiscal shocks over time is still apparent.



**Figure F1: Selected Impulse Responses for the U.S. Estimated on the Full Sample (1980Q1–2010Q4)**



## Appendix G – Data Sources

	Government spending	Output	Private consumption	Interest rate
AUS	General government; Final consumption expenditure; PLUS General government; Gross fixed capital formation; Australian Bureau of Statistics	Gross Domestic Product  Australian Bureau of Statistics	Households; Final consumption expenditure  Australian Bureau of Statistics	13-WEEK TREASURY BILLS  IMF IFS
CAN	Government final consumption expenditure PLUS Gross Fixed Capital Formation: General government OECD QNA	Gross Domestic Product  IMF IFS	Household Consumption Expenditure incl NPISHs  IMF IFS	TREASURY BILL RATE  IMF IFS
CH	Government Consumption Expend. Sa PLUS Government gross fixed capital formation (yearly) IMF IFS and OEO: Economic Outlook (OECD)	Gross Domestic Product Sa  IMF IFS	Househ.cons.expend.,incl.npishs  IMF IFS	TREASURY BILL RATE  IMF IFS
JAP	Government Consumption Expend. Sa PLUS Gross fixed capital formation: General government IMF IFS and OECD QNA	Gross Domestic Product Sa  IMF IFS	Househ.cons.expend.,incl.npishs  IMF IFS	Call rate (Bank of Japan) adjusted before 1985 as in Miyao (2005).
UK	Central Gov: Current expenditure: Total payable MINUS Central Gov: Current expenditure: Net Social Benefits payable Office for National Statistics	Gross Domestic Product at market prices: Current price: sa Office for National Statistics	Household final consumption expenditure: National concept CP SA Office for National Statistics	TREASURY BILL RATE  IMF IFS
US	Government consumption expenditures and gross investment NIPA Table Bureau of Economic Analysis	Gross domestic product NIPA Table Bureau of Economic Analysis	Personal consumption expenditures NIPA Table Bureau of Economic Analysis	Federal Funds Rate  IMF IFS

General: Population and CPI are taken from IMF IFS. Total central government debt is taken from OECD Statistics.

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