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Fiscal Adjustments and Debt-Dependent Multipliers: Evidence from the U.S. Time Series

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Abstract

Using sign restrictions within a time-varying parameter vector autoregressive (TVP-VAR) framework, we provide new time-series evidence of debt-dependent multipliers for the U.S. while simultaneously obtaining larger multipliers during recessions in line with previous studies. The Ricardian channel where households reduce consumption expecting larger fiscal adjustments is shown to be relevant for the debt-dependent multipliers. The TVP-VAR framework also allows us to observe changes in the magnitude of fiscal adjustments. We find that the larger fiscal adjustments in the presence of rising indebtedness is the major driving force behind the smaller multipliers in the post-Volcker period rather than debt accumulation itself.

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Keywords: Bayesian VARs; Time-varying parameters; Fiscal multipliers; Fiscal policy.

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1 Introduction

The past decade has witnessed increased attention to the size of government spending multipliers and their heterogeneities over time and across countries. Investigating sources of heterogeneity in multipliers across countries, the literature has provided ample evidence that government spending multipliers are large in countries with low public debt (e.g., Ilzetzki, Mendoza and Végh (2013); Nickel and Tudyka (2014); Huidrom et al. (2020)). The role of public debt in affecting the size of multipliers has also become a very relevant issue for the United States. As illustrated in Figure 1, the public debt-to-GDP ratio in the U.S. has been on an upward trajectory since the 1980s. After the Global Financial Crisis, it has soared to the level above the thresholds used to define high-debt countries in previous studies.

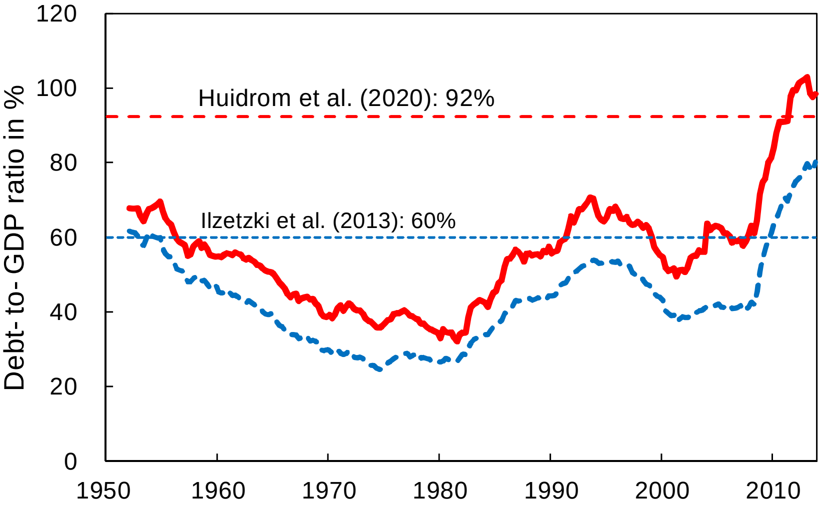

FIG. 1. U.S. debt-to-GDP ratio. *Notes:* The red solid line and the blue dashed line represent the debt-to-GDP ratio of general government and that of federal government, respectively. The horizontal lines indicate the threshold debt-to-GDP ratios used to define high-debt countries in Huidrom et al. (2020) and Ilzetzki, Mendoza and Végh (2013). The thresholds used in Huidrom et al. (2020) and Ilzetzki, Mendoza and Végh (2013) are those for general government and federal government, respectively.

However, public debt dependency of government spending multipliers in the U.S. time-series data has been somewhat neglected in the literature. Although time variation in the U.S. multipliers is an area of active research, existing studies have focused on its state-dependent nature across business cycles relying on a regime switching framework. The growing body of empirical evidence suggests that multipliers are larger in recessions than in expansions (e.g., Auerbach and Gorodnichenko (2012); Bachmann and Sims (2012); Candelon and Lieb (2013); Caggiano et al. (2015)).[1] In a similar vein, Bernardini and Peersman (2018) find larger multipliers in periods of private debt overhang while considering public debt as a control variable.

Whereas theoretical literature highlights the importance of policy regimes in affecting the size of multipliers, there has been relatively limited empirical evidence from the U.S. time series with a few exceptions. Bilbiie, Meier and Müller (2008) find smaller multipliers in the post-1980 period than in the preceding period and attribute the cause to changes in the conduct of monetary policy after Volcker's appointment as Fed Chairman.[2] Ramey and Zubairy (2018) report rather mixed results on the size of multipliers when monetary policy is constrained by the zero lower bound.[3] Leeper, Traum and Walker (2017) demonstrate that monetary-fiscal policy regime is the dominant factor in determining the size of multipliers, but they do not provide evidence of time variation in multipliers across different regimes.[4]

The nexus between public debt and fiscal policy effects has been studied since Giavazzi and Pagano (1990) found cases of expansionary fiscal adjustments from Danish and Irish experiences in the 1980s.[5] The transmission where households reduce consumption in anticipation of future fiscal adjustments has been examined in the following literature (e.g., Blanchard (1990); Sutherland (1997); Perotti (1999)). Huidrom et al. (2020) call the transmission a *Ricardian channel* and consider the channel as the underlying cause of the debt-dependent multipliers.

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[1] Studies that consider data from a panel of countries also find business cycle dependency of multipliers (e.g., Auerbach and Gorodnichenko (2013); Riera-Crichton, Vegh and Vuletin (2015)). For its theoretical account, see Michaillat (2014), Canzoneri et al. (2016), and Shen and Yang (2018). In contrast, Ramey and Zubairy (2018) find little evidence of business cycle-dependent multipliers from their U.S. historical data.

[2] Bilbiie, Meier and Müller (2008) also suggest that smaller multipliers in the post-Volcker period can be attributed to increased asset market participation as well as the more active monetary policy of the period. In theory, asset market participation allows households to save or borrow to smooth their consumption in anticipation of future fiscal adjustments. Therefore, its increase could also represent strengthening of the *Ricardian channel* where households reduce consumption expecting larger fiscal adjustments.

[3] Theoretical literature predicts large multipliers when interest rates are at the zero lower bound (e.g., Woodford (2011); Christiano, Eichenbaum and Rebelo (2011)).

[4] Leeper, Traum and Walker (2017) calculate multipliers based on estimated DSGE models under different policy regimes. Although multipliers are shown to be larger in regime F (active fiscal policy coupled with passive monetary policy) than in regime M (active monetary policy coupled with passive fiscal policy) in general, they do not find significant difference between the log marginal data densities for the two regimes. They only report modest time variation in multipliers in regime M. In contrast, Traum and Yang (2011) report that regime F is never favored by the post-war U.S. data.

[5] The literature on the expansionary effects of fiscal adjustments ('expansionary austerity hypothesis') remains divided (e.g., Alesina, Favero and Giavazzi (2019); House, Proebsting and Tesar (2020)).

On the other hand, the empirical literature investigating the size of U.S. multiplier documents the importance of capturing dynamics of fiscal adjustments (e.g., Chung and Leeper (2007); Favero and Giavazzi (2012); Corsetti, Meier and Müller (2012)). Bohn (1998) finds a positive correlation between the magnitude of fiscal adjustments and the debt-to-GDP ratio in providing evidence of the government's reaction to debt accumulation. In search of theoretical grounds for debt-dependent multipliers, Bi, Shen and Yang (2016) show that larger magnitude of fiscal adjustments induces stronger negative effects on consumption, thus leading to smaller multipliers when debt levels are high.

Against this background, this paper aims to provide time-series evidence of debt-dependent multipliers from the U.S. data and to investigate the transmission paying particular attention to the role of fiscal adjustments. For these purposes, we employ a time-varying parameter vector autoregressive (TVP-VAR) model with stochastic volatility developed by Primiceri (2005), in which time-varying contemporaneous relations among variables are assumed. Unlike regime-switching models widely used in the previous literature, the TVP-VAR model allows the parameters to vary continuously over time in a stochastic manner and, hence, is suitable for capturing permanent and gradual changes in the transmission mechanism.[6] Therefore, the model may well describe possible changes in household behavior and those in the magnitude of fiscal adjustments. Although rapid changes in the economic state are difficult to capture within the model, we consider them with the assistance of sign restrictions following Canova and Pappa (2011).[7] Together with the assumption of time-varying contemporaneous relations among variables, we identify government spending shocks during recessions and expansions by imposing additional sign restrictions in accordance with the phases of the business cycle on a period-by-period basis. The method allows us to simultaneously find both cyclical and

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[6] Primiceri (2005) provides a succinct discussion of the advantages and disadvantages of TVP-VAR models over regime-switching models.

[7] Auerbach and Gorodnichenko (2012) discuss the disadvantage of a TVP-VAR model in capturing the state of the business cycle.

structural variations in multipliers within a single TVP-VAR framework.[8]

The analysis provides evidence of two heterogeneities in multipliers: larger multipliers in recessions than in expansions and smaller ones in the post-Volcker period than in the preceding period. A negative correlation between government spending multipliers and public debt is also presented. We then examine the underlying cause of the decline in multipliers in the post-Volcker period by augmenting the baseline model with interest rate and private consumption. Comparing the results with those of the baseline model confirms the relevance of the Ricardian channel. By applying our TVP-VAR framework to the bivariate VAR methodology of Canzoneri, Cumby and Diba (2001) and Canzoneri, Cumby and Diba (2011), we further show that the magnitude of fiscal adjustments was increased during most of the post-Volcker period. The Granger causality test among the debt-to-GDP ratio, the magnitude of fiscal adjustments, and the size of multiplier suggests that the increased magnitude of fiscal adjustments in the presence of rising indebtedness was the major driving force for the decline in multipliers.

The paper most closely related to ours is Kirchner, Cimadomo and Hauptmeier (2010), which is the only study that we are aware of which explore the debt dependency of government spending multipliers based on time-series data.[9] By conducting regression analysis on the multipliers calculated from their estimated TVP-VAR model for the Euro area and possible explanatory factors, they conclude that an increase in debt-to-GDP ratio has a negative impact on the multipliers. Our study differs from them in that we consider the business cycle dependency of multipliers aside from the debt dependency with the assistance of sign restriction identification. Furthermore, while Kirchner, Cimadomo and Hauptmeier (2010) focus on the relationship between multipliers and debt-to-GDP ratio, this paper addresses that the Ricardian channel operates in response to the increased magnitude of fiscal adjustments rather than debt

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[8] Bi, Shen and Yang (2016) address the difficulty in isolating the debt-dependent government spending effects based on structural VAR estimations because of various interrelated state variables.

[9] Application of TVP-VAR framework to fiscal policy analysis has been relatively limited when comparing it with that to monetary policy. Although there has been a growing interest in applying the TVP-VAR framework to fiscal policy analysis, those studies, such as Rafiq (2012), Pereira and Lopes (2014), and Glocker, Sestieri and Towbin (2019), focus on capturing time-varying effects of fiscal policy rather than investigating their transmission using data from Japan, the U.S., and the U.K., respectively.

accumulation itself.

The remainder of this paper is organized as follows. Section 2 discusses the empirical methodology. Section 3 reports the results. Section 4 investigates the underlying transmission mechanism of the debt-dependent multipliers. Section 5 concludes.

2 Empirical methodology

2.1 A VAR model with time-varying parameters and stochastic volatility

We consider the following VAR (p) model with time-varying parameters and stochastic volatility:

$$y_t = B_{1,t} y_{t-1} + \cdots + B_{p,t} y_{t-p} + u_t, \tag{2.1}$$

for $t = p+1, ..., T$, where y_t is a $k \times 1$ vector of observed variables and $B_{i,t}$, $i = 1, ...p$, are $k \times k$ matrices of time-varying coefficients. The u_t is a $k \times 1$ vector of heteroskedastic shocks that are assumed to be normally distributed with a zero mean and a time-varying covariance matrix, Ω_t. Following established practice, we decompose u_t as $u_t = A_t^{-1} \Sigma_t \varepsilon_t$, where

$$A_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ a_{21,t} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ a_{k1,t} & \cdots & a_{kk-1,t} & 1 \end{bmatrix}, \tag{2.2}$$

$$\Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{k,t} \end{bmatrix}, \tag{2.3}$$

and $\varepsilon_t \sim N(0, I_k)$. It follows that $A_t \Omega_t A_t' = \Sigma_t \Sigma_t'$. Let β_t be a stacked $k^2 p \times 1$ vector of the elements in the rows of the $B_{1,t}, ...B_{p,t}$, and a_t be the vector of non-zero and non-one elements of the A_t. Following Primiceri (2005), we assume that these vectors follow a random walk process:

$$\beta_{t+1} = \beta_t + u_{\beta,t}, \tag{2.4}$$

$$a_{t+1} = a_t + u_{a,t}, \tag{2.5}$$

$$h_{t+1} = h_t + u_{h,t}, \tag{2.6}$$

$$\begin{bmatrix} \varepsilon_t \\ u_{\beta,t} \\ u_{a,t} \\ u_{h,t} \end{bmatrix} \sim N \left(0, \begin{bmatrix} I & O & O & O \\ O & \Sigma_\beta & O & O \\ O & O & \Sigma_a & O \\ O & O & O & \Sigma_h \end{bmatrix} \right), \tag{2.7}$$

where $h_t = [h_{1,t}, \ldots, h_{k,t}]'$ with $h_{j,t} = \ln \sigma_{j,t}^2$ for $j = 1, ..., k$, and I is a k-dimensional identity matrix. The prior distributions for the initial values are given by $\beta_{p+1} \sim N(\mu_{\beta_0}, \Sigma_{\beta_0})$, $a_{p+1} \sim N(\mu_{a_0}, \Sigma_{a_0})$, and $h_{p+1} \sim N(\mu_{h_0}, \Sigma_{h_0})$. Observe that the model allows both the parameters that govern contemporaneous relations among variables and the log of the variance for the shocks to evolve over time as a random walk.

The stochastic volatility assumption makes the likelihood function of the model difficult to construct and requires Bayesian inference via Markov Chain Monte Carlo (MCMC) methods. To estimate a model that contains a relatively large number of variables, we rely on the efficient algorithm proposed by Nakajima, Kasuya and Watanabe (2011), which is developed by modifying Primiceri (2005)'s original algorithm. Following Nakajima (2011*a*), we further assume for simplicity that Σ_β, Σ_a, Σ_h, Σ_{β_0}, Σ_{a_0}, and Σ_{h_0} are all diagonal matrices.[10] Regarding the

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[10] Although the assumption is not essential, it greatly simplifies the inference procedures for a_t and h_t, thereby contributing to increase the efficiency of the algorithm (e.g., Primiceri (2005); Nakajima, Kasuya and Watanabe (2011)). Moreover, we do not expect a significant difference in results from allowing for correlations among elements of a_t, β_t, and h_t, as in Primiceri (2005), Nakajima (2011*a*), and Nakajima (2011*b*), respectively.

sampling of β_t and a_t, we use the simulation smoother of de Jong and Shephard (1995) because the model can be written as a linear Gaussian state space form conditional on the rest of the parameters.[11] In contrast, in sampling h_t, we employ the multi-move sampler of Shephard and Pitt (1997) and Watanabe and Omori (2004) for non-linear and non-Gaussian state space models. The multi-move sampler is more efficient than the single-move sampler of Jacquier, Polson and Rossi (1994).[12] Furthermore, it enables us to draw a sample from the exact conditional posterior density of the stochastic volatility, unlike the mixture sampler of Kim, Shephard and Chib (1998). Appendix A provides a more detailed outline of the MCMC algorithm used in this study.

We use U.S. quarterly data for the period from 1952:Q1 to 2013:Q4.[13] The observed variables include government spending, gross domestic product (GDP), debt-to-GDP ratio, and the GDP deflator. The government spending and GDP are expressed in real per capita terms. We use the logarithm for all variables except the debt-to-GDP ratio. All variables are seasonally adjusted and detrended with a linear and quadratic trend. The lag length is set to $p = 4$, following Blanchard and Perotti (2002). See Appendix B for a detailed description of the data sources.

2.2 Identification strategies

The TVP-VAR framework allows parameters to vary continuously over time in a stochastic manner and, hence, it is not suitable for capturing rapid changes in the economic state. Nevertheless, we can consider the effects of such changes by implementing a shock identification

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[11] We employ the simulation smoother of de Jong and Shephard (1995) instead of the multi-state sampler of Carter and Kohn (1994), which is widely used in previous TVP-VAR studies. The multi-state sampler generates the entire state vector at once and therefore converges more quickly than the single-state sampler that yields a strong correlation among the samples. However, the method is prone to the problem of degeneracies because the entire state vector is constructed recursively. The simulation smoother of de Jong and Shephard (1995) avoids the problem by drawing disturbances rather than states.

[12] The shortcoming of using the single-move sampler is that it leads to slow convergence when state variables are highly autocorrelated. The multi-move sampler reduces the inefficiency by generating randomly selected blocks of disturbances rather than each state variable at a time.

[13] The sample period starts at the time when quarterly data series on public debt is available. Because we examine the role of monetary policy in affecting the size of multipliers in the next section, the sample excludes the period of monetary policy normalization, which began with the tapering of quantitative easing in January 2014. Our sample, on the other hand, covers the zero interest-rate policy period in light of the findings of Nakajima (2011*a*). Based on the Japanese experience, Nakajima (2011*a*) documents that a zero lower bound on nominal interest rates has negligible effects on impulse responses in a TVP-VAR model with stochastic volatility.

through sign restrictions in each period. As Canova and Pappa (2011) suggest, the sign restriction approach enables us to study the effectiveness of fiscal policy under a certain economic state by imposing additional sign restrictions. Together with the assumption that the parameters governing contemporaneous relations among variables are time variant, we can impose different sets of sign restrictions on a period-by-period basis, considering the economic state of each period. To implement the sign restriction approach within the TVP-VAR framework, we exploit the algorithm proposed by Rubio-Ramírez, Waggoner and Zha (2010) (RWZ algorithm, hereafter), as in Benati (2008). The algorithm allows us to identify several shocks in a highly parameterized TVP-VAR model for each period with great efficiency. Thus, it is possible to replicate the impact of government spending shocks that reflect the effects of rapid changes in the economic state in addition to permanent and gradual changes in the transmission mechanism.

The RWZ algorithm proceeds as follows. We draw an independent standard normal $k \times k$ matrix Z_s for period s. The QR decomposition of Z_s gives an orthogonal matrix Q_s that satisfies $Q_s Q_s' = I$ and an upper triangular matrix R_s. Using $A_s^{-1}\Sigma_s Q_s$, we generate impulse responses for each MCMC replication. If the impulse response satisfies the restrictions, we keep the Q_s; otherwise, we discard it. The combination of Q_s' and ε_s, $\varepsilon_s^* = Q_s'\varepsilon_s$ is now regarded as a new set of structural shocks with the same covariance matrix as the original shock ε_s. Because Q_s is orthogonal, the new shocks are orthogonal to each other by design. Because contemporaneous relations among variables are assumed to be time varying in our TVP-VAR model, the algorithm is particularly appealing for identifying shocks on a period-by-period basis.[14]

Table 1 reports the sign restrictions that we employed in calculating impulse responses.[15] We identify two structural shocks: an expansionary government spending shock and a positive demand shock. Thus, orthogonality to a demand shock is imposed in identifying a government

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[14] Although we cannot give an economic interpretation of the orthogonal matrix Q_s as described by Baumeister and Hamilton (2015), we rely on the algorithm to preserve its computational efficiency. As argued by Arias, Rubio-Ramírez and Waggoner (2018), alternative approach could become computationally inefficient.

[15] To compare the results with those of other studies, we restrict our focus in this study to a traditional unanticipated government spending shock.

spending shock in the spirit of Mountford and Uhlig (2009). We impose a minimum set of contemporaneous restrictions to make our identification as agnostic as possible.[16] In particular, we leave the response of output to a government spending shock unrestricted following Mountford and Uhlig (2009). A government spending shock is assumed to increase the debt-to-GDP ratio, which is the key identifying restriction that distinguishes the shock from other shocks.[17] To distinguish the effects of a government spending shock during recession from that during expansion, we use a different set of restrictions for that shock. Following Canova and Pappa (2011), we assume that a government spending shock during recession is accompanied by a simultaneous fall in the GDP deflator while being agnostic on the response of the GDP deflator during expansion. On the other hand, a demand shock is assumed to increase GDP and the GDP deflator and to decrease the debt-to-GDP ratio.

TABLE 1
Sign restrictions

	Shocks		
Variables	Gov. Spending (Expansion)	Gov. Spending (Recession)	Demand
Government spending	+	+	
GDP			+
Debt-to-GDP ratio	+	+	−
GDP deflator		−	+

Notes: The table shows the signs imposed on the impulse responses of the variables to an expansionary government spending shock and a positive demand shock. A blank indicates that the variable's response is unrestricted. A positive [negative] sign indicates that the variable's response is restricted to being positive [negative] on impact.

To define the state of the business cycle, we use our detrended GDP data as the indicator of economic slack.[18] Okun's Law suggests that a one-percentage point decrease in GDP from its potential causes a half-percentage point increase in unemployment rate. On the other hand, conventional wisdom suggests that a recession is typically accompanied by a two-percentage

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[16] The choice of the period during which to restrict the responses does not change the basic results. It is also computationally burdensome to estimate impulse responses from a TVP-VAR model that imposes sign restrictions for several periods.

[17] The restriction shares similarities with those in previous studies (e.g., Canova and Pappa (2011); Enders, Müller and Scholl (2011); Bouakez, Chihi and Normandin (2014)).

[18] Some kind of indicator is necessary to define the state of the business cycle. Auerbach and Gorodnichenko (2012) use a seven-quarter moving average of the output growth rate as an index that changes the probability of economic state. Ramey and Zubairy (2018) use a 6.5 percent unemployment rate as the threshold value to define high and low unemployment states.

points increase in unemployment rate within a year, which can be reinterpreted as a half-percentage point increase within a quarter. Applying the Okun's Law to the conventional wisdom on the relationship between unemployment and recession, we define recessions as the periods where a more than one-percentage point decrease in detrended quarterly GDP data is observed.

3 Results

3.1 Two types of heterogeneities in multipliers

Figure 2 presents the stochastic volatilities of the reduced-form innovations. The time variation in the volatility estimates are largely consistent with those reported in previous studies on monetary policy analysis. The volatility of the output shocks declined sharply in the early 1980s as in Canova and Gambetti (2009) and Mumtaz and Zanetti (2013).[19] As reported in Primiceri (2005), the volatility of price shocks reached its highest peak during the Great Inflation of the mid-1970s. A reduction in the volatility of government spending shocks can also be found in Justiniano and Primiceri (2008). Since the estimation results here are largely consistent with those reported in previous studies, we can conclude that the time-varying volatilities are well captured in our model. The inclusion of stochastic volatility in the TVP-VAR model appears to be essential to appropriately detecting structural changes in the transmission of government spending shocks.

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[19] The volatility of the unemployment innovation reported in Cogley and Sargent (2005) and Primiceri (2005) shares similar time variation.

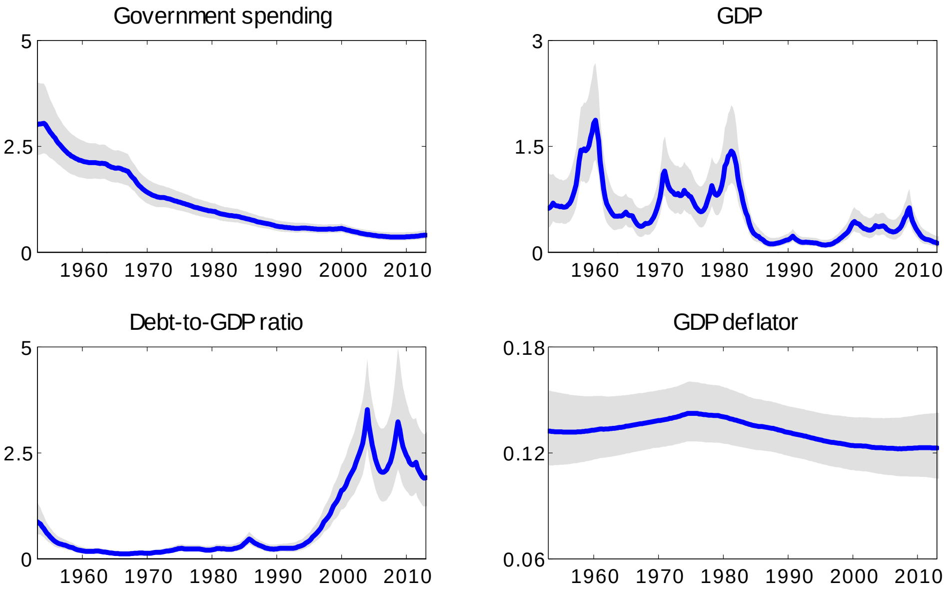

FIG. 2. Stochastic volatilities. *Notes:* The solid lines represent posterior mean with the shaded areas representing the 16th-84th percentile ranges.

Figure 3 presents the impulse responses of output to government spending shocks at selected periods of recessions and expansions. We picked up the responses of the period when the maximum impact on output (peak multiplier) takes the largest and smallest values among those during recessions and expansions. The impulse response at time t is computed for each MCMC replication on the basis of the estimated time-varying parameters at time t.[20] We convert the impulse responses to the government spending multipliers using the sample average ratio of output to government spending following Auerbach and Gorodnichenko (2012).[21]

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[20] Koop, Pesaran and Potter (1996) propose a method to calculate impulse responses considering the history of observations that affects impulse responses in non-linear models. However, because we expect a slight difference from using the computationally demanding method as argued in Koop, Leon-Gonzalez and Strachan (2009), we follow the simple computational procedure used in Primiceri (2005) and Koop, Leon-Gonzalez and Strachan (2009).

[21] Ramey and Zubairy (2018) point out a potential problem arising from the use of the sample average ratio to calculate multipliers by considering the large variation found in their long samples of historical data. Nevertheless, we use the average ratio not only because it is relatively stable in our post-war sample, but also because we intend to highlight the time variation in multipliers without interference from changes in the ratio.

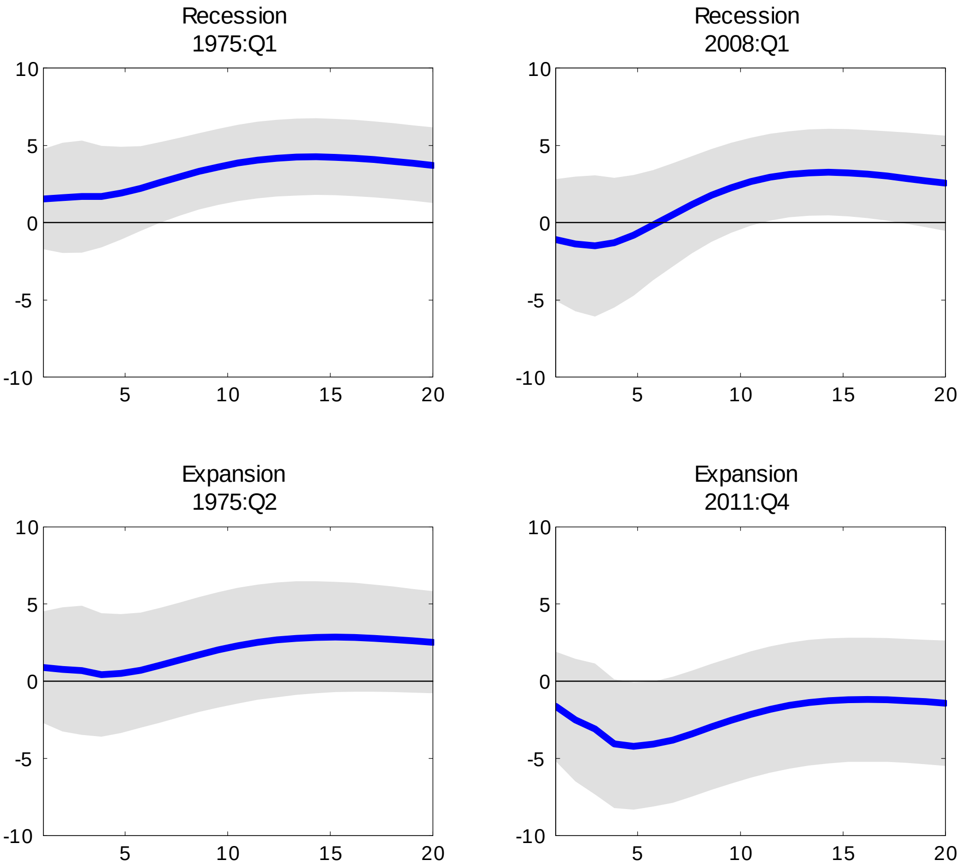

FIG. 3. Impulse responses during recessions and expansions. *Notes:* The solid lines represent posterior mean impulse responses of output to a one-dollar increase in government spending with the shaded areas representing the 16th-84th percentile ranges.

The upper panels show the impulse responses to government spending shocks during the periods of recessions. The shapes of the impulse responses are very similar to those estimated by Blanchard and Perotti (2002). After remaining unchanged or declining for about one year, the government spending multipliers become larger and reach their highest peak around a three-year horizon. Comparison of impulse responses at the two representative periods indicates that the expansionary output effects become smaller over time, while the peak multipliers are still positive even in the late 2000s. Time variation in the impulse response is more pronounced when comparing those during the periods of expansions. The lower panels show the impulse responses to government spending shocks at the two representative periods of expansions. The expansionary effects become smaller over time as those observed in recessions, however, negative multipliers can be observed during the 2010s expansion.

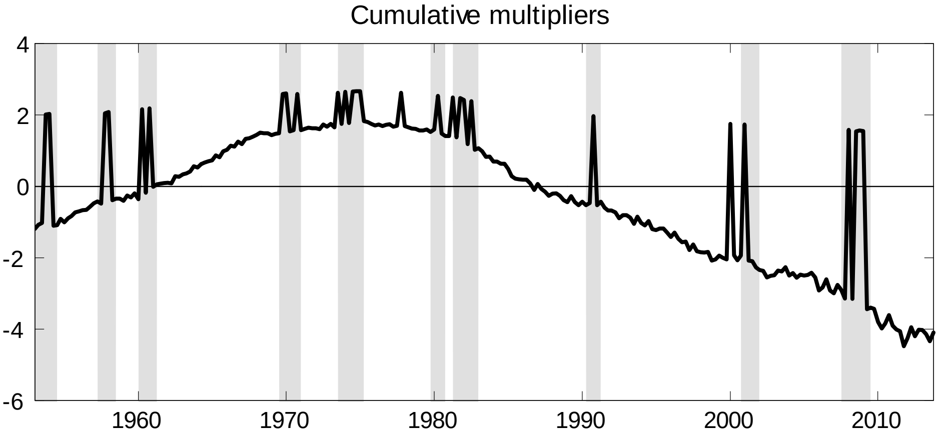

FIG. 4. Evolution of cumulative multipliers. *Notes:* The cumulative multipliers are calculated as the cumulative changes in output over the cumulative changes in government spending evaluated at a five-year horizon using the posterior mean impulse responses after a one-dollar increase in government spending. The shaded areas represent recessions as defined by the NBER.

To illustrate the time variation, we compute cumulative multipliers using the posterior mean impulse responses. Figure 4 presents the cumulative multipliers calculated as the cumulative changes in output over the cumulative changes in government spending evaluated at a five-year horizon after government spending shocks. Our identification strategies allow us to observe both cyclical and structural variations. The cumulative multipliers in recessions are larger than those in expansions and continue to be positive even in the 2000s while showing moderate downward trend since the 1980s. Although we define the state of the business cycle relying on rules of thumb, larger multipliers are mostly observed during periods of recessions defined by the NBER. On the other hand, the cumulative multipliers in expansions exhibit a substantial declining trend since the 1980s and falls into negative territory in the 1990s. The negative multipliers indicate that fiscal adjustments during these periods can have expansionary effects on output, providing support for the expansionary austerity hypothesis introduced by Giavazzi and Pagano (1990).

Table 2 reports the averages of the peak and cumulative multipliers over either the entire sample or subsample periods, such as recession, expansion, pre-Volcker, and post-Volcker periods. For comparative purposes, we put the corresponding multipliers reported in Auerbach and Gorodnichenko (2012). In line with the findings of previous studies, we obtain larger multipliers in recession than in expansion. The difference between the sizes of multipliers in recession and expansion is comparable to that reported in Auerbach and Gorodnichenko (2012). The smaller multipliers observed in the post-Volcker period than those in the preceding period corroborate the findings of Bilbiie, Meier and Müller (2008). The analysis provides evidence of two heterogeneities in multipliers: larger multipliers in recessions than in expansions and smaller ones in the post-Volcker period than in the preceding period.

TABLE 2
Multipliers

	Average				Range	
	Peak		Cumulative		Peak	Cumulative
	This paper	AG	This paper	AG		
Full sample	1.14	1.00	-0.25	0.57	-1.19 – 4.26	-4.47 – 2.67
Recession	2.28	2.48	0.91	2.24	-0.80 – 4.26	-3.44 – 2.67
Expansion	0.87	0.57	-0.52	-0.33	-1.19 – 4.25	-4.47 – 2.63
Pre-Volcker period	1.97	-	0.93		0.20 – 4.26	-1.19 – 2.67
Post-Volcker period	0.50	-	-1.15		-1.19 – 4.10	-4.47 – 2.53

Notes: The table shows the averages and ranges of the peak and cumulative multipliers calculated over either the entire sample or the subsample periods (recession, expansion, pre-Volcker, and post-Volcker). The periods of recessions and expansions are those defined by the NBER. The peak and cumulative multipliers are evaluated at a five-year horizon using the posterior mean impulse responses after a one-dollar increase in government spending. The cumulative multipliers are calculated as the cumulative changes in output over the cumulative changes in government spending. The columns labeled AG report the corresponding results of Auerbach and Gorodnichenko (2012).

3.2 Extended experiments

The results from the baseline model show that the government spending multipliers in the post-war U.S. are large in recessions and small in the post-Volcker period. Because business cycle-dependent nature of U.S. multipliers has already been studied extensively, we henceforth focus our analysis on the change in the size of multipliers between the pre- and post-Volcker periods. One explanation for the decline is that more active monetary policy during the post-Volcker period offsets the stimulative effects of government spending strongly (e.g., Bilbiie, Meier and Müller (2008)). On the other hand, it should be recalled that the debt-to-GDP ratio starts showing an upward trend around the same time as Paul Volcker was appointed as Fed Chairman. Figure 5 displays a scatter plot of the point estimates of cumulative multipliers during expansions against historical data on debt-to-GDP ratio of corresponding periods. The observed negative correlation suggests debt-dependent nature of the U.S. multipliers. Therefore, we investigate whether the decline in multipliers during the post-Volcker period can be attributed to more active monetary policy or debt accumulation of the period.

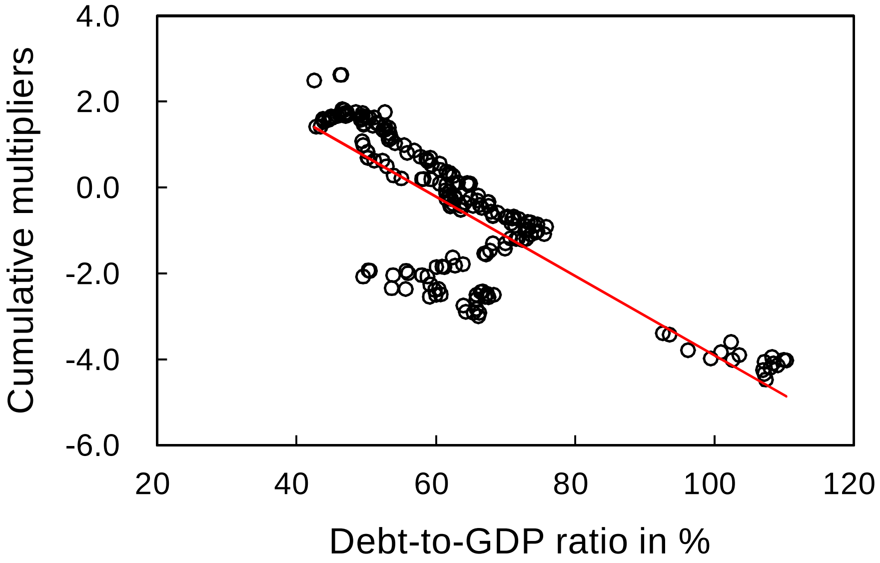

FIG. 5. Correlation between multipliers and debt. *Notes:* The figure plots the estimated cumulative multipliers and historical data on debt-to-GDP ratio. The cumulative multipliers are calculated as the cumulative changes in output over the cumulative changes in government spending evaluated at a five-year horizon using the posterior mean impulse responses after a one-dollar increase in government spending during expansions as defined by the NBER. R-squared: 0.659.

We begin by examining the role of monetary policy by augmenting the baseline model with interest rate. Like other variables, interest rate is detrended with a linear and quadratic trend. See Appendix B for a detailed description of the data source. The responses of interest rate to a government spending shock and a demand shock are both left unrestricted. The estimated volatility of interest rate shocks depicted in Figure 6 is consistent with those reported in previous studies (e.g., Cogley and Sargent (2005); Primiceri (2005); Canova and Gambetti (2009); Mumtaz and Zanetti (2013)). The volatility of interest rate shocks increased substantially around the time of Volcker's appointment and showed a large decline in the early 1980s.

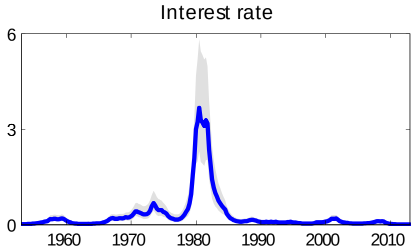

FIG. 6. Stochastic volatility. *Notes:* The solid line represents posterior mean with the shaded area representing the 16th-84th percentile range.

As shown in Figure 7, the inclusion of interest rate to the baseline model does not change the time variation of cumulative multipliers. Cumulative response of interest rate, on the other hand, shows little time variation. Although monetary policy responses during recessions appear to have become more active throughout the post-Volcker period, the responses during expansions do not show a clear trend. The negative responses of interest rate seem puzzling but the counterintuitive results can be found in previous studies, such as Mountford and Uhlig (2009).[22] The results do not suggest stronger offsetting monetary policy response during the post-Volcker period, leading us to conclude that the decline in multipliers cannot be attributed to the change in the conduct of monetary policy.

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[22] Mountford and Uhlig (2009) do not impose a sign restriction on the response of interest rate to a government spending shock as we did in this paper. Enders, Müller and Scholl (2011) obtain a positive response of interest rate to a government spending shock while restricting the response to be positive.

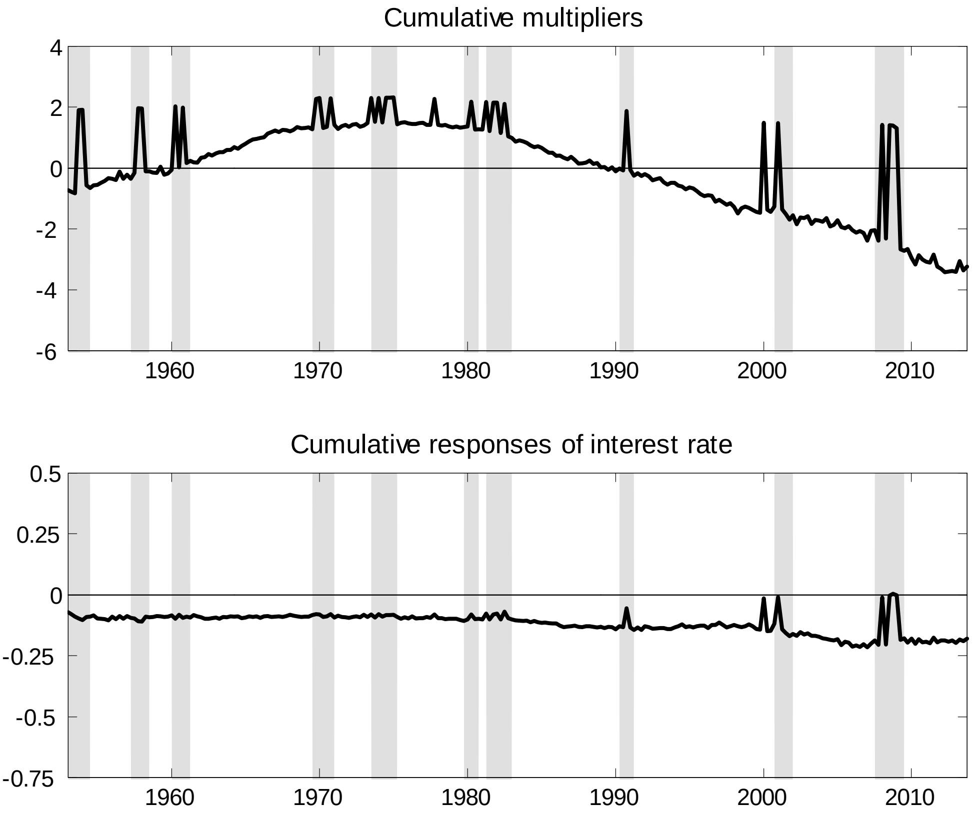

FIG. 7. Evolution of cumulative responses of output and interest rate. *Notes:* The cumulative responses are calculated as the cumulative changes in output [interest rate] over the cumulative changes in government spending evaluated at a five-year horizon using the posterior mean impulse responses after a one-dollar [one-percentage point] increase in government spending. The shaded areas represent recessions as defined by the NBER.

We now proceed to examine the role of debt accumulation. Because the Ricardian channel has been considered as the primary cause of debt-dependent multipliers (e.g., Huidrom et al. (2020)), we examine its relevance by augmenting the baseline model with private consumption. Private consumption is seasonally adjusted, expressed in logarithm and real per capita term, and detrended with a linear and quadratic trend. See Appendix B for a detailed description of the data source. We impose the same set of restrictions on the response of private consumption as that on output response. The impulse response of consumption is scaled by the sample average ratio of consumption to government spending so that the magnitude of the response is comparable to that of government spending multipliers. Figure 8 illustrates the similarity between the time variation patterns in the cumulative multipliers and cumulative responses of consumption. Their co-movement indicates that the decline in multipliers during post-Volcker period is mostly led by the consumption responses to government spending shocks.

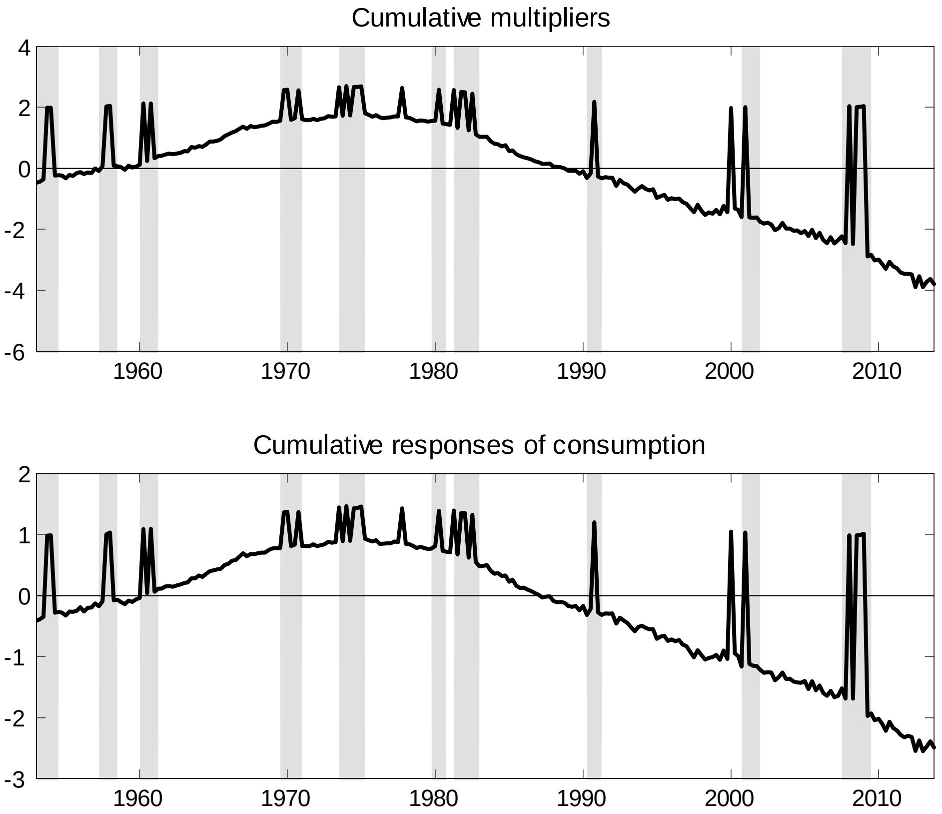

FIG. 8. Evolution of cumulative responses of output and consumption. *Notes:* The cumulative responses are calculated as the cumulative changes in output [consumption] over the cumulative changes in government spending evaluated at a five-year horizon using the posterior mean impulse responses after a one-dollar increase in government spending. The shaded areas represent recessions as defined by the NBER.

4 Explaining the debt-dependent multipliers

4.1 Time variation in the magnitude of fiscal adjustments

The results from the extended experiments in previous section suggest the relevance of the Ricardian channel. When public debt is high, households reduce consumption expecting a larger magnitude of fiscal adjustments thereby making the effects of government spending less stimulative. In this section, we turn our attention to the role of fiscal adjustments in the debt-dependent multipliers. In providing historical evidence of fiscal adjustments, Bohn (1998) finds a positive correlation between the magnitude of fiscal adjustments and the debt-to-GDP ratio. Therefore, smaller multipliers during times of high debt could be attributed to larger magnitude of fiscal adjustments as assumed in Bi, Shen and Yang (2016).

Canzoneri, Cumby and Diba (2001) and Canzoneri, Cumby and Diba (2011) present a VAR-based methodology to test whether fiscal policy follows a Ricardian regime, i.e., fiscal policy adjusts the path of primary surpluses to stabilize the debt-to-GDP ratio. Their methodology is attractive because we can easily extend it to our TVP-VAR framework. Following the specification employed in Canzoneri, Cumby and Diba (2001) and Canzoneri, Cumby and Diba (2011), we estimate a bivariate TVP-VAR model with stochastic volatility in Surplus/GDP and Liabilities/GDP with two lags. See Appendix B for a detailed description of the data sources. Figure 9 presents the estimated stochastic volatilities. The overall results for the volatility of Surplus/GDP shocks shows a pattern similar to the volatility of tax shocks estimated by Gonzalez-Astudillo (2013), indicating that the stochastic volatility assumption effectively captures the fiscal events.[23]

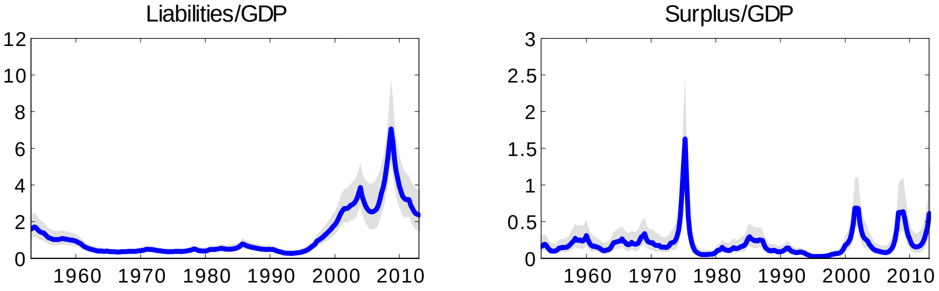

FIG. 9. Stochastic volatilities. *Notes:* The solid lines represent posterior mean with the shaded areas representing the 16th-84th percentile ranges.

Figure 10 presents the impulse responses of Surplus/GDP and Liabilities/GDP to an increase in Surplus/GDP. The Surplus/GDP and Liabilities/GDP are ordered first in the left and the right panels, respectively. The former is consistent with a non-Ricardian regime and the latter makes more sense in a Ricardian regime. Because the point estimate of Liabilities/GDP declined the least and most in 1972:Q1 and 2007:Q3, respectively, when Liabilities/GDP is ordered first, Figure 10 compares the impulse responses in these periods. Regardless of the ordering, Liabilities/GDP declined for several years in response to a Surplus/GDP shock across different

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[23] The stochastic volatility of Surplus/GDP shocks increased the most around the time of the Tax Reduction Act of 1975, and increased during tax reforms and measures such as the Reagan Tax Reform of 1981 and 1986, the Bush Tax Cuts of 2001 and 2003, and the American Recovery and Reinvestment Act of 2009.

sample dates. The results are very similar to those obtained by Canzoneri, Cumby and Diba (2001) and Canzoneri, Cumby and Diba (2011), suggesting that the U.S. government followed Ricardian regime throughout the post-war period. As Canzoneri, Cumby and Diba (2001) and Canzoneri, Cumby and Diba (2011) discuss, a non-Ricardian interpretation is implausible because it requires a negative correlation between present and future surpluses, which we cannot observe. Furthermore, the TVP-VAR framework reveals that one unit of deterioration in surplus leads to a larger decline in Liabilities/GDP in 2007:Q3 than in 1972:Q1. Note that the degree of the decline in Liabilities/GDP, which measures the magnitude of fiscal adjustments, shows a widening trend until 2007:Q3. The observed timing of the largest fiscal adjustment is consistent with D'Erasmo, Mendoza and Zhang (2016) who find a evidence of structural change leading to smaller fiscal adjustments in the post-2008 U.S. data.

The increase in the magnitude of fiscal adjustments occurred around the same time as the passage of the Congressional Budget and Impoundment Act of 1974, which established the Congressional Budget Office. Since then, Congress introduced a variety of budget rules in an attempt to impose fiscal discipline on the budgetary process. By examining the effects of budget rules, Auerbach (2008) concludes that these rules appear to have had some success with deficit control. Such policy change in the presence of debt accumulation might have contributed to raising expectations of the future fiscal adjustments, thereby leading to smaller multipliers.

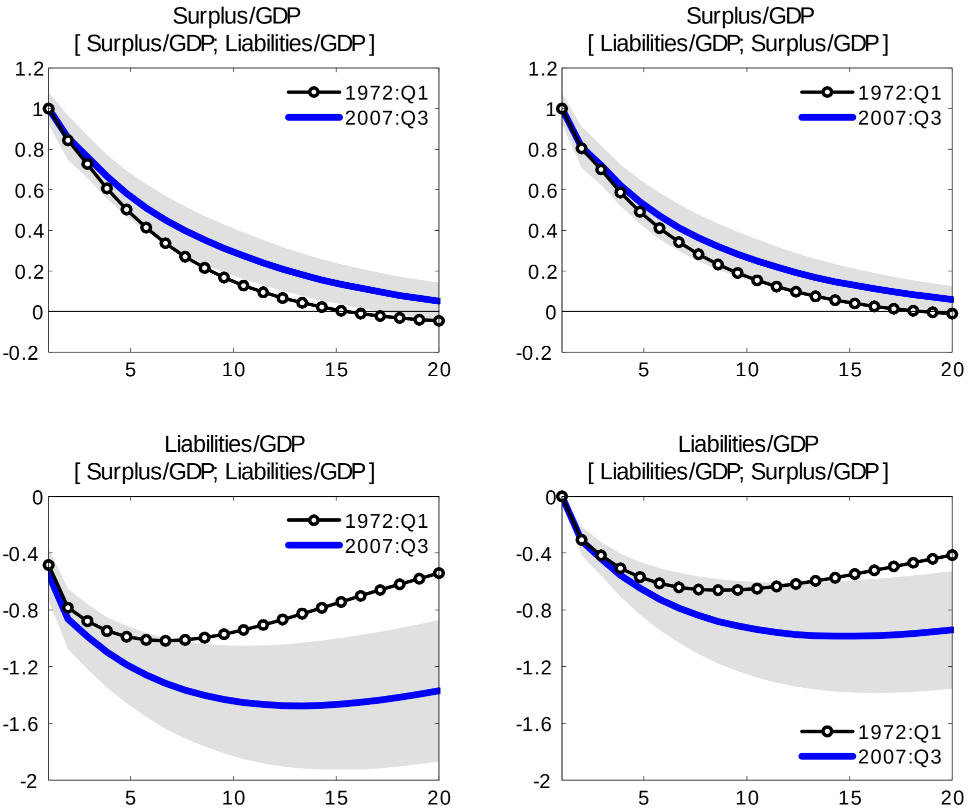

FIG. 10. Evolution of surplus and debt dynamics. *Notes:* The figure shows impulse responses of Surplus/GDP and Liabilities/GDP to a one-percentage point increase in Surplus/GDP. The solid lines represent posterior mean impulse responses for 2007:Q3 with the shaded areas representing the 16th-84th percentile ranges. The solid lines with circles represent posterior mean impulse responses for 1972:Q1. Surplus/GDP is ordered first in the left column and is reversed in the right column.

4.2 Investigating the debt-multiplier nexus

Our next question is whether the observed increase in the magnitude of fiscal adjustments has contributed to the decline in multipliers during the post-Volcker period. In order to see that, we examine the Granger-causality relations among the debt-to-GDP ratio, the size of cumulative multiplier, and the magnitude of fiscal adjustments proxied by the cumulative response of liabilities to a surplus shock estimated in the bivariate TVP-VAR model in Surplus/GDP and Liabilities/GDP. The cumulative response of liabilities is calculated as the cumulative change in Liabilities/GDP over the cumulative change in Surplus/GDP using the posterior mean impulse responses. As the magnitude of fiscal adjustments does not depend on the state of the business cycle, we calculate cumulative multipliers without taking it into consideration.

To cope with possible non-stationarity of the variables, we employ the procedure of Toda and Yamamoto (1995) to test for their causal relationship. The first step of the procedure is to select the optimal lag length (k) of the VAR model in levels. The Akaike information criterion (AIC) suggests $k = 5$. As a second step, we conduct the Augmented Dickey-Fuller (ADF) unit root test to determine the maximum order of integration ($d_{\max}$) that might occur in the model. Toda and Yamamoto (1995) show that we can test restrictions on the first k coefficient matrices of a ($k + d_{\max}$)th-order VAR model in levels using the standard asymptotic theory, even if the variables are integrated or cointegrated. We then test the null hypothesis of no Granger causality using a standard Wald statistic for the first k coefficient matrices of the ($k + d_{\max}$)th-order VAR model in levels. In fact, the ADF test results show that cumulative multipliers and debt-to-GDP ratios are processes integrated of order 1 (i.e., $d_{\max} = 1$) as reported in Table 3.

TABLE 3
Unit-root and causality test results

Null hypothesis	Test statistics and p-values			
ADF	t-statistic at level		t-statistic at first difference	
CM has a unit root	-2.6573	(0.2555)	-26.1752	(0.0000)**
FA has a unit root	-3.2081	(0.0853)*	-4.2524	(0.0044)**
DR has a unit root	-1.6291	(0.7788)	-10.9165	(0.0000)**
Granger (Toda-Yamamoto procedure)	Wald chi-square test statistic			
FA does not Granger-cause CM	9.8405	(0.0799)*		
CM does not Granger-cause FA	9.2073	(0.1011)		
DR does not Granger-cause FA	16.5662	(0.0054)**		
FA does not Granger-cause DR	18.8549	(0.0020)**		
DR does not Granger-cause CM	8.5981	(0.1262)		
CM does not Granger-cause DR	6.3292	(0.2755)		

Notes: CM stands for the cumulative multiplier calculated as the cumulative change in output over the cumulative change in government spending using the posterior mean impulse responses after a one-dollar increase in government spending. FA stands for the magnitude of fiscal adjustments measured as the cumulative response of liabilities to a surplus shock. FA is calculated as the cumulative change in Liabilities/GDP over the cumulative change in Surplus/GDP using the posterior mean impulse responses after a one-percentage point increase in Surplus/GDP. In calculating the FA, Liabilities/GDP is placed first in the ordering. Both CM and FA are evaluated at a five-year horizon. DR stands for debt-to-GDP ratio. Figures between parentheses are p-values. A double asterisk (**) denotes significant at the one percent level; a single asterisk (*) denotes significant at the ten percent level.

The results suggest that the magnitude of fiscal adjustments (FA) appear to Granger-cause the cumulative multiplier (CM), while the null hypothesis of no-Granger-causality in the opposite direction cannot be rejected. In addition to the unidirectional causality running from the magnitudes of fiscal adjustments to the multiplier, we also find a bidirectional causality between the debt-to-GDP ratio (DR) and the magnitude of fiscal adjustments. Interestingly, the results do not support direct causal relationships between the debt-to-GDP ratio and the cumulative multiplier.

Although we provide evidence that multipliers are negatively correlated with debt-to-GDP ratio, Granger causality analysis tells us that the larger magnitude of fiscal adjustments in the presence of higher indebtedness was the major driving force for the decline in multipliers rather than debt accumulation itself.

5 Conclusions

This study provides new time-series evidence of government spending multipliers during the post-war period in the United States. We obtain two types of heterogeneities in multipliers: large multipliers in recessions and small ones in the post-Volcker period. Both phenomena have been shown in previous studies, but this study differs from them in that we address the two heterogeneities in multipliers simultaneously within a single TVP-VAR framework using the assistance of sign restriction identification. In particular, we provide the empirical evidence for the negative correlation between debt and multipliers by analyzing U.S. time-series data, which has been neglected in the literature.

Another contribution of the study is to investigate the underlying transmission mechanism of U.S. debt-dependent multipliers. After examining the relevance of the Ricardian channel, we find that the magnitude of fiscal adjustments was increased during most of the post-Volcker period by applying TVP-VAR technique to test for changes in a fiscal policy regime. The larger magnitude of fiscal adjustments is shown to be the major driving force for the decline in multipliers rather than debt accumulation itself. The results could have major policy implications for fiscal adjustment strategies during when fiscal stimulus is necessary.

Nevertheless, there remains much work ahead. Although our atheoretical approach is a flexible way to model the evolution of time-series data, it has limitations in explaining the underlying mechanism. Therefore the development of a theoretical model that accounts for the time variation in multipliers and its underlying transmission reported in this paper. Moreover, while we do not consider the relevance of a sovereign risk channel as the U.S. economy has supposedly not yet reached the fiscal limit, it would become worth exploring to consider the channel as the concerns over the U.S. debt sustainability increase in the future (e.g., Corsetti et al. (2013); Huidrom et al. (2020)).

A Markov Chain Monte Carlo Methods

This appendix outlines the MCMC algorithm used to estimate the TVP-VAR models presented in this paper. Given the data, the algorithm allows us to sample parameters and hyperparameters from their posterior density. In what follows, x denotes the entire history of x_t to the end of the sample period. Letting $f(x \mid z)$ denote the conditional density of x given z, the MCMC algorithm repeats the following steps:

1. Initialize $\beta, a, h, \Sigma_\beta, \Sigma_a, \Sigma_h$.
2. Draw β from $f(\beta \mid a, h, \Sigma_\beta, y)$.
3. Draw Σ_β from $f(\Sigma_\beta \mid \beta, y)$.
4. Draw a from $f(a \mid \beta, h, \Sigma_a, y)$.
5. Draw Σ_a from $f(\Sigma_a \mid a, y)$.
6. Draw h from $f(h \mid \beta, a, \Sigma_h, y)$.
7. Draw Σ_h from $f(\Sigma_h \mid h, y)$.
8. Go to 2.

For the first step, we set the initial states of the parameters as $\beta_{p+1} \sim N(0, 10I)$, $a_{p+1} \sim N(0, 10I)$, and $h_{p+1} \sim N(0, 50I)$. We postulate an inverse-Gamma distribution for the m-th diagonal elements of the covariance matrices. The priors are specified as $(\Sigma_\beta)_m^2 \sim IG\left(10, 10^{-6}\right)$, $(\Sigma_a)_m^2 \sim IG\left(5, 10^{-3}\right)$, and $(\Sigma_h)_m^2 \sim IG\left(5, 10^{-3}\right)$. We execute 30,000 MCMC replications and discard the first 5,000 draws to estimate the TVP-VAR models. To reduce autocorrelation among the draws, we save only every fifth draw.

A.1 Drawing β

For notational convenience, we rewrite equation (2.1) as

$$y_t = X_t \beta_t + A_t^{-1} \Sigma_t \varepsilon_t, \tag{A.1}$$

where $X_t = I_k \otimes \left[y'_{t-1}, ..., y'_{t-k} \right]$ and $\otimes$ denotes the Kronecker product. Because the observation equation (A.1) and state equation (2.4) constitute a linear Gaussian state-space representation for the dynamic behavior of y_t, we can apply the simulation smoother of de Jong and Shephard (1995) to draw samples of β from its posterior density conditioned on a, h, Σ_β, and y.

A.2 Drawing a

We can write equation (A.1) as

$$A_t \left(y_t - X_t \beta_t \right) = \Sigma_t \varepsilon_t. \tag{A.2}$$

Let $\widehat{y}_t = y_t - X_t \beta_t$ and $\widehat{X}_t$ be the $k \times \frac{k(k-1)}{2}$ matrix defined by

$$\widehat{X}_t = \begin{bmatrix} 0 & \cdots & \cdots & 0 \\ -\widehat{y}_{1,t} & 0 & \cdots & 0 \\ 0 & -\widehat{y}_{[1,2],t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & -\widehat{y}_{[1,\ldots,k-1],t} \end{bmatrix},$$

where $\widehat{y}_{[1,\ldots,q],t}$ represents the row vector $[\widehat{y}_{1,t}, \widehat{y}_{2,t}, ..., \widehat{y}_{q,t}]$, where $q \leq k-1$. We can express equation (A.2) as

$$\widehat{y}_t = \widehat{X}_t a_t + \Sigma_t \varepsilon_t. \tag{A.3}$$

Because the observation equation (A.3) and state equation (2.5) can be treated as a linear Gaussian state-space model, assuming that Σ_a and Σ_{a_0} are diagonal matrices, we can apply the simulation smoother of de Jong and Shephard (1995) to draw samples of a from its posterior density conditioned on β, h, Σ_a, and y.

A.3 Drawing h

For the stochastic volatilities, we apply the multi-move sampler developed by Shephard and Pitt (1997) and Watanabe and Omori (2004) because the system of equations consists of (A.1), and (2.6) is not linear in h. The diagonality assumptions of Σ_h and Σ_{h_0} allow us to make inferences on $\{h_{j,t}\}_{t=p+1}^{T}$ separately for $j = 1, ..., k$. Let $y^*_{j,t}$ be the j-th element of $A_t\widehat{y}_t$. Now, consider the following system of equations:

$$y^*_{j,t} = \exp\left(\frac{h_{j,t}}{2}\right)\varepsilon_{j,t}, \tag{A.4}$$

$$h_{j,t+1} = h_{j,t} + \eta_{j,t}, \tag{A.5}$$

$$\begin{pmatrix}\varepsilon_{j,t}\\ \eta_{j,t}\end{pmatrix} \sim N\left(0, \begin{pmatrix}1 & 0\\ 0 & \nu_j^2\end{pmatrix}\right),$$

where $\varepsilon_{j,t}$ and $\eta_{j,t}$ are the j-th elements of ε_t and $u_{h,t}$, respectively, and ν is the j-th diagonal element of Σ_h. The prior distribution for the initial value is given by $\eta_{j,p} \sim N(0, \nu^2_{j,o})$, where $\nu^2_{j,o}$ is the j-th diagonal element of Σ_{h_0}.

Drawing samples of h conditional on β, a, Σ_h, and y is difficult because of an analytically intractable form of its posterior density. One way is to draw each sample of h_t conditional on $h_{\backslash t}$, β, a, Σ_h, and y; however, the method tends to produce a highly correlated sample sequence.[24] Therefore, we divide the state variables $\{h_{j,t}\}_{t=p+1}^{T}$ into $K+1$ blocks and draw each block conditional on the elements of the other blocks and parameters. Let the end elements of the blocks be

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[24] See Shephard and Pitt (1997) and Kim, Shephard and Chib (1998).

h_{j,k_n} for $n = 1, ..., K$. The end conditions of blocks k_n, called "stochastic knots," are determined randomly over iterations. To cope with possible degeneracies, we draw $\eta_{j,p+1}, ..., \eta_{j,T-1}$ instead of $h_{j,p+2}, ..., h_{j,T}$, which can be constructed using (A.5) given the sampled $h_{j,p+1}$. Suppose we draw samples from a typical block $h_{j,r}, ..., h_{j,r+d}$, where $r \geq p+1$, $d \geq 1$, and $r+d \leq T$. By Bayes' theorem, the posterior conditional density of a block of disturbances can be expressed as

$$\begin{aligned} & f(\eta_{j,r-1}, ..., \eta_{j,r+d-1} \mid h_{j,r-1}, h_{j,r+d+1}, y^*_{j,r}, ..., y^*_{j,r+d}, \nu_j, \nu_{j,o}) \\ & \propto \prod_{t=r}^{r+d} \frac{1}{e^{h_{j,t}/2}} \exp\left(-\frac{y^{*2}_{j,t}}{2e^{h_{j,t}}}\right) \times \prod_{t=r-1}^{r+d-1} f\left(\eta_{j,t}\right) \times f\left(h_{j,r+d}\right), \end{aligned} \tag{A.6}$$

where

$$f\left(\eta_{j,t}\right) = \begin{cases} \exp\left(-\frac{\eta^2_{j,p}}{2\nu^2_{j,o}}\right) & (t = p), \\ \exp\left(-\frac{\eta^2_{j,t}}{2\nu^2_j}\right) & (t \geq p+1), \end{cases}$$

$$f\left(h_{j,r+d}\right) = \begin{cases} \exp\left(-\frac{\left(h_{j,r+d+1} - h_{j,r+d}\right)^2}{2\nu^2_j}\right) & (r+d < T), \\ 1 & (r+d = T). \end{cases}$$

To draw $\eta_{j,r-1}, ..., \eta_{j,r+d-1}$ from the density (A.6), we consider a proposal density expressed in logarithmic form by taking the logarithm of (A.6) and applying the second-order Taylor approximation to

$$g\left(h_{j,t}\right) \equiv -\frac{h_{j,t}}{2} - \frac{y^{*2}_{j,t}}{2e^{h_{j,t}}}$$

around a certain point $h_{j,t} = \widehat{h}_{j,t}$, which we choose to be near the mode of the posterior density. We can sample from the proposal density by defining artificial variables

$$h^*_{j,t} = \begin{cases} \sigma^*_{j,t}\left(g'(\widehat{h}_{j,t}) - g''(\widehat{h}_{j,t})\widehat{h}_{j,t} + \frac{h_{j,t+1}}{\nu^2_j}\right) & (t = r+d < T), \\ \widehat{h}_{j,t} + \sigma^*_{j,t} g'(\widehat{h}_{j,t}) & (t = r, ..., r+d-1 \text{ and } t = r+d = T), \end{cases}$$

where

$$\sigma^*_{j,t} = \begin{cases} \frac{\nu_j^2}{1-g''(\widehat{h}_{j,t})\nu_j^2} & (t = r + d < T), \\ -\frac{1}{g''(\widehat{h}_{j,t})} & (t = r, ..., r + d - 1 \text{ and } t = r + d = T), \end{cases}$$

and then considering the following equation

$$h^*_{j,t} = h_{j,t} + \zeta_{j,t}, \tag{A.7}$$

where $\zeta_{j,t} \sim N(0, \sigma^*_{j,t})$. Using (A.5) and (A.7), we can formulate a linear Gaussian state-space model and draw samples applying the simulation smoother of de Jong and Shephard (1995). The sampling is the same as that for the proposal density. Hence, we use the Accept-Reject Metropolis-Hastings algorithm in Tierney (1994) to produce draws from the correct density (A.6) as the sampling process is iterated.

A.4 Drawing hyperparameters

Let $\theta = (\beta, a, h)$, m-th element of θ_t be $\theta_{m,t}$, and the prior for the m-th diagonal element of the covariance matrix of θ be given by $(\Sigma_\theta)^2_m \sim IG(s_{\theta_0}/2, S_{\theta_0}/2)$. Because we assume that Σ_θ is a diagonal matrix, the m-th diagonals of covariance matrix $(\Sigma_\theta)^2_m$ can be sampled independently. The posterior density conditioned on θ is then given by $(\Sigma_\theta)^2_m \mid \theta \sim IG(\widehat{s}_{\theta_m}/2, \widehat{S}_{\theta_m}/2)$, where

$$\widehat{s}_{\theta_m} = s_{\theta_0} + T - p - 1,$$

$$\widehat{S}_{\theta_m} = S_{\theta_0} + \sum_{t=p+1}^{T-1} (\theta_{m,t+1} - \theta_{m,t})^2 .$$

B Description of Data Sources

We obtain all quarterly data from the Federal Reserve Bank of St. Louis's FRED database. Seasonally adjusted series for real government spending, real gross domestic product, and real private consumption are Real Government Consumption Expenditures and Gross Investment (GCEC96), Real Gross Domestic Product (GDPC1), and Real Personal Consumption Expenditures (PCECC96), respectively. To convert the series into per-capita terms, we divide them by the seasonally adjusted Civilian Labor Force (CLF16OV). The ratios of output and consumption to government spending used to calculate the multipliers are constructed from seasonally adjusted series for Gross Domestic Product (GDP), Personal Consumption Expenditures (PCEC), and Government Consumption Expenditures and Gross Investment (GCE), respectively. We use the seasonally adjusted GDP Chain-type Price Index (GDPCTPI) as the price. We use the 3-Month Treasury Bill Secondary Market Rate (TB3MS) as the nominal interest rate. The debt-to-output ratio is calculated by dividing the sum of federal, state, and local government liabilities by the seasonally adjusted Gross Domestic Product (GDP). We use the seasonally adjusted liabilities of the Federal government (FGDSLAQ027S) and those of the State and local governments (SLGLIAQ027S) in the calculation. The Surplus/GDP is calculated by dividing the seasonally adjusted primary surplus by the Gross Domestic Product (GDP). The primary surplus is defined as Net Government Saving (TGDEF) minus the difference between income receipts on assets (W059RC1Q027SBEA) and interest payments (A180RC1Q027SBEA). The Liabilities/GDP is calculated in the same way as the debt-to-output ratio.

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