Fiscal Policy, Interest Rates, and Output: Equilibrium-Correction Dynamics in the US Economy

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Abstract

Joint modelling of fiscal and monetary policies should elucidate on their interaction. We construct an eight-dimensional parsimonious structural vector equilibrium correction model (PSVECM) of the US macro economy over the last five decades. The fiscal deficit is found to be one of the five cointegration vectors, constraining fiscal policy in the long run. In contrast, the share of the government sector is found not to be mean reverting. To overcome the common problem of ad-hoc assumptions regarding the direction of instantaneous causality, we use graph-theoretical methods to identify the causal structure of the model from the data. Model reduction procedures allow to control for the course-of-dimensionality inhibiting such high-dimensional vector autoregressive systems. Impulse-response analysis of the parsimonious system facilitated the precise measurement of the dynamic Keynesian fiscal multiplier, where we distinguish between deficit-spending and balanced-budget government spending shocks (as in the so-called Haavelmo, 1945, theorem). Our estimates of the long-run multiplier are 1.62 in case of the bond-financed and 1.77 in case of the tax-financed spending shock, with both being significant greater than one at a 95% confidence level. Monetary policy is neutral is the long-run but have permanent effects on the level of output. Increasing the federal funds rate by a percentage point is followed by falling tax revenues while government spending is largely unchanged, thus inflating the fiscal deficit in the short- and medium run.

Keywords: Cointegrated VAR; Gets modelling; graph theory; deficit; balanced budget multiplier; spending multiplier; fiscal policy; monetary policy.

JEL classification: C32; E63; E52; G12; H62.

1 Introduction

One outcome of the 2007-2008 Global Financial Crisis and the the subsequent Great Recession is the re-emergence of fiscal policy as a powerful tool in the economic policy management of major economies around the world. Falling output was followed by falling tax revenues which when coupled with bailing out the financial system explains worsening budget deficits in various countries. Given a global economy that is yet to fully recover, and is characterised by high debt levels, deficits, and unconventional monetary policies including near-zero interest rates, a natural question ought to be asked: how does the budget deficit interact with interest rates? This empirical study answers this question and more through the analysis of US data. Our contribution to the literature is twofold. First, we analyse the interaction between fiscal policy and monetary policy and how they have affected long-maturity bond yields over the last fifty years. Second, we measure fiscal multipliers over the same period, thereby characterising the extent to which fiscal policy affects output. A characteristic of our approach is the emphasis of theoretically-consistent long-run relationships which supports the structural interpretation we attach to our results. For example, we explicitly include the deficit as a cointegration relation to allow us to study the dynamic feedback between this important budget constraint and the rest of the economy. Our results have a Keynesian flavour. From a Keynesian perspective, increasing government spending - spending, henceforth - or cutting taxes can be used to stimulate aggregate demand. This may be especially necessary during recessions. According to Ilzetzki et al. (2013), fiscal expansion if well-targeted to optimise the fiscal multiplier can stimulate aggregate demand and subsequently take an economy out of a downturn faster than if no intervention were undertaken. In fact, empirical evidence in Feldstein (1982) and Eisner (1992), among others, links budget deficits and output. This is in opposition to the Ricardian equivalence hypothesis in Barro (1989) that budget deficits do not affect output. The deficit-output debate is one with real and potentially long-lasting economic consequences. Alesina and Ardagna (2010) look at fiscal stimuli and adjustments in OECD countries between 1970 and 2007. They find: (1) tax-cut-based fiscal stimuli more likely to increase growth compared to increasing spending, and (2) fiscal adjustment in the form of a cut in spending and no tax increase is more likely to lower the deficit and the debt-to-GDP ratio than one based on a tax increase. Counter arguments posit that fiscal expansion - often entailing an increase in government debt levels - may be necessary to stop a recession from getting worse. It is important to study fiscal and monetary policy simultaneously not least because governments (to an extent) react to changes in their borrowing costs as demonstrated in de Groot et al. (2014). That there is a fiscal reaction to an increase in the interest rate at which the governments borrows can improve budget discipline, de Groot et al. (2014) argues.[1]

1.1 Fiscal policy and output

One branch of the fiscal policy literature focusses on its relationship with output. Studies on this often include, among other aspects, estimations of spending and/or tax multipliers. Blanchard and Perotti (2002) combine a structural vector autoregressive (SVAR) modelling and event-study approach to investigate the response of output and its components to tax and spending shocks in the postwar US. Large fiscal events such as the 1975 tax cut are used in the event-study section. Using institutional information and the elasticity of fiscal variables to economic activity to achieve identification, their findings are largely in line with standard Keynesian theory predictions. Positive spending shocks increase private consumption and output. Positive tax shocks have a negative effect on output. Increasing spending or taxes reduces investment spending by the private sector. Afonso and Souza (2012) look at US data 1970(3)-2007(4) and include the government inter-temporal budget constraint in modelling the macroeconomic effects of fiscal policy. They include the response of fiscal variables to government debt dynamics. The observed response is also Keynesian in nature. A positive spending shock has a positive but small effect on gross domestic product (GDP) dynamics, private consumption, private investment, and asset markets. Stock

[1] Markets do not however impose 'budgetary discipline', at least in a timely manner, as was evident when for several years the rates at which some peripheral eurozone countries was markedly lower given their budget positions. de Groot et al. (2014) argue for fiscal rules to complement markets as an enforcer of fiscal sustainability.

prices react quickly to fiscal policy shocks but house prices react more persistently. When the shock is to revenue, a crowding-out effect is detected as a positive response in private investment is quickly eroded. It is claimed that taking debt dynamics into account makes GDP and long-term interest rates more responsive, in addition to more persistent fiscal policy effects. Rossi and Zubairy (2011) finds fiscal shocks are more relevant in explaining output fluctuations in the medium term while monetary shocks are associated more with business cycle fluctuations. The approach in Rossi and Zubairy (2011) is interesting in that it simultaneously studies fiscal and monetary shocks on the macroeconomy. We too take this approach to jointly model fiscal and monetary policy, justified by the idea that the two policies can (indirectly) interact via their effects on common variables. This is certainly the case for the US where monetary policy has low unemployment as one of its goals while at the same time government-run fiscal policies do affect the level of unemployment.

Favero (2002) jointly models monetary and fiscal policy in Germany, France, Italy, and Spain, observing that not jointly modelling the two policies causes some estimated parameters to be insignificant and ignores important interactions between the two. Favero (2002) finds (1) 1970s monetary policy by non-German authorities was not able to stabilise inflation. Inflation stabilisation was achieved in the 1980s and 1990s when domestic monetary policy was tied to German monetary policy, (2) stable inflation has been achieved despite a lack of fiscal discipline, and (3) the interaction between fiscal and monetary authorities depends on the response spending and taxes to interest payments on public debt. Afonso and Souza (2011) focusses on the link between fiscal policy and asset markets for the US, UK, Germany, and Italy. Fiscal shocks are identified following Blanchard and Perotti (2002) above. Like Favero and Givazzi (2008), the specification in Afonso and Souza (2011) includes a government debt variable to capture effect of debt dynamics feedback on fiscal policy. For the US, spending shocks have a positive and persistent effect on house prices but a negative effect on stock prices. Shocks to government revenues have a negative impact on house prices, and a small but positive impact on stock prices. In fact, fiscal policy shocks only have a minor effect on the behaviour of stock markets and house prices. Perotti (2004) studies fiscal policy effects in the US, West Germany, the UK, Canada, and Australia, finding spending and tax cut effects on GDP and its components weakened after 1980. While relatively large positive effects are observed for private consumption, there is no response from private investment. Fatas and Mihov (2001) finds that consumption and employment increase in response to increases in spending.

One way to analyse fiscal policy effects is by measuring fiscal multipliers. The spending multiplier tells us how much output increases by when spending goes up. Consensus among economists on the size of fiscal multipliers is elusive. Part of the disagreement can be attributed to how fiscal shocks are identified and whether the researcher takes a Keynesian or classical view. Ricco (2014) argues that ignoring policy anticipation effects and and assuming perfect information results in wrong estimations of fiscal multipliers. Estimate of the spending multiplier lie between 0.5 and 2.5 according to Chinn (2013). On whether fiscal multipliers are dependent on prevailing economic conditions, Ramey and Zubairy (2014) do not find evidence that spending multipliers are different based on slack in the economic system. In fact, they argue that "spending multipliers were not necessarily higher than average during the Great Recession" when interest rates were near zero. Some recent studies on fiscal multipliers during recessions include but are not limited to Auerbach and Gorodnichenko (2013), Auerbach and Gorodnichenko

(2012), Bachmann and Sims (2012). Fatas and Mihov (2001) finds a spending multiplier of more than one, driven by an increase in private consumption. The response of investment to spending is insignificant. Auerbach and Gorodnichenko (2012) analyse fiscal multiplier variability over the business cycle. Using regime-switching models, fiscal multipliers are found to be larger during recessions than in expansions. Their analysis of disaggregated spending components finds military spending to have the largest multiplier. They also find that taking into account the predictability of fiscal policy increases multipliers in recessions. Perotti (2004) finds a US spending multiplier of more than one based on pre-1980 data.

1.2 Fiscal policy and interest rates

There are mixed results on the interaction between fiscal policy and interest rates, as are the variety of methodologies employed. Event studies, SVARs, and combinations of the two are quite popular. Owing to the approach in this paper, the VAR literature commands the most attention here which should allow for a clearer comparison of results. Often, bonds are investigated in the paradigm of monetary policy. However, unprecedented government intervention in the economy in response to the Great Recession has made fiscal policy a much more active component of economic policy making, necessitating analysis of the interaction between long-maturity bond yields and fiscal policy. We include the federal funds rate to represent monetary policy. In a way, we are heeding the caution in Rossi and Zubairy (2011) that ignoring that "both monetary and fiscal policy shocks simultaneously affect macroeconomic variables incorrectly attributes some macroeconomic fluctuations to the wrong source." Favero and Givazzi (2008) analyse the impact of fiscal shocks while allowing the level of public debt to affect the debt service cost, tax, and spending. They argue that "omitting such a feedback can result in incorrect estimates of the dynamic effects of fiscal shocks." They explain the absence of fiscal shock effects on long-term interest rates as due to misspecified VARs that exclude a debt feedback, in addition to not endogenising debt dynamics. The level of debt-to-GDP ratio, they argue, impacts long-term interest rate.

Marattin et al. (2011) uses cointegration to study the impact of fiscal shocks on government debt and long-term interest rate in the US, Germany, and Italy for the 1983-2009 period. Using the common trends methodology to distinguish transitory shocks (financial and inflationary) from permanent shocks (fiscal and monetary) they find (1) debt accumulation is followed by higher long-term interest rate for Germany and Italy but not for the US. The reaction of long-term interest rate in the US explained by liquidity effects. (2) Fiscal shocks determine both permanent and cyclical components of the long-term interest rate. Debt shocks have asymmetric effects depending on debt/GDP levels for Italy, and Germany but not the US. Laubach (2011) studies fiscal variables and interest rates under two scenarios: under heightened levels of sovereign default risk and, when the risk that the government will default on its debt obligations is of no concern to creditors. Again, under normal default risk conditions, results are Keynesian. Contractionary fiscal policy results in lower interest rates, real economic activity, and prices as the Federal Reserve responds with a cut in (short-term) rates. However, a weak economic environment leads to a decline in the surplus/GDP ratio, and a subsequent increase in the debt/GDP ratio. Laubach (2009) looks at links between projected deficits and public debt on one hand and long-horizon forward rates. Deficit and debt effects on interest rates are significant, both statistically and economically, with parameter estimates that are consistent with the neo-classical growth model. It is claimed that the effects of deficit and (public) debt projections by the Congressional Budgetary Office

(CBO) in the US are evident at the longer end of the yield curve. A percentage point increase in the projected deficit-to-GDP (debt-to-GDP) ratio results in interest rates rising by 25 (3 to 4) basis points. Gale and Orszag (2003) give a broad review of the literature on fiscal policy and interest rates. They suggest that studies that incorporate expected deficits tend to find a link between deficits and interest rates. They argue that deficits may increase nominal interest rates because (1) they reduce aggregate savings if foreign capital inflows and domestic private savings rises are insufficient to compensate for the fall in public saving, and (2) they lead to an increase in the stock of public debt. A higher outstanding amount of government bonds commands a higher interest rate as investors demand higher a premium to hold additional government bonds as opposed to other financial assets. Also, expected future deficits have significant effects on long-term bond yields. They also emphasise the negative long-term effect of deficits on the economy especially via reduced national saving rates that result in lower national income. In analysis of financial variables behaviour around periods of major changes in the fiscal stance in OECD countries for the period 1960-2002, Ardagna (2009) finds that long-term government bond yields fall in periods of budget consolidation but rise during fiscal deterioration. Where the fiscal policy is associated with a permanent reduction in public debt, There is a strong effect on long-term government bond yields. Stock markets surge as a result of fiscal adjustments involving expenditure reductions but fall during fiscal expansions. Importantly, these results depend on prevailing fiscal conditions and the type of fiscal policy: a spending cut that permanently reduces government debt during high-deficit periods is associated with bigger falls in interest rates.

Engen and Hubbard (2004) analyse the effect of federal government debt and interest rates. Owing to the dependence of results on model specifications, they use various specification on the same data set. They conclude that an increase in debt of 1% of GDP, ceteris paribus, increases the real long-term interest rate by about 0.03%. In a discussion of a trend in the long-term interest rate and its drivers, Brook (2003) identifies cyclical and portfolio factors as the main drivers of the 2000-2003 fall in real long-term interest rates. For selected European countries, falling inflation and exchange rates could also have lowered the equilibrium real interest rate. Attention is also drawn to US evidence pointing to a causal link from fiscal variables to real long-term interest rate. This link is characterised by both the actual and projected fiscal fiscal positions, underlying the importance of 'expectations' in this relationship. Further, an international dimension is also explored, with US originated shocks having a noteworthy effect on European and Japanese bonds than vice versa. Over all, the general picture from the literature is in agreement with the findings of this paper which are in line with the traditional Keynesian view that expansionary fiscal policy has a positive impact on output.

The paper will proceed as follows: In the next section we will introduce the data set and discuss the creation of the fiscal variables. In §3 we will introduce the econometric methodology. This is then applied to data in §4, where we discuss particular methodological issues and present the empirical findings. The model is presented in §5. It is used in §6 for the impulse response analysis of three policy experiments: (i) a balanced-budget government spending shock, (ii) a deficit-spending shock, and (iii) a fed-funds rate shock. The results will allow the estimation of the dynamic fiscal multiplier.

2 The Data

The aim of this paper is to estimate the size of the fiscal multiplier for the post-war US economy using a large parsimonious structural vector equilibrium correction model (PSVECM). We collect quarterly data on the US economy for the 1960Q1-2013Q4 period, with the sample size dictated by data availability. The data include GDP, government spending, net taxes, inflation expectations, the GDP deflator, the personal consumption expenditures (PCE) price index,[2] the federal funds rate, the 30-year maturity government bond yield, and the 30-year maturity Moody's Baa-rated corporate bond yield. Table 1 gives details and transformations of the time series characterising our 8-dimensional system.

Table 1 *Variable details*

Time series Description	Source: Label	Model variables
GDP, SA, AR	BEA: GDP	$y_t = 100\ \log(\text{GDP}/\text{GDPDEF})$
Net taxes, SA, AR	BEA: T	$\tau_t = 100\ \log(\text{T}/\text{GDPDEF})$
Govt spending, SA, AR	BEA: G	$g_t = 100\ \log(\text{G}/\text{GDPDEF})$
GDP deflator, SA	BEA: GDPDEF	GDPDEF
Inflation expectations	University of Michigan*	$\pi_t^e = 100\ \log(1+\Pi^e/100)$
Personal consumption expenditures deflator, SA	BEA : PCEPI	$\pi_t = 400\ \Delta\log(\text{PCEPI})$
Federal funds rate, NSA	FRED: FEDFUNDS	$i_t = 100\ \log(1{+}\text{FEDFUNDS}/100)$
Government bond yield, NSA	FRED: GS30†	$r_t = 100\ \log(1{+}\text{GS30}/100)$
Corporate bond yield, NSA	FRED: Baa	$b_t = 100\ \log(1{+}\text{Baa}/100)$

* Mean of the expected change in prices during the next year from Table 32 in the Survey of Consumers.
† Own calculation of missing based on GS20 (see appendix)

We define net tax and spending in the spirit of Blanchard and Perotti (2002). This should allow for comparing of results with this widely cited study on US fiscal policy. Net taxes are defined as the sum of tax and non-tax receipts, contributions for government social insurance less net transfer payments and net interest payments. We use net tax as opposed to gross tax because we are interested in the government budget constraint. Taking gross tax would ignore the fact that part of the current receipts have to be spent on prior commitments such as interest payments and social security transfers. Government spending is defined as consumption expenditures and gross government investment. We discuss this matter in more detail in the following.

2.1 Measuring government spending and net taxation

The literature on US fiscal policy from the last decade refers extensively to the Blanchard and Perotti (2002) study, making it a good benchmark to compare our results. They too work with total government data, defining net taxes as "the sum of Personal Tax and Non-tax Receipts, Corporate Profits Tax Receipts, Indirect Business Tax and Nontax Accruals, and Contributions for Social Insurance, less Net Transfer Payments to Persons and Net Interest Paid by Government. Government spending is Purchases of Goods and Services, both current and capital" (Blanchard and Perotti (2002), p.1336). Our definition of the fiscal variables (see Table 2) follows the motivation of Blanchard and Perotti (2002), but the two

[2] 'Inflation expectations' is a survey-based measure that moves more closely with consumption-based price indices than with the GDP deflator. To exploit this potential long-run relation, we use the PCE index to calculate inflation while the GDP deflator is retained to deflate GDP, net taxes, and spending.

Table 2 *Definition of the fiscal variables*

	consumption expenditures	(16)
+	gross government investment	(34)
=	government spending	

	personal current taxes	FG(3)
+	taxes on production and imports	FG(4)
+	taxes on corporate income	FG(7)
+	taxes from the rest of the world	FG(10)
+	contributions for government social insurance	FG(11)
+	income receipts on assets	FG(12)
+	current transfer receipts	FG(16)
−	current transfer payments to persons	FG(24)
−	interest payments	FG(29)
+	personal current taxes	SLG(3)
+	taxes on production and imports	SLG(6)
+	taxes on corporate income	SLG(10)
+	contributions for government social insurance	SLG(11)
+	income receipts on assets	SLG(12)
+	current transfer receipts	SLG(16)
−	federal grants-in-aid	SLG(17)
−	government social benefit payments to persons	SLG(23)
−	interest payments	SLG(24)
=	net taxation	

Note: The number in parentheses correspond to tax and spending component lines in Tables 3.1, 3.2 and 3.3 (Bureau of Economic Analysis, June 2014). FG: federal government, SLG: state and local government.

sets of series differ slightly. This difference is inevitable, given the numerous data revisions, and component re-classifications that NIPA tables have undergone over the last twelve years.[3] It is worth noting that the data cover total government, i.e., federal, state and local governments.

The fiscal series in this study are compared to those of Blanchard and Perotti (2002) in Figure 1. For the period over which the two samples overlap, we can see from the top right graph that spending in both studies are almost identical. This view is further supported by their difference plot in the bottom graph. It appears that our spending variable is just a level shift up. Differences in tax are more pronounced, with a level shift downwards in our tax measure obvious in the top left and bottom right graphs. This level shift between the two data sets is also clear in the deficit plots given by the lower left graph. These differences notwithstanding, we believe that our tax and spending definitions approximate well those in Blanchard and Perotti (2002), as is evident in Figure 1 and Table 3.

2.2 Inflation

Inflation is represented by the forward-looking inflation expectations measure from the Survey of Consumers run by the University of Michigan/Reuters and an actual inflation measure from the PCE price index. Inflation expectations are included to capture agent expectations of the path of prices in the economy and to reduce the 'price puzzle' problem common in VAR analysis. This puzzle involves a price rise in response to tightening monetary policy, such as an increase in thefed funds rate. According to Figure 2, the relationship between these two measures appears stable over time, making them viable candidates for a cointegration relation. This is supported by the result in Table 6 where $\pi - \pi^e$ is $I(0)$.

[3] Blanchard and Perotti (2002) takes 'federal corporate profits tax' data from the Quarterly Treasury Bulletin. Our fiscal data are solely from the NIPA.

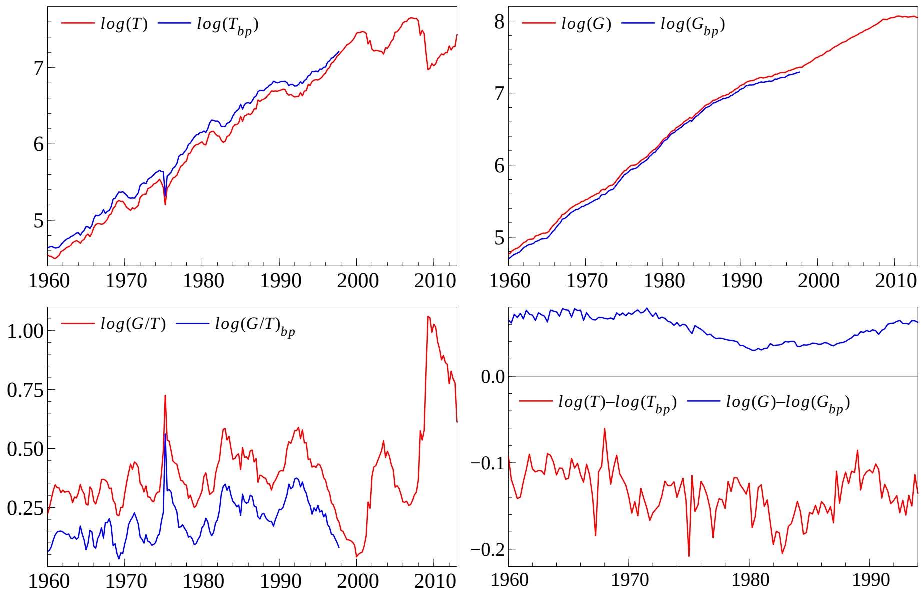

Figure 1 *Our fiscal series versus Blanchard and Perotti (2002)*

Table 3 *Summary statistics: our fiscal series versus Blanchard and Perotti (2002).*

	Study	τ	g	$\tau - g$
mean	B&P (2002)	5.945	6.138	-0.193
	1960Q1-1997Q4	5.816	6.195	-0.379
	1960Q1-2013Q4	6.269	6.673	-0.404
median	B&P (2002)	6.070	6.175	-0.179
	1960Q1-1997Q4	5.953	6.215	-0.360
	1960Q1-2013Q4	6.459	6.909	-0.365
std. dev.	B&P (2002)	0.786	0.833	0.087
	1960Q1-1997Q4	0.786	0.826	0.097
	1960Q1-2013Q4	0.996	1.021	0.186

2.3 Interest rates

The three interest rates represent the financial sector with the federal funds rate as the monetary policy proxy. The Treasury bond yield is the cost of borrowing for thirty years by the government. The corporate bond yield represents the average interest rate faced by firms when they issue debt maturing in thirty years time. Treasury bond yield data is only available from February 1977 and is also missing between 2002M3 and 2006M1, a period during which no thirty-year maturity Treasuries were issued by the government. We use splicing (details in appendix 7) together with the twenty-year maturity bond yield to approximate the missing data. All interest rate series plots are given in Figure 3.

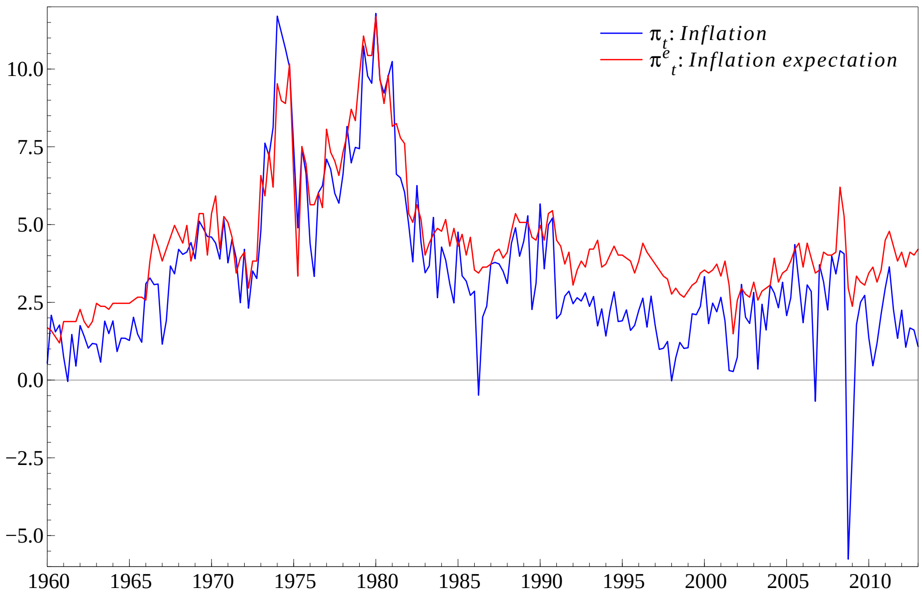

Figure 2 *Inflation expectations, and actual inflation*

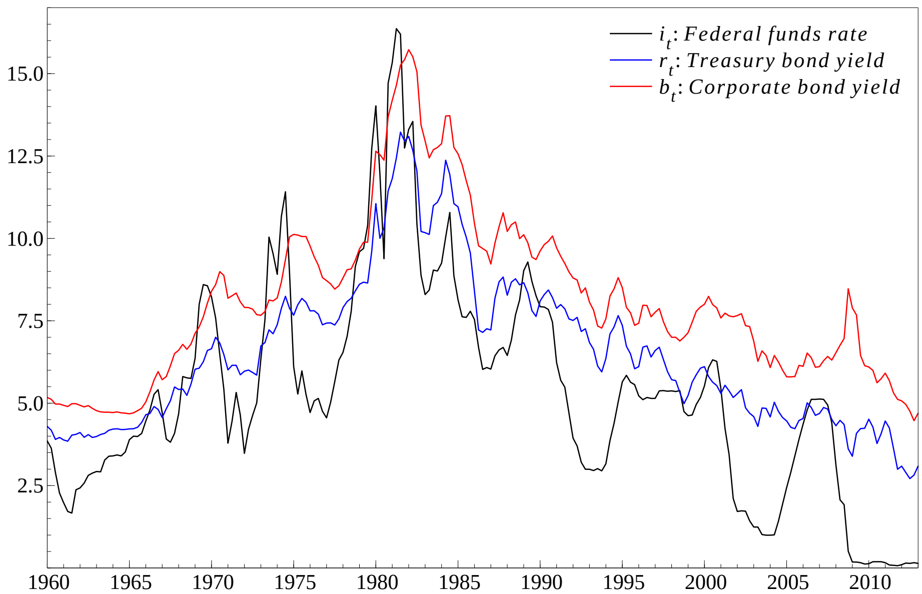

Figure 3 *The federal funds rate, the government bond yield, and the corporate bond yield.*

2.4 Unit roots

The unit-root test profiles of variables are in tables 4, 5, and 6. Only the tax share of GDP appears to be $I(0)$. All the other variables are $I(1)$ and so have to be differenced once to make them stationary. We also test for unit roots on a selection of economic theory-inspired relations. This serves as a preliminary check on the (expected) stationarity of prospective cointegration relations. They include: (i) the deficit $(\tau - g)_t$, (ii) the term structure of interest rates $(r - i)_t$, (iii) the risk premium $(b - r)_t$,(iv) the actual-expected inflation difference $(\pi^e - \pi)_t$, and (v) the real short-term interest rate $(i - \pi)_t$. They are all $I(0)$ as expected. That the deficit and $(\tau - y)_t$ are $I(0)$ while $(g - y)_t$ is $I(1)$ is a contradiction because it implies that an $I(0)$ variable cointegrates with an $I(1)$ variable. However, at this stage it is helpful to keep in mind that unit root tests are only suggestive and not definitive given their low power. Furthermore, $(\tau - y)_t$ actually has a unit root (p-value 0.277) if the test is specified with 0 lags as selected by the Schwarz information criteria (SIC).[4] Also, the ADF finds the deficit to be $I(0)$ regardless of whether the test lags are chosen based on the Akaike, Schwarz or Hannan-Quinn criteria. Impulse response analysis will confirm that after a shock, the deficit is only ever temporarily away from equilibrium.

Table 4 *Unit root tests on variables in levels*

	μ	γ	π	p	t-adf(π)	5%*CV*
y_t	8.930 (0.029)*	0.017 (0.065)	-0.024	2 (0.014)*	-2.043 (0.574)	-3.401
$(\tau - y)_t$	-19.047 (0.000)**	-0.024 (0.003)**	-0.109	5 (0.146)	-4.162 (0.006)**	-3.431
τ_t	14.060 (0.000)**	0.044 (0.001)**	-0.081	4 (0.005)**	-3.747 (0.021)**	-3.431
$(g - y)_t$	-6.464 (0.003)**	-0.005 (0.002)**	-0.044	3 (0.001)**	-3.006 (0.133)	-3.431
π_t^e	0.325 (0.023)*	-0.001 (0.230)	-0.069	2 (0.002)**	-2.369 (0.152)	-2.875
π_t	0.334 (0.039)*	-0.002 (0.189)	-0.101	2 (0.001)**	-2.598 (0.095)	-2.875
i_t	0.171 (0.121)	-0.002 (0.053)	-0.009	7 (0.005)**	-1.030 (0.272)	-1.942
r_t	0.087 (0.265)	-0.001 (0.080)	-0.002	5 (0.037)*	-0.484 (0.505)	-2.875
b_t	0.119 (0.138)	-0.001 (0.185)	-0.001	1 (0.000)**	-0.466 (0.512)	-2.942

Sample: 1960Q1-2013Q4. Tests based on $\Delta x_t = \mu + \gamma t + \pi x_{t-1} + \sum_{j=1}^{p} \phi_j \Delta x_{t-j} + \varepsilon_t$ with the lag length selected by the Akaike Information Criteria (AIC). The null hypothesis, $H_0 : \pi = 0$, implies presence of a unit root and is rejected when t-adf $<$ CV.

[4] However, the Hannan-Quinn criterion (HQ) selects 4 lags and $(\tau - y)_t$ is $I(0)$ according to a 0.013 p-value, in line with the Akaike information criteria (AIC) benchmark test specification. $(g - y)_t$ is $I(0)$, regardless of the information criteria used in the test specification.

Table 5 *Unit root tests on variables in differences*

	μ	γ	π	p	t-adf(π)	5%CV
Δy_t	0.428 (0.000)**	-0.002 (0.062)	-0.558	1 (0.014)*	-7.168 (0.000)**	-2.875
$\Delta(g-y)_t$	0.005 (0.972)	-0.001 (0.651)	-0.543	2 (0.007)**	-5.913 (0.000)**	-3.431
$\Delta\pi_t^e$	0.098 (0.389)	-0.001 (0.409)	-1.519	1 (0.00)**	-14.491 (0.000)**	-3.431
$\Delta\pi_t$	0.149 (0.452)	-0.001 (0.392)	-2.234	8 (0.006)**	-6.631 (0.000)**	-3.431
Δi_t	0.105 (0.342)	-0.001 (0.242)	-0.914	6 (0.003)**	-6.608 (0.000)**	-3.341
Δr_t	0.002 (0.926)	-0.001 (0.121)	-0.89	4 (0.036)*	-7.255 (0.000)**	-1.942
Δb_t	0.000 (0.999)	-0.000 (0.209)	-0.654	0	-10.219 (0.000)**	-1.942

Table 6 *Unit root tests on prospective cointegration relations*

	μ	γ	π	p	t-adf(π)	5%CV
$(\tau-g)_t$	-2.748 (0.003)**	-0.009 (0.179)	-0.067	6 (0.074)	-3.140 (0.025)*	-2.876
$(r-i)_t$	-0.071 (0.486)	0.003 (0.002)	-0.223	8 (0.010)	-5.126 (0.000)**	-3.431
$(b-r)_t$	0.209 (0.000)**	-0.001 (0.057)	-0.130	1 (0.000)**	-4.363 (0.001)**	-2.875
$(\pi^e-\pi)_t$	0.057 (0.703)	-0.004 (0.008)**	-0.440	5 (0.002)**	-3.852 (0.016)*	-3.431
$(i-\pi^e)_t$	0.032 (0.673)	-0.002 (0.097)	-0.059	7 (0.002)**	-1.982 (0.046)*	-1.942
$(i-\pi)_t$	0.229 (0.082)	-0.002 (0.365)	-0.081	2 (0.000)**	-2.357 (0.018)*	-1.942

3 Econometric Methodology

In contrast to the existing literature, we follow a data-driven modelling approach that combines the VAR based cointegration analysis of Johansen (1995) and Juselius (2006) with the graph-theoretic approach of Spirtes et al. (2001) implemented in TETRAD for the search for instantaneous causal relations and the automatic general-to-specific model selection algorithm implemented in *PcGets* of Krolzig and Hendry (2001) for the selection of a congruent parsimonious structural vector equilibrium correction model.

3.1 Methodology

The General-to-specific approach implemented in this paper follows the modelling approach of Krolzig (2003) and consists of the following four stages (see Hoover et al. (2009), for a related approach):

(i) *Specification of the general unrestricted system.*

We commence from a reduced-form vector autoregressive (VAR) model of order p and dimension K, without any equation-specific restrictions, to capture the characteristics of the data:

$$\boldsymbol{y}_t = \nu + \sum_{j=1}^{p} \boldsymbol{A}_j \boldsymbol{y}_{t-j} + \varepsilon_t, \tag{1}$$

where $\varepsilon_t \sim \mathsf{NID}(\mathbf{0}, \boldsymbol{\Sigma})$ is a Gaussian white noise process. This step involves the specification of the deterministic terms, selection of the lag length, p, and misspecification tests to check the validity of the assumptions made.

(ii) *Johansen cointegration tests* and *identification of the cointegration vectors*.

The Johansen procedure for determining the cointegration rank, r, is then applied to the VAR in (1) mapped to its vector equilibrium-correction mechanism (VECM) representation:

$$\Delta \boldsymbol{y}_t = \boldsymbol{\nu} + \boldsymbol{\Pi} \boldsymbol{y}_{t-1} + \sum_{j=1}^{p-1} \boldsymbol{\Gamma}_j \Delta \boldsymbol{y}_{t-j} + \varepsilon_t. \tag{2}$$

For a cointegrated vector process, the reduced-rank matrix, $\boldsymbol{\Pi}$, can be decomposed into a $K \times r$ dimensional loading matrix, $\boldsymbol{\alpha}$, and cointegration matrix, $\boldsymbol{\beta}$, containing the information of the long-run structure of the model, i.e., $\boldsymbol{\Pi} = \boldsymbol{\alpha}\boldsymbol{\beta}'$. The Johansen procedure delivers unique estimates of $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ as a result of requiring $\boldsymbol{\beta}$ to be orthogonal and normalized. These estimates provide a value for the unrestricted log-likelihood function to be compared to the log-likelihood under economically meaningful overidentifying restrictions, $\boldsymbol{\beta}^r$:

$$\Delta \boldsymbol{y}_t = \boldsymbol{\nu} + \boldsymbol{\alpha} \boldsymbol{\beta}^{r'} \boldsymbol{y}_{t-1} + \sum_{j=1}^{p-1} \boldsymbol{\Gamma}_j \Delta \boldsymbol{y}_{t-j} + \varepsilon_t, \tag{3}$$

with $\boldsymbol{\Sigma} = \mathsf{E}[\varepsilon_t \varepsilon_t']$. The empirical modeling procedure for finding the cointegration relations follows Juselius (2006).

(iii) *Graph-theoretic search for instantaneous causal relations.*

The determination of the contemporaneous causal links between the variables has been advanced by modern graph-theoretic methods of searching for causal structure based on relations of conditional independence developed by computer scientists (Pearl (2000)) and philosophers (Spirtes et al. (2001)). Following Demiralp and Hoover (2003), who introduced this approach to econometrics, we use the PC algorithm implemented in TETRAD 4 (see Spirtes et al. (2005) for details). The PC algorithm exploits the information embedded in the residual variance-covariance matrix, $\hat{\boldsymbol{\Sigma}}$, of the system in (6). A causal structure is represented by a graph with arrows from causes to caused variables. To detect the directed acyclic graph, the algorithm starts by assuming that all variables are linked to each other through an undirected link. In the elimination stage, connections are first removed between variables which are unconditionally uncorrelated. Then connections are eliminated for variables which are uncorrelated conditional on other variables. Having identified the skeleton of the graph, the orientation step of the algorithm seeks to orient the undirected edges by logical reasoning. This involves the analysis of indirect connections by taking into account the whole graph, considering every pair of variables, exploiting already directed edges and the acyclicality condition.

If all edges could be oriented, a directed acyclic graph (DAG) results. Based on the identified contemporaneous causal structure of the system, the VECM in (6) can be represented as a *recursive* structural vector equilibrium correction mechanism (SVECM). By a suitable ordering of the variables of the system, the DAG can be mapped to a lower-triangular contemporaneous matrix, $\boldsymbol{B}^r$, with units on the diagonal and non-zero lower-off-diagonal elements representing the causal links found by the PC algorithm. In contrast to a traditional orthogonalisation with the help of a Choleski decomposition of $\hat{\boldsymbol{\Sigma}}$, this approach results in an overidentified SVECM in the majority of cases. The zero lower-triangular elements of $\boldsymbol{B}^r$ provide testable overidentifying constraints allowing to verify the validity of the selected contemporaneous structure. Most importantly, as the contemporaneous causal structure captured by $\boldsymbol{B}^r$ is data determined, it avoids the problems associated with the ad-hoc nature of orthogonalised structural VAR models. [5]

(iv) *Single-equation reductions of the recursive SVECM.*

Here we consider *Gets* reductions of the SVECM to reduce the complexity of the model and to overcome the curse of dimensionality. Starting point is the structural VECM with long-run relations $\boldsymbol{\beta}^r$ determined by stage (ii) and contemporaneous structure $\boldsymbol{B}^r$ given by the corresponding directed acyclic graph:

$$\boldsymbol{B}^r \Delta \boldsymbol{y}_t = \boldsymbol{\delta} + \tilde{\boldsymbol{\alpha}} \left(\boldsymbol{\beta}^{r\prime} \boldsymbol{y}_{t-1} \right) + \sum_{j=1}^{p-1} \boldsymbol{\Upsilon}_j \Delta \boldsymbol{y}_{t-j} + \boldsymbol{\eta}_t, \quad \boldsymbol{\eta}_t \sim \mathsf{NID}(\mathbf{0}, \boldsymbol{\Omega}), \tag{4}$$

where $\boldsymbol{B}^r$ is the lower-triangular matrix found by TETRAD and $\boldsymbol{\Omega}$ is a diagonal variance-covariance matrix. A single-equation based *Gets* reduction procedure such as *PcGets* can be applied to the equations in (4) straightforwardly and, as shown in Krolzig (2001), without a loss in efficiency.

[5]% If the PC algorithm finds a link but has insufficient information to identify if, say, ‘A causes B’ or ‘B causes A’, an undirected edge emerge. In this case, there exists a set of contemporaneous causal structures, $\{\boldsymbol{B}^{(i)}\}$, that are all consistent with the data evidence. An additional modelling stage is then required for the selection of $\boldsymbol{B}^r$ and, thus, the identification of the direction of causality. Having applied the model reduction step in (iv) to each SVECM associated with one of the found contemporaneous causal structures, the dominant econometric model is finally selected in (v).

The parameters of interest are the coefficients collected in the intercept, $\boldsymbol{\delta}$, the adjustment matrix $\tilde{\boldsymbol{\alpha}}$ and the short-run matrices $\boldsymbol{\Gamma}_j$ in the structural VECM. The result is a parsimonious structural vector equilibrium correction model denoted PSVECM, which is nested in (4) and defined by the selected $\boldsymbol{\delta}^*$, $\tilde{\boldsymbol{\alpha}}^*$ and $\boldsymbol{\Upsilon}_j^*$ with $j = 1, \ldots, p-1$.

(v) *Selection of the dominant PSVECM.*

If the graph-theoretical search in (iii) produces an acyclic graph with at least one undirected edge, the determination of the direction of instantaneous causal relations has to rely on the information from the PSVECMs resulting from the *Gets* reduction of the SVECMs as defined by the set of contemporaneous causal structures. As the PSVECMs are mutually non-nested and the union is usually unidentified, we propose to select the PSVECM with the greatest penalized likelihood. Thus the dominant design of the contemporaneous effects matrix according to information criteria such as Akaike or Schwarz would be used.

4 Empirical findings

We estimate a structural vector error-correction model (SVECM) and use it to analyse the dynamics of eight key US economic variables spanning more than fifty years. The modelling procedure is general-to-specific. We start with an unrestricted VAR(p) model and determine the lag length p. We then determine the number cointegrating relations in the system the trace test from Johansen (1988) and Johansen (1995). These are linear relations among (some, or all of) the series that are stable in the long-run. Next, we apply the PC algorithm from Pearl (2000) and Spirtes et al. (2000) to the residuals from the identified cointegrated VAR to retrieve the contemporaneous relationships structure among the variables. By mapping this contemporaneous structure into the VECM, we estimate the structural VECM. The SVECM still has several insignificant parameters at this stage. We therefore use the *Gets* reduction procedure in Krolzig (2003) to drop insignificant terms, leaving behind a parsimonious structural model (PSVECM) that is a congruent representation of the data generating process (DGP). It is with this PSVECM that we implement economic analysis. We carry out impulse response analyse to understand how shocks propagate the system.

4.1 The VAR model

We start by estimating the unrestricted 8-dimensional reduced-form VAR(4) model in (5). $\boldsymbol{x}_t = (y_t, \tau_t, g_t, \pi_t^e, \pi_t, i_t, r_t, b_t)'$, $\boldsymbol{\mu}$ is the vector of intercepts and has dimension 8×1, $\boldsymbol{\gamma}$ is the 8×1 vector of trend-coefficients, $\boldsymbol{A}_j$ an 8×8 matrix of coefficients at the j^{th} lag. $\boldsymbol{u}_t$ is a Gaussian vector of white noise processes each with zero mean and $\boldsymbol{\Sigma}$ their variance-covariance matrix.

$$\boldsymbol{x}_t = \boldsymbol{\mu} + \boldsymbol{\gamma} t + \sum_{j=1}^{p} \boldsymbol{A}_j \boldsymbol{x}_{t-j} + \boldsymbol{u}_t, \quad \boldsymbol{u}_t \sim \mathsf{NID}(\boldsymbol{0}, \boldsymbol{\Sigma}) \tag{5}$$

We need the correct lag length p to estimate (5) and of course, the resulting model should pass the usual diagnostic tests, including having autocorrelation-free residuals. The four starting lags are motivated by a need to be consistent with the vast majority of the literature on fiscal and monetary shocks. This choice is also based on the fact that we are working with quarterly data. To check whether

Table 7 *VAR lag length determination. Sample: 1960Q1-2013Q4*

Order	logL	LR	AIC	SC	HQ
0	-3606.282		34.1724	34.4258	34.2748
1	-1881.823	3286.233	18.5773	19.7744*	19.0197*
2	-1795.855	157.338	18.3008	20.5804	19.2220
3	-1722.750	128.277	18.2147*	21.5078	19.5456
4	-1669.105	90.083*	18.3123	22.6188	20.0529

* indicates selected lag order. LR: sequential modified LR test statistic (each test at 5% level). AIC: Akaike information criterion. SC: Schwarz information criterion. HQ: Hannan-Quinn information criterion.

the lag length can be reduced, we use various information criteria in Table 7. Clearly, the criteria do not agree on one, three, or four lags. But the choice of four lags is within the general-to-specific spirit since any insignificant terms will be dropped in the final model. We therefore choose four lags as indicated by the LR test.

4.2 Cointegration

Cointegration analysis aims to identify any linear relationships in the data that are stable in the long-run. Looking at the time series plots of our eight variables in figures 2, and 3, there is strong co-movement amongst (some of) the variables. If these co-movements are linear and stable, they could represent cointegration relations. This is supported by results in tables 4 and 6 showing that while all but the $(\tau - y)_t$ variable are $I(1)$ in *levels*, some linear combinations of these variables do produce $I(0)$ *relations*. Potential cointegrating relations include: the deficit, the term structure of interest rates, the risk premium, the expected-actual inflation relation, and the real short-term interest rate. A formal test to determine the number of cointegrating relations is given in Table 8. The Johansen trace test, Johansen (1988), is based on (6), which is just the error-correction form of (5) less $\Delta \boldsymbol{x}_{t-j}$ lags. The number of cointegrating relations is given by the rank of matrix $\boldsymbol{\Pi}$, where $\boldsymbol{\Pi} = \boldsymbol{\alpha}\boldsymbol{\beta}'$ in (6).

$$\Delta \boldsymbol{x}_t = \boldsymbol{\mu} + \boldsymbol{\alpha}(\gamma t + \boldsymbol{\beta}' \boldsymbol{x}_{t-1}) + \boldsymbol{u}_t, \quad \boldsymbol{u}_t \sim \mathsf{NID}(\mathbf{0}, \boldsymbol{\Sigma}) \tag{6}$$

Results in Table 8 show that at the benchmark 5% significance level, there are four cointegrating relations in the data. It is vital at this stage that the correct number of cointegrating relations is determined, given its importance to proceeding analysis. One runs the risk of making wrong inference if more relations specified than exist in the data. On the other hand, specifying less relations than exist means excluding important information from the analysis, especially in a long-run dynamics study like ours. To this effect, a careful interpretation of the trace test results is warranted. At the traditional 5% significance level, the trace test in Table 8 rejects $H_0 : rank(\boldsymbol{\Pi}) \leq r$, for $r = 1$, 2, or 3, but not $r \leq 4$, which is not rejected with 0.073 probability, thereby suggesting four cointegration relations in the data. However, we argue that there are five cointegration relations based on the following reasons. First, results in Table 6 suggest a rank of 5, possibly involving relations: $\{(\tau - g)_t$ or $(\tau - y)_t\}$, $(r - i)_t$, $(b - r)_t$, $(\pi^e - \pi)_t$, and $(i - \pi)_t$. Relations 2-5 were identified in Krolzig and Sserwanja (014a). Second, if relation 1 is the deficit, then it can be justified from economic theory as a binding budget constraint for the government. There is empirical evidence, notably Bohn (1998) and Blanchard and Perotti (2002) among others, that

Table 8 *Cointegration Rank test of Johansen (1988) for CVAR with restricted trend and unrestricted constant.,*

null	trace statistic	5% CV	p-value
$r=0$	254.208***	187.470	0.0000
$r \leq 1$	187.395***	150.558	0.0001
$r \leq 2$	136.994***	117.708	0.0017
$r \leq 3$	91.129**	88.803	0.0336
$r \leq 4$	61.848*	63.876	0.0732
$r \leq 5$	36.635	42.915	0.1840
$r \leq 6$	14.379	25.872	0.6262
$r \leq 7$	5.129	12.517	0.5778

*,**,*** indicate significance at 10%, 5% and 1% significance, respectively.

the deficit is indeed stationary, albeit at only the 5% significance level. Finally, while a looser criteria for rejecting $r=4$, 7.3% is still less than 10%, a threshold that is sometimes used in the literature. Certainly, the 18.4% p-value on which the rank of 5 is based is a stronger criteria. We can therefore be reasonably confident that there are 5 linear and stable long-run relations in the data. The five cointegrating relations indeed suffice to identify the long-run with a 0.1959 joint p-value.

4.3 Contemporaneous causal relationships between variables

There are various ways to identify monetary and fiscal policy shocks as discussed in Perotti (2007). These are often motivated by what the researcher assumes to be the correct transmission mechanism of the policy in question. Choleski decomposition is a popular identification technique.[6] However, this approach is criticised for assuming the causality direction. It ignores agents who anticipate policy changes and alter their actions accordingly. Misidentifying shocks this way could therefore lead to under-estimation of fiscal multipliers, as pointed out in Ricco (2014). One solution to the 'lack-of-anticipation' critique levelled at traditional identification procedures is the 'narrative' approach in Ramey and Shapiro (1998), Edelberg et al. (1999), Burnside et al. (2004), Romer and Romer (2010), Ramey (2011) and in part, Blanchard and Perotti (2002), among others.[7] This route often involves pinpointing particular times in history when tax or spending policy changed but not in response to the prevailing state of the economy. These could be increased spending to finance a war or an unanticipated increase in taxes. These shocks are therefore deemed exogenous. Imposing sign restrictions on impulse responses as in Mountford and Uhlig (2009) is another route to shock identification.

How we identify shocks in this study is motivated by the need to *let the data speak.* Furthermore, our data-driven identification produces a SVECM that is a valid reduction of a Choleski-identified sys-

[6]This involves constructing a lower-triangular matrix of contemporaneous causal effects. The implication is that a shock to variable one is instantaneously transmitted to all the other variables, a shock to variable two is is transmitted to all other variables but only with a lag to variable one, and so on. A criticism of this approach is it depends on the researcher to determine which shock effects are immediate and which act with a lag. Fatas and Mihov (2001) discusses fiscal shocks identified by Choleski decomposition.

[7]The 'event-study' methodology was developed in Romer and Romer (1989) to analyse monetary policy.

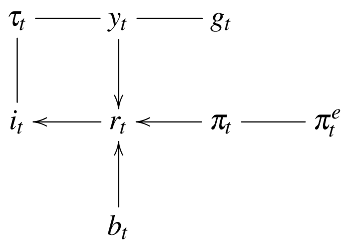

Figure 4 *Instantaneous causality as found by Tetrad*

tem since the imposed restrictions pass the likelihood ratio test. To this effect, we use the *conservative* version of PC (CPC) algorithm implemented in the TETRAD software project at Carnegie Mellon University. Details on how this algorithm is used in economics to determine the contemporaneous causal order in SVAR analysis are in Demiralp and Hoover (2003). Spirtes and Glymour (1991), Spirtes et al. (2010), Pearl (2000), and Spirtes et al. (2000) provide further information on this algorithm and its roots in philosophy and computer science. Briefly, it is a graph-theory-based technique that can take as input covariance matrix data and output a directed acyclic graph (DAG) representing the contemporaneous causal pattern in the data generating process. It determines the causal structure among variables by analysing their conditional *in*dependence based on tests of conditional correlation.[8]

We use as input for the algorithm the residuals from the VECM(3) after identifying the long-run structure. The significance level for the dependence test is set to 10%.[9] The graph below gives the causal pattern found by the algorithm. In all, there 8 significant within-quarter interactions among the variables. However, only half of these are oriented with the algorithm unable to orient the remaining 4. These have to be oriented via other means.

We orient the remaining four links by analysing the 12 model permutations that result from the non-oriented interactions. Ahe Akaike (AIC), Hannan-Quinn (HQ), and Schwarz (SC) information criteria all choose model 5. However, the long-run (Π) matrix for PSVECM5 has a positive eigenvalue, suggesting instability in system defined by causal order 5. This instability is actually apparent in explosive impulse responses from this model. On the other hand, Model 6, despite not being preferred by any of the likelihood-based model ranking measures, generates five eigenvalues lying in the $(-1,0)$ interval and 3 zero eigenvalues. This is what is expected according to the five cointegrating relations identified earlier. In fact, model 6 impulse response functions are quite reasonable. Further, Model 6 falls within the 5-8 range of models that are theoretically consistent. We therefore map the causal structure underlying model 6 into matrix $\boldsymbol{B}^r$ and estimate the PSVECM.

The identified causal structure can be mapped into the contemporaneous matrix $\boldsymbol{B}^r$ reported in Table

[8] If r_{ij} is the unconditional correlation coefficient between variables i and j, then the correlation of i and j conditional on k is $r_{ij|k} = (r_{ij} - r_{ik}r_{jk})/(\sqrt{1-r_{ik}^2}\sqrt{1-r_{jk}^2})$. The significance of the correlation coefficient is determined using Fisher's z-statistic with $H_0 : r_{ij|k} = 0$ and $z = ln((1+r_{ij|k})/(1-r_{ij|k})) \sim \mathrm{N}(0,1/(T-3))$

[9] The TETRAD 5.1.0-3 manual (p.89) suggests a 5% significance level for dependence for samples of less than 500 observations. With 211 observations, this would suggest the use of $\alpha = 5\%$. However, the overidentifying restrictions imposed by the resulting SVECM are rejected by the likelihood ratio test. Setting $\alpha = 10\%$ gives an SVECM that passes the LR test.

Table 9 *Determining the causal order of undirected links.*

PSVECM	Causal Order				AIC	SC	HQ
M_1	y←g,	y←τ,	τ→i,	π^e←π	-7.656 (3)	-5.623 (5)	-6.834 (2)
M_2	y←g,	y←τ,	τ→i,	π^e→π	-7.561 (9)	-5.607 (7)	-6.771 (7)
M_3	y→g,	y←τ,	τ→i,	π^e←π	-7.574 (6)	-5.620 (6)	-6.784 (6)
M_4	y→g,	y←τ,	τ→i,	π^e→π	-7.479 (11)	-5.605 (8)	-6.722 (10)
M_5	y←g,	y→τ,	τ←i,	π^e←π	-7.684 (1)*	-6.699 (1)*	-6.882 (1)*
M_6	y←g,	y→τ,	τ←i,	π^e→π	-7.589 (4)	-5.683 (2)	-6.819 (3)
M_7	y←g,	y→τ,	τ→i,	π^e←π	-7.661 (2)	-5.517 (9)	-6.794 (5)
M_8	y←g,	y→τ,	τ→i,	π^e→π	-7.566 (7)	-5.501 (10)	-6.732 (9)
M_9	y→g,	y→τ,	τ←i,	π^e←π	-7.588 (5)	-5.650 (3)	-6.805 (4)
$M_1 0$	y→g,	y→τ,	τ←i,	π^e→π	-7.493 (10)	-5.634 (4)	-6.742 (8)
$M_1 1$	y→g,	y→τ,	τ→i,	π^e←π	-7.565 (8)	-5.468 (11)	-6.717 (11)
$M_1 2$	y→g,	y→τ,	τ→i,	π^e→π	-7.470 (12)	-5.453 (12)	-6.655 (12)

Figure in parenthesis gives a model's ranking out of 12.

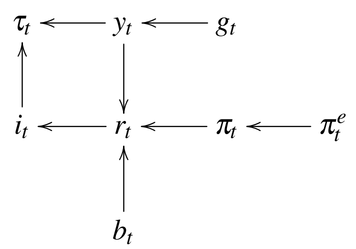

Figure 5 *Instantaneous causality: Selected Directed Acyclic Graph*

Table 10 *Instantaneous causality: Contemporaneous feedback matrix*

$$
\boldsymbol{B}^r \boldsymbol{x}_t = \begin{pmatrix} 1 & . & . & . & . & . & . & . \\ b_{yg} & 1 & . & . & . & . & . & . \\ 0 & 0 & 1 & . & . & . & . & . \\ 0 & 0 & b_{\pi\pi^e} & 1 & . & . & . & . \\ 0 & 0 & 0 & 0 & 1 & . & . & . \\ 0 & b_{ry} & 0 & b_{r\pi} & b_{rb} & 1 & . & . \\ 0 & 0 & 0 & 0 & 0 & b_{ir} & 1 & . \\ 0 & b_{\tau y} & 0 & 0 & 0 & 0 & b_{\tau i} & 1 \end{pmatrix} \begin{pmatrix} g_t \\ y_t \\ \pi_t^e \\ \pi_t \\ b_t \\ r_t \\ i_t \\ \tau_t \end{pmatrix}
$$

Note: . indicates Choleski-type upper-triangular zero constraints;
0 indicates over-identifying zero constraints.

10. The variables are ordered as to ensure that $\boldsymbol{B}^r$ is lower triangular and can be compared to Cholesky decomposition. The causal order is not unique, but its choice of does not affect the further analysis. The overidentifying restrictions imposed by the DAG results in a highly parsimonious design.

4.4 Computer-automated Gets single-equation reductions of the SVECM

As high-dimensional VAR models suffer from the curse of dimensionality, a model reduction is required to generate meaningful impulse responses. We are using general-to-specific model selection algorithm implemented in *PcGets* of Krolzig and Hendry (2001). Starting point is the structural VECM with the identified long-run relations $\boldsymbol{\beta}$ from the Johansen (1995)-Juselius (2006) approach and contemporaneous structure $\boldsymbol{B}^r$ given by the corresponding directed acyclic graph:

$$
\boldsymbol{B}^r \Delta \boldsymbol{x}_t = \boldsymbol{\delta} + \boldsymbol{\alpha}\delta t + \boldsymbol{\alpha}\boldsymbol{\beta}' \boldsymbol{x}_{t-1} + \sum_{j=1}^{p-1} \boldsymbol{\Upsilon}_j \Delta \boldsymbol{x}_{t-j} + \boldsymbol{\omega}_t, \quad \boldsymbol{\omega}_t \sim \mathsf{NID}(\mathbf{0}, \boldsymbol{\Omega}), \tag{7}
$$

where $\boldsymbol{B}^r$ is the lower-triangular matrix found by TETRAD and $\boldsymbol{\Omega}$ is a diagonal variance-covariance matrix. A single-equation based *Gets* reduction procedure such as *PcGets* can be applied to the equations in (7) straightforwardly and, as shown in Krolzig (2001), without a loss in efficiency. The parameters of interest are the coefficients collected in the intercept, $\boldsymbol{\delta}$, the adjustment matrix $\tilde{\boldsymbol{\alpha}}$ and the short-run matrices $\boldsymbol{\Upsilon}_j$ in the structural VECM. The result is a parsimonious structural vector equilibrium correction model denoted PSVECM, which is nested in (7) and defined by the selected $\boldsymbol{\delta}^*$, $\tilde{\boldsymbol{\alpha}}^*$ and $\boldsymbol{\Upsilon}_j^*$ with $j = 1, \ldots, p-1$.

5 The Model

Following We have estimated a parsimonious structural model (PSVECM) to analyse interaction between fiscal policy and interest rates regarding their effect on output. Misspecification tests in Table 11 reveal that some of the model residuals are heteroscedastic. However, our model passes most of the usual diagnostic tests. Critically, all equations pass the autocorrelation test (up to 4^{th} order). Also, none suffers ARCH effects. The RESET test is also passed although the tax equation only passes at the lower 1% threshold. The few violations notwithstanding, our model seems satisfactory for use in analysis.

Table 11 *PSVECM misspecification tests*

Test	Δy_t	$\Delta \tau_t$	Δg_t	$\Delta \pi^e_t$	$\Delta \pi_t$	Δi_t	Δr_t	Δb_t
AR 1-4:	0.99 (0.4149)	0.86 (0.4904)	1.58 (0.1820)	1.09 (0.3644)	0.87 (0.4829)	1.09 (0.3644)	0.68 (0.6056)	0.46 (0.7666)
ARCH 1-4:	1.96 (0.1026)	2.41 (0.0509)	0.74 (0.5628)	2.14 (0.0769)	0.71 (0.5843)	2.32 (0.0590)	0.75 (0.5624)	1.85 (0.1203)
Hetero:	1.55 (0.0426)	*4.84 (0.0000)	**0.53 (0.9487)	0.92 (0.5595)	1.43 (0.1378)	3.538 (0.0000)	**1.30 (0.1428)	1.68 (0.0176) *
RESET:	0.002 (0.9650)	6.76 (0.0100)	*0.57 (0.4510)	1.24 (0.2664)	0.99 (0.3210)	1.10 (0.2962)	3.79 (0.0530)	0.14 (0.7100)

*,** indicates rejection at 5% and 1% significance level, respectively.

The model dynamics of output, government spending and net taxes are captured in equations (8)-(**??**). Most coefficients are theoretically-consistent, especially those on long-run relations which are our main interest. The dynamics of real GDP are determined by (8), which shows that the deficit has a negative effect on GDP growth.A 1% increase in G/T is followed by a 0.0079% fall in real GDP in the next quarter, ceteris paribus. While statistically significant, this magnitude is arguably of little economic relevance. On the other hand, increasing the liquidity premium by a percentage point elicits a 0.17% rise in real output. After spending rises by 1%, GDP increases by 0.21% contemporaneously. This is an interest result because 0.21 is also the average ratio of spending-to-GDP for the US economy.

$$\begin{aligned}\Delta\widehat{y}_t = \; & \underset{(0.1)}{0.98} - \underset{(0.003)}{0.0079}\,(g-\tau)_{t-1} + \underset{(0.03)}{0.17}\,(r-i)_{t-1} + \underset{(0.06)}{0.14}\,\Delta y_{t-1} + \underset{(0.008)}{0.038}\,\Delta\tau_{t-2} + \underset{(0.04)}{0.21}\,\Delta g_t \\ & - \underset{(0.04)}{0.1}\,\Delta g_{t-3} - \underset{(0.06)}{0.12}\,\Delta\pi^e{}_{t-2} - \underset{(0.05)}{0.11}\,\Delta\pi^e{}_{t-3} - \underset{(0.03)}{0.076}\,\Delta\pi_{t-1} + \underset{(0.03)}{0.047}\,\Delta\pi_{t-2} + \underset{(0.06)}{0.18}\,\Delta i_{t-1} \\ & - \underset{(0.05)}{0.18}\,\Delta i_{t-2} + \underset{(0.2)}{0.52}\,\Delta r_{t-1} - \underset{(0.2)}{0.96}\,\Delta b_{t-1} + \underset{(0.4)}{1.6}\,\Delta i1971(1)_t + \underset{(0.6)}{2.7}\,\mathrm{i}1978(2)_t \\ & \hat{\sigma} = 0.56,\ R^2 = 0.58\end{aligned} \tag{8}$$

Equation (9) suggests taxes are highly endogenous, reacting to four out of five cointegration relations. Taxes are error-correcting via the deficit with a 1% increase in G/T leading to a 0.042% rise in real tax. In other words, an increase in the deficit if followed by a tax rise.

$$\begin{aligned}\Delta\widehat{\tau}_t = \; & \underset{(0.01)}{0.042}\,(g-\tau)_{t-1} - \underset{(0.17)}{0.45}\,(r-i)_{t-1} - \underset{(0.35)}{2.4}\,(b-r)_{t-1} + \underset{(0.2)}{0.57}\,(\pi-\pi^e)_{t-1} + \underset{(0.3)}{2.2}\,\Delta y_t + \underset{(0.3)}{1.2}\,\Delta y_{t-1} \\ & - \underset{(0.05)}{0.09}\,\Delta\tau_{t-1} - \underset{(0.7)}{1.82}\,\Delta b_{t-1} - \underset{(2.5)}{18.7}\,\Delta i1975(2)_t - \underset{(3.5)}{18.3}\,\mathrm{i}2008(2)_t + \underset{(3.5)}{15.5}\,\mathrm{i}2013(1)_t + \underset{(2.4)}{13.6}\,\Delta i2013(2)_t \\ & \hat{\sigma} = 3.42,\ R^2 = 0.62\end{aligned} \tag{9}$$

The liquidity premium has a negative effect on taxes, which is surprising since a positive liquidity premium indicates expected increase in economic activity, and therefore an increase in tax collections. One explanation of the sign is that inflation from a relatively higher government bond causes the *real* tax fall. A rise in $(b-r)$, which tends to widen during periods of low economic activity, leads to lower taxes. Combining long-run effects from the liquidity and risk premia, we infer that the government bond yield has a positive effect on tax. For the final cointegration relation effect, inflation expectations above inflation by a percentage point leads real taxes fall by 0.57%. Short-run effects are dominated by output and some dummies. Dummies $\Delta i1975(2)$ and $i2008(2)$ capture the 1975 (temporary) tax cut and the 2007-08 tax rebate. $i2013(1)$ and $\Delta i2013(2)$ are likely due to effects from expiration of the Bush tax cuts of 2001 and 2003.[10] Spending is also error-correcting via the deficit.

Interestingly, the deficit is the only long-run relation affecting spending. At a speed of 1.6% per quarter, spending adjusts slower than tax (4% adjustment speed per quarter) to maintain the stationary relationship.

$$\begin{aligned}\Delta\widehat{g}_t = \underset{(0.1)}{1.1} &- \underset{(0.003)}{0.016}\,(g-\tau)_{t-1} - \underset{(0.01)}{0.034}\,\Delta\tau_{t-1} + \underset{(0.06)}{0.18}\,\Delta g_{t-1} - \underset{(0.07)}{0.22}\,\Delta\pi^e{}_{t-2} - \underset{(0.08)}{0.26}\,\Delta\pi^e{}_{t-3} \\ &+ \underset{(0.05)}{0.11}\,\Delta\pi_{t-3} - \underset{(0.3)}{0.063}\,\Delta r_{t-3} - \underset{(0.3)}{0.41}\,\Delta b_{t-3} + \underset{(0.6)}{2.3}\,\Delta i1963(3)_t + \underset{(0.9)}{2.9}\,\mathrm{i1965(3)}_t + \underset{(0.9)}{3.7}\,\mathrm{i1967(1)}_t \\ &\hat{\sigma} = 0.85,\ R^2 = 0.35\end{aligned} \tag{10}$$

Equations (11) and (12) describe inflation dynamics in the system. Both expected inflation and actual inflation error-correct, with the later adjusting about four times faster (63%) than the former (15%) per quarter. Krolzig and Sserwanja (014a) finds a comparable quarterly adjustment speed of 16% for inflation expectations. The Federal Reserve's preference and targeting of low, stable inflation since the early 1980s has probably anchored inflation expectations and created a high degree of hysteresis in this variable.

$$\begin{aligned}\Delta\widehat{\pi}^e{}_t = \underset{(0.1)}{0.54} &- \underset{(0.07)}{0.36}\,(b-r)_{t-1} + \underset{(0.04)}{0.15}\,(\pi-\pi^e)_{t-1} - \underset{(0.05)}{0.41}\,\Delta\pi^e{}_{t-1} - \underset{(0.05)}{0.38}\,\Delta\pi^e{}_{t-2} + \underset{(0.03)}{0.067}\,\Delta\pi_{t-3} \\ &- \underset{(0.1)}{0.23}\,\Delta r_{t-3} + \underset{(0.6)}{3.3}\,\mathrm{i1973(1)}_t + \underset{(0.4)}{2.7}\,\Delta 4i1974(1)_t - \underset{(0.6)}{4}\,i1975(2)_t + \underset{(0.6)}{2.3}\,\mathrm{i1977(1)}_t \\ &+ \underset{(0.6)}{2.2}\,\mathrm{i2008(2)}_t \\ &\hat{\sigma} = 0.56,\ R^2 = 0.58\end{aligned} \tag{11}$$

Actual inflation, on the other hand, is more likely to be driven by economic fundamentals and so will change as they do. The risk premium is another long-run relation affecting both inflation measures, but differently. During recessions when inflation expectations are low, the risk premium rises as investors move from riskier financial assets and into safer government bonds. However, in an expansion actual inflation rises and as investors move into equities, corporate bond yields rise relative to government bond yields. Dummies $i2008(2)$ and $i2008(4)$ are quite notable because they likely capture the 2008 oil price shock and the financial crisis and Great Recession that took hold in late 2008. Oil prices rose steeply

[10]The 'Economic Growth and Tax Relief Reconciliation Act of 2001' and the 'Jobs and Growth Tax Relief Reconciliation Act of 2003' also known as the 'Bush tax cuts' expired. The highest marginal tax rate also increased from 35% to 39.5%.

around the summer of 2008.

$$\Delta\widehat{\pi}_t = -\underset{(0.039)}{0.083}(r-i)_{t-1} + \underset{(0.05)}{0.19}(b-r)_{t-1} - \underset{(0.07)}{0.63}(\pi-\pi^e)_{t-1} - \underset{(0.06)}{0.25}\Delta y_{t-3} + \underset{(0.08)}{0.96}\Delta\pi^e{}_t$$
$$+ \underset{(0.09)}{0.31}\Delta\pi^e{}_{t-1} - \underset{(0.06)}{0.11}\Delta\pi_{t-1} - \underset{(0.9)}{7.4}\text{ i2008(4)}_t \qquad (12)$$
$$\hat{\sigma} = 0.89,\ R^2 = 0.49$$

Equations (13), (14), and (15) represent the financial markets. As the monetary policy equation, (15) has a Taylor Rule effect in the interaction between the federal funds rate and the $(\pi - \pi^e)$ relation. Interaction with the liquidity premium captures the expectations hypothesis of the term structure of interest rates. Interestingly, the federal funds rate is sensitive to the deficit. Monetary policy is clearly accommodative by over 30 basis points during recessions which is when the deficit tends to rise. The bond equations are both error-correction via the risk premium, with the Treasury bond doing so at a faster speed. In addition, they are both sensitive to the real interest rate, especially the corporate bond. So, restrictive monetary policy can act through the real short-term interest rate to stabilize long-term interest rates, and therefore inflation.

$$\Delta\widehat{b}_t = \underset{(0.07)}{0.23} - \underset{(0.02)}{0.13}(r-i)_{t-1} - \underset{(0.04)}{0.11}(b-r)_{t-1} - \underset{(0.01)}{0.05}(i-\pi)_{t-1} + \underset{(0.03)}{0.065}\Delta y_{t-3} + \underset{(0.004)}{0.011}\Delta\tau_{t-1}$$
$$+ \underset{(0.004)}{0.014}\Delta\tau_{t-2} - \underset{(0.004)}{0.010}\Delta\tau_{t-3} - \underset{(0.018)}{0.030}\Delta g_{t-2} - \underset{(0.02)}{0.054}\Delta\pi_{t-1} - \underset{(0.01)}{0.044}\Delta\pi_{t-2} - \underset{(0.03)}{0.08}\Delta i_{t-1}$$
$$- \underset{(0.03)}{0.101}\Delta i_{t-2} + \underset{(0.08)}{0.515}\Delta r_{t-1} - \underset{(0.08)}{0.194}\Delta b_{t-1} + \underset{(0.06)}{0.146}\Delta b_{t-2} + \underset{(0.3)}{1.1}\text{ i1979(4)}_t + \underset{(0.2)}{0.90}\Delta i1980(1)_t$$
$$+ \underset{(0.3)}{1.8}\text{ i2008(4)}_t$$
$$\hat{\sigma} = 0.25,\ R^2 = 0.58 \qquad (13)$$

$$\Delta\widehat{r}_t = -\underset{(0.05)}{0.24} + \underset{(0.03)}{0.2}(b-r)_{t-1} - \underset{(0.02)}{0.064}(\pi-\pi^e)_{t-1} - \underset{(0.006)}{0.022}(i-\pi)_{t-1} + \underset{(0.02)}{0.068}\Delta y_t + \underset{(0.01)}{0.029}\Delta g_{t-1}$$
$$- \underset{(0.01)}{0.038}\Delta g_{t-2} - \underset{(0.02)}{0.097}\Delta\pi^e{}_{t-1} - \underset{(0.02)}{0.043}\Delta\pi^e{}_{t-2} + \underset{(0.01)}{0.04}\Delta\pi_t + \underset{(0.02)}{0.047}\Delta\pi_{t-1} + \underset{(0.01)}{0.037}\Delta\pi_{t-2}$$
$$+ \underset{(0.02)}{0.039}\Delta i_{t-2} + \underset{(0.02)}{0.035}\Delta i_{t-3} + \underset{(0.06)}{0.24}\Delta r_{t-1} + \underset{(0.04)}{0.88}\Delta b_t - \underset{(0.06)}{0.25}\Delta b_{t-1} - \underset{(0.1)}{0.56}\Delta i1980(2)_t$$
$$- \underset{(0.2)}{1.5}\text{ i2008(4)}_t$$
$$\hat{\sigma} = 0.18,\ R^2 = 0.81 \qquad (14)$$

$$
\begin{aligned}
\widehat{\Delta i_t} = & -\underset{(0.001)}{0.0033}\ (g-\tau)_{t-1} + \underset{(0.02)}{0.086}\ (r-i)_{t-1} + \underset{(0.03)}{0.088}\ (\pi-\pi^e)_{t-1} + \underset{(0.05)}{0.27}\ \Delta y_{t-1} - \underset{(0.04)}{0.074}\ \Delta g_{t-1} \\
& -\underset{(0.03)}{0.069}\ \Delta g_{t-3} + \underset{(0.05)}{0.098}\ \Delta \pi^e{}_{t-1} + \underset{(0.05)}{0.16}\ \Delta \pi^e{}_{t-2} + \underset{(0.04)}{0.13}\ \Delta \pi^e{}_{t-3} + \underset{(0.05)}{0.37}\ \Delta i_{t-1} - \underset{(0.05)}{0.1}\ \Delta i_{t-2} \\
& + \underset{(0.05)}{0.12}\ \Delta i_{t-3} + \underset{(0.09)}{0.62}\ \Delta r_t + \underset{(0.2)}{0.55}\ \Delta r_{t-1} - \underset{(0.1)}{0.51}\ \Delta r_{t-2} - \underset{(0.2)}{0.68}\ \Delta b_{t-1} + \underset{(0.1)}{0.33}\ \Delta b_{t-2} \\
& + \underset{(0.3)}{1.5}\ \Delta i1973(3)_t + \underset{(0.5)}{4.8}\ \mathrm{i}1980(4)_t - \underset{(0.3)}{2.7}\ \Delta i1981(4)_t + \underset{(0.6)}{3.3}\ \mathrm{i}2009(1)_t \\
& \hat{\sigma} = 0.46,\ R^2 = 0.71
\end{aligned} \tag{15}
$$

Overall, fiscal and monetary variables interact both in the short and long-run. This interaction is both direct - such as the $(r-i)$ effect in the tax equation - as well as indirectly through other variables.

6 Three Policy Experiments and the Fiscal Multiplier

Before we will consider the impulse response analysis of the model, we look into the measurement problems involved with estimating the fiscal multiplier. The focus is then on the system impulse responses for a ten-year period. Confidence intervals are also included, constructed via bootstrap with 5000 replications following Hall (1992). Based on these results, we will finally provide estimates of the fiscal multiplier before concluding by considering a monetary policy shock with focus on its consequences for fiscal policy.

6.1 Measuring the Keynesian fiscal multiplier

The aim of this paper is to estimate the size of the multiplier for the post-war US economy using a large-scale parsimonious structural vector equilibrium correction model (PSVECM). For the measurement of the fiscal multiplier we will rely on the methods of impulse response analysis.

We shall consider the deficit-spending and the balanced-budget multiplier. The spending multiplier gives the change in GDP due to a change in spending. The balanced budget multiplier gives the change in GDP due to a simultaneous change in spending and tax that leaves the deficit unchanged. If both spending and revenue change by the same amount, the Haavelmo theorem posits that national income will also change by the same amount, suggesting a multiplier of one. Matthiessen (1966) questioned the validity of the 1:1 multiplier, while still claiming it to be non-zero. This is in contrast to a deficit-spending multiplier which is greater than one.

Consider a closed economy with a Keynesian consumption function and autonomous investment spending. The goods market equilibrium is given by

$$
Y = \bar{I} + \bar{C} + c(Y-T) + G \tag{16}
$$

such that effective demand is

$$
Y = \frac{\bar{I} + \bar{C} - cT + G}{1-c}. \tag{17}
$$

In case of deficit-financed government spending shock, we have $dT = 0$, such that the fiscal multiplier results as in Keynes (1936):

$$M = dY/dG = \frac{1}{1-c}. \tag{18}$$

For a tax-financed government spending shock, $\Delta T = \Delta G$, Haavelmo (1945) showed that

$$M = dY/dG = 1. \tag{19}$$

Since our model is formulated in logs with $y = \log Y$, $g = \log G$, $\tau = \log T$, the multiplier will appear as an elasticity. Therefore, it is worth noting that we should expect (i) under deficit spending ($\Delta T = 0$):

$$\mu \equiv \frac{dy}{dg} \equiv \frac{dY/Y}{dG/G} = \frac{1}{1-c}\frac{G}{Y} \tag{20}$$

and (ii) for the tax-financed spending $dT = dG$ ('Haavelmo Theorem')

$$\mu \equiv \frac{dy}{dg} \equiv \frac{dY/Y}{dG/G} = \frac{G}{Y} \approx 0.2. \tag{21}$$

Allowing for dynamic responses to shocks requires to focus on the dynamic multiplier. For the Robertson lag in the consumption function, $C_t = \bar{C} + c(Y_{t-1} - T_{t-1})$, we would get:

$$M(0) = 1, \quad M(h) \underset{h\to\infty}{\longrightarrow} \frac{1}{1-c}, \tag{22}$$

$$\mu(0) = 1, \quad \mu(h) \underset{h\to\infty}{\longrightarrow} \frac{1}{1-c}\frac{G}{Y}. \tag{23}$$

Alternatively, we could take into account the cumulated effects of the shock when measuring the dynamic multiplier.

$$\begin{aligned} M_t(h) &= \frac{\sum_{i=0}^{h} dY_{t+i}}{\sum_{i=0}^{h} dG_{t+i}} = \frac{\sum_{i=0}^{h} Y_{t+i} dy_{t+i}}{\sum_{i=0}^{h} G_{t+i} dg_{t+i}} \\ &\approx \overline{G/Y}^{-1} \mu_t(h) = \overline{G/Y}^{-1} \frac{\sum_{i=0}^{h} dy_{t+i}}{\sum_{i=0}^{h} dg_{t+i}} \end{aligned} \tag{24}$$

where dy_{t+h} and dg_{t+h} denote the responses to a fiscal shock h quarters ago.

The analysis analyis above could be expanded by considering an IS-LM model as a simple framework for exploring the interaction between budget deficits and and real output. The Keynesian model posits that fiscal policy influences economic activity by affecting aggregate demand. If there are underutilised resources in the economy, for example during a recession, then increasing the budget deficit - tax cuts, increased spending, or a combination of the two - should put upward pressure on aggregate demand. As aggregate demand expands via the fiscal multiplier, output increases. Expansionary fiscal policy shifts the IS curve to the right such that the IS and LM schedules intersect at a new equilibrium with higher output and interest rates. The higher interest rate level offsets some of the multiplier effects by crowding out private investment.

6.2 The deficit-spending shock

We start by investigating the effects of a deficit spending shock represented by $\varepsilon_t^g = 1$ and $\varepsilon_t^\tau = 0$. The results are depicted in figures 6 and 7. After spending goes up by 1%, output rises by 0.21% on impact. The rises in output, tax, and spending are all still significant ten years after the initial shock. The

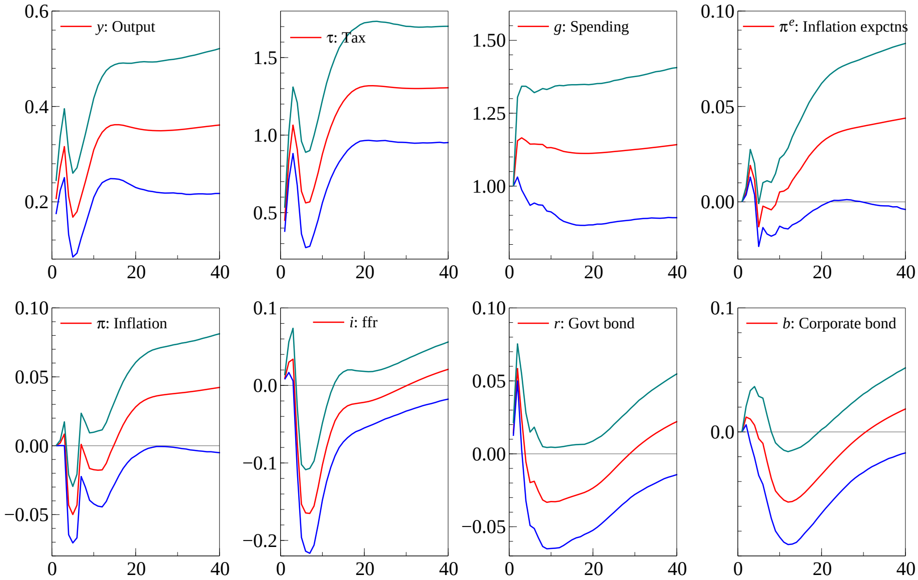

Figure 6 *Level variables response to a 1% increase in spending*

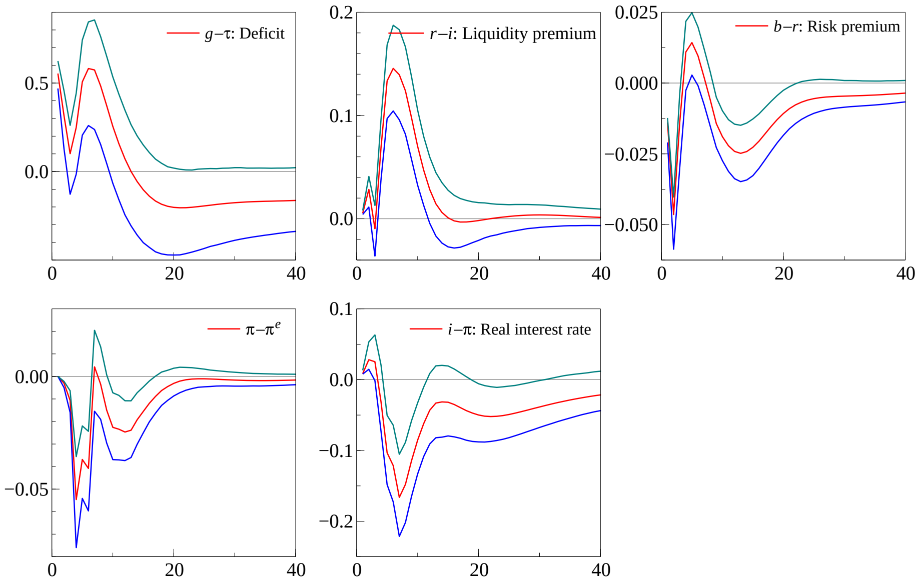

Figure 7 *Long-run relation response to a 1% increase in spending*

responses of inflation and interest rates are similar to those after a Haavelmo shock, suggesting that the spending component dominates the tax component in the Haavelmo shock. According to Figure 7, deficit spending stimulates the economy to the extent that it reduces the risk premium and the real short-term interest rate, albeit temporarily. The (temporary) increase in the liquidity premium also points to the spending shock having a stimulating effect on economic activity.

6.3 The balanced-budget government spending shock

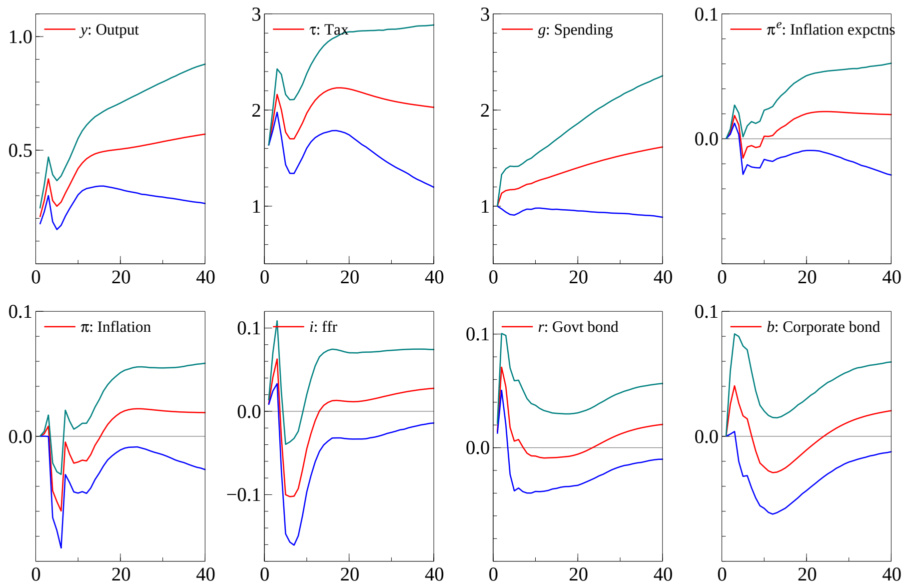

Figure 8 *Level variable response to a tax-financed spending shock*

In addition to a deficit-spending only or tax only shocks, we are also interested in the effect of a *simultaneous* shock to both fiscal variables. As mentioned above, where this is done such that the deficit remains unchanged, we have a balanced budget shock, otherwise known as the Haavelmo theorem. Such an exercise contributes to the on-going public discussion on how to stimulate the economy: changing spending, taxes, or a mixture of the two. The Haavelmo shock requires that $T\Delta\tau = G\Delta g$, where for T and G we use the respective sample means $\bar{T}$ and $\bar{G}$. This reduces to $\Delta\tau = 1.63\Delta g$. Figure 8 is for impulse responses to a Haavelmo shock. GDP, tax, and spending all rise significantly over the next 10 years. However, there is no change of economic significance in inflation. There is a temporary increase in the Treasury yield relative to the fed funds rate. This steepening in the yield curve is seen reaction of the liquidity premium in Figure 9 which, as expected, has all changes in long-run relations as temporary. The deficit is notable for it takes nearly 15 years to return to its long-run path.

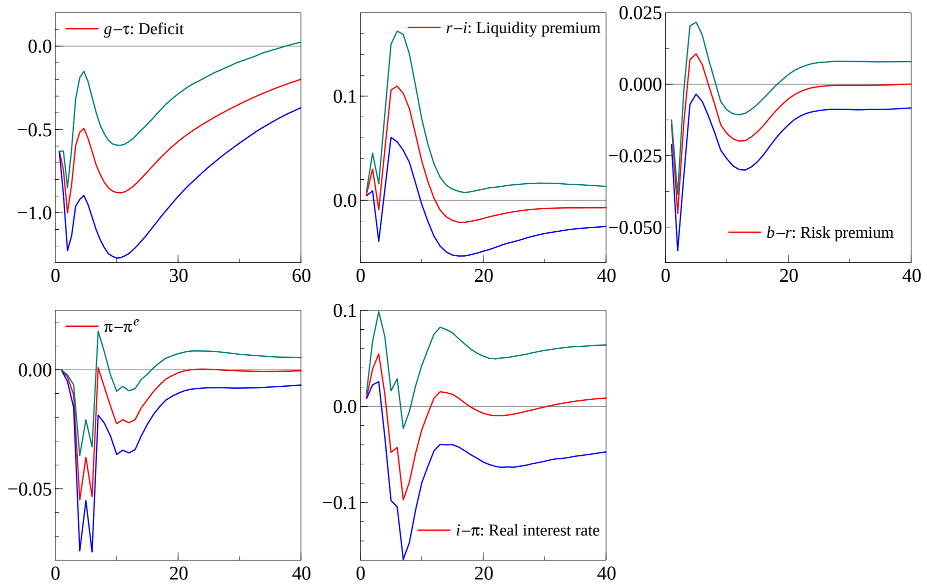

Figure 9 *Long-run relation response to a tax-financed spending shock*

6.4 The fiscal multiplier

Based on the impulse responses derived in the previous two subsections, we are now in position to the estimate the dynamic multiplier for both the deficit- and tax-financed spending shocks. We propose to define the dynamic multiplier, $M_t(h)$, as the ratio of the cumulative change in GDP to the cumulative change in government spending up to h quarters after the shock:

$$M_t^X(h) = \frac{\sum_{i=0}^{h} \nabla Y_{t+i}}{\sum_{i=0}^{h} \nabla G_{t+i}} \approx \frac{\sum_{i=0}^{h} Y_{t+i} \nabla y_{t+i}}{\sum_{i=0}^{h} G_{t+i} \nabla g_{t+i}} \approx \left(\overline{G/Y}\right)^{-1} \frac{\sum_{i=0}^{h} \nabla y_{t+i}}{\sum_{i=0}^{h} \nabla g_{t+i}}, \tag{25}$$

where ∇g_{t+i} and ∇y_{t+i} denote responses of log government spending and log GDP to a fiscal shock i quarters ago. Since $g_t - \tau_t \sim I(1)$, note that $\overline{G/Y}$ is defined here only as the sample mean.

Table 12 *Fiscal Multipliers*

	1 qrt	4 qrt	8 qrts	12 qrts	20 qrts	peak (qrts)
Deficit-spending multiplier						
K&S (2014)	1.04*	0.75*	1.24*	1.60*	1.60*	1.64*(14)
B&P (2002)	0.84*	0.45	0.54	1.13*	0.97*	1.29*(15)
Haavelmo multiplier						
K&S (2014)	1.04*	1.09*	1.57*	1.85*	1.81*	1.87*(13)

* response significant at 5%.

The top panel of Table 12 compares multipliers in this study against those in Blanchard and Perotti (2002) over a five year horizon after a shock to spending. Our multiplier is significant over the 20 quarters, unlike that by Blanchard and Perotti (2002) which fluctuates from being significant in quarter one, insignificant in quarters four to eight and the significant after twelve quarters. Our multiplier converges to 1.62, so our model estimates that a $1 increase in government spending results in a $1.62 increase in GDP. This is in contrast to the 1.29 multiplier that Blanchard and Perotti (2002) finds. However, the Haavelmo multiplier converges to a higher level of 1.77. The balanced budget stimulus generates a higher increase in output - 14 cents more - than a purely spending stimulus. A plot of the two multipliers can be seen in Figure 10.

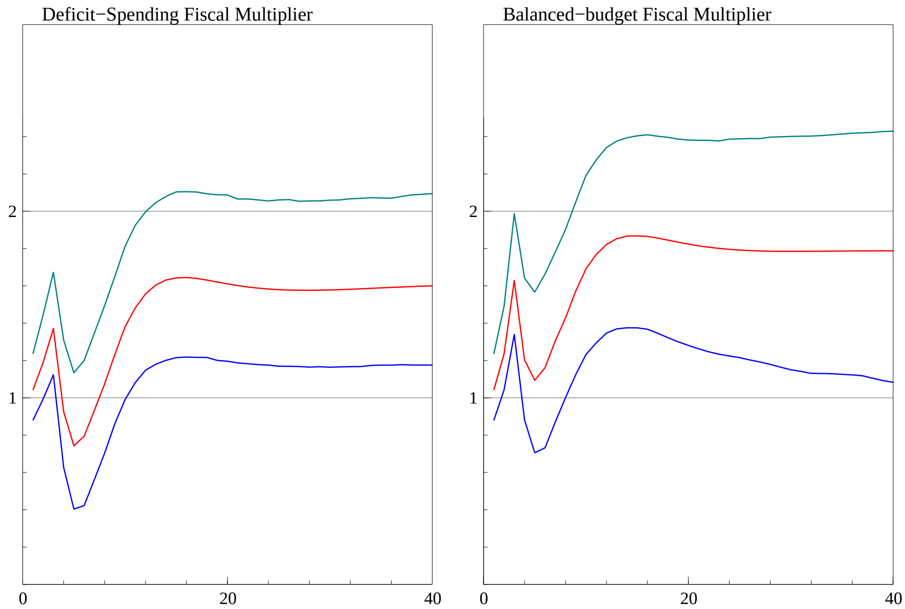

Figure 10 *Haavelmo shock versus deficit-spending shock*

Both multipliers start at value close to one, meaning that the increase in output is almost entirely due to the increase in government demand. After three to four years the multiplier peaks at values of 1.64 and 1.87, respectively. These are very close to long-run multiplier. Interestingly, the Haavelmo multiplier exceeds the deficit-spending multiplier. This is in sharp contrast to he original Keynesian theory, predicting a Haavelmo multiplier of one.

6.5 A monetary policy shock

Joint modelling of fiscal policy and monetary policy captures the effects of the actions of one policy maker on economic variables that are of interest to another policy maker: the effect of fiscal policy on monetary policy, and vice versa. We have indeed seen above that spending and tax shocks affect the federal funds rate in the long-run, according to equation (15). Monetary policy also affects fiscal variables not just in the short-run but also when the liquidity premium relation affects taxes, for example. These effects are augmented by results from impulse response analysis where there are significant, albeit temporary, changes in tax revenues after a monetary policy shock. For other variable responses, inflation falls temporarily and with a lag. The Treasury yield suffers no significant changes but the corporate bond yield by 31 bps. A falling liquidity premium, and rising real short-term interest rate point to monetary policy's potency in cooling an over-heating economic activity, at least temporarily. Such an policy is helped by an increase in the risk premium.

The impulse responses in Figures 11 and 12 show a pronounced and long-lived effect of a tightening of monetary policy (in form of a 1% point increase in the federal funds rate) on the fiscal deficit. This

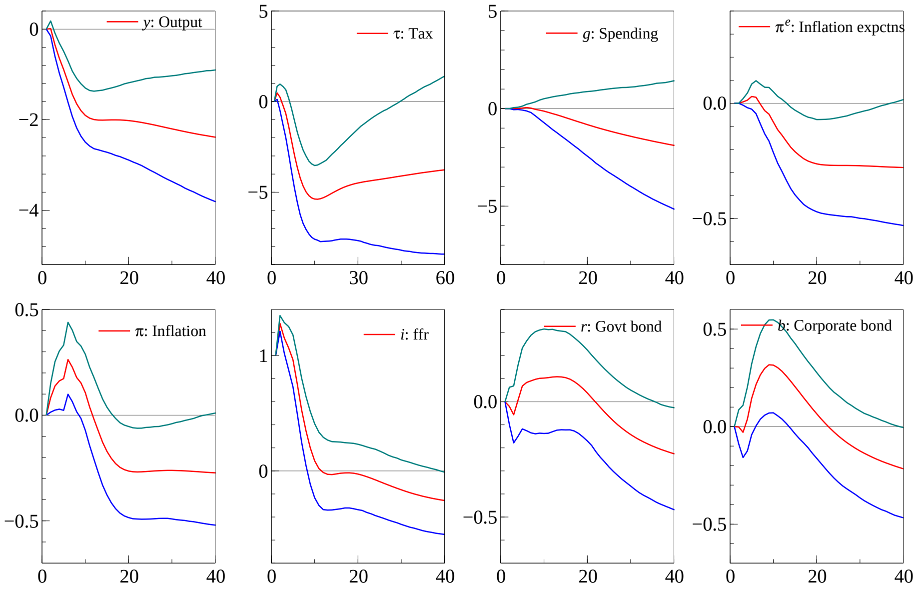

Figure 11 *Level response to a* 1% *point increase in the federal funds rate*

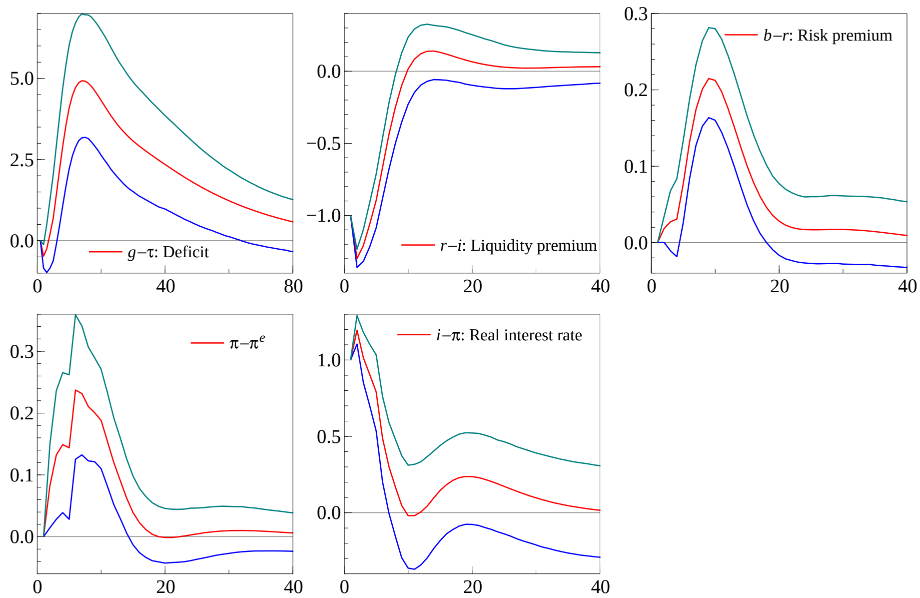

Figure 12 *Long-run relation response to a* 1% *point increase in the federal funds rate*

suggests that the expansionary stance of the Federal Reserve since the Global Financial Crisis has been supportive in controlling the deficit.

7 Conclusion

We have investigated the dynamics of fiscal and monetary policy with respect to their effect on output, inflation, and long-term interest rates. Jointly modelling monetary and fiscal policy allows us to capture the extent of the interaction between the government and the central bank insofar as one's actions affect the other. This is in addition to the effect of either policy maker's actions on output, inflation, and long-run interest rates. In particular, we investigate the Haavelmo shock, the idea that a simultaneous increase in spending and taxes which leaves the deficit unchanged should have a significant effect on output. This is indeed found to be the case based on a balanced budget multiplier of 1.77 that we estimate. A spending only multiplier is found to be 1.62. We find that fiscal policy directly affects monetary policy via the deficit, with the federal funds rate falling in response to an increase in the deficit. The effects of monetary policy tightening are qualitatively in line with findings in the literature with output and inflation falling, while corporate longer maturity bond yields rise. The temporary increase in the risk premium suggests that the corporate bond yield rises faster and by more than the government bond, evidence that the central bank can alter economic conditions by targeting the risk premium. That the Haavelmo shock significantly affects output offers a powerful tool in the use of taxes and spending for economic stabilisation. Such a policy offers a viable compromise between proponents for tax or spending-based stabilisation of the economy.

References

Afonso, A. and M. R. Souza (2011). What are the effects of fiscal policy on asset markets? *Economic Modelling 28*, 1871–1890. 3

Afonso, A. and M. R. Souza (2012). The macroeconomics of fiscal policy. *Applied Economics 44:34*, 4439–4454. 2

Alesina, A. and S. Ardagna (2010). Large changes in fiscal policy: Taxes versus spending. *NBER 24*, 35–68. 2

Ardagna, S. (2009). Financial markets' behavior around episodes of large changes in the fiscal stance. *European Economic Review 53*, 37–55. 5

Auerbach, A. J. and Y. Gorodnichenko (2012). Measuring the output responses to fiscal policy. *American Economic Journal : Economic Policy 4(2)*, 1–27. 4

Auerbach, A. J. and Y. Gorodnichenko (2013). Fiscal multipliers in recession and expansion. *University of Chicago Press, Fiscal policy after the financial crisis, edited by Alberto Alesin and Francesco Giavazzi*. 4

Bachmann, R. and E. R. Sims (2012). Confidence and the transmission of government spending shocks. *Journal of Monetary Economics 59*, 235–249. 4

Barro, R. J. (1989). The ricardian approach to budget deficits. *The Journal of Economic Perspectives 3*(2), pp. 37–54. 2

Blanchard, O. and R. Perotti (2002). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. *The Quarterly Journal of Economics, MIT Press 117(4)*, 1329–1368. 2, 3, 6, 7, 8, 15, 16, 27, 28

Bohn, H. (1998). The behavior of u.s. public debt and deficits. *The Quarterly Journal of Economics 113*(3), 949–963. 15

Brook, A. M. (2003). Recent and prospective trends in real long-term interest rates: Fiscal policy and other drivers. *OECD Economic Department Working Paper No. 367*. 5

Burnside, C., M. Eichenbaum, and J. D. M. Fisher (2004). Fiscal shocks and their consequences. *Journal of Economic Theory 115 (1)*, 89–117. 16

Chinn, M. (2013). Fiscal multipliers. *The New Palgrave Dictionary of Economics*. 3

de Groot, O., F. Holm-Hadulla, and N. Leiner-Killinger (2014). Cost of borrowing shocks and fiscal adjustment. *Federal Reserve Board, and European Central Bank*. 2

Demiralp, S. and K. D. Hoover (2003). Searching for the causal structure of a Vector Autoregression. *Oxford Bulletin of Economics and Statistics 65*, 745–767. 13, 17

Edelberg, W., M. Eichenbaum, and J. D. M. Fisher (1999). Understanding the effects of a shock to government purchases. *Review of Economic Dynamics 2 (1)*, 166–206. 16

Eisner, E. (1992). Deficits: Which, how much and so what? *American Economic Review 82*(2), 295–298. 2

Engen, M. E. and R. G. Hubbard (2004). Federal government debt and interest rates. *NBER Macroeconomics Annual 19*. 5

Fatas, A. and I. Mihov (2001). The effects of fiscal policy on consumption and employment: Theory and evidence. *CEPR Discussion Paper No. 2760*. 3, 4, 16

Favero, C. (2002). How do monetary and fiscal authorities behave? *Universita Bocconi, IGIER Working Paper No. 214*. 3

Favero, C. and F. Givazzi (2008). Debt and the effects of fiscal policy. *Universita Bocconi*. 3, 4

Feldstein, M. (1982). Government deficits and aggregate demand. *Journal of Monetary Economics 9*(1), 1 – 20. 2

Gale, W. G. and P. R. Orszag (2003). Economic effects of sustained budget deficits. *National Tax Journal 56 (3)*. 5

Haavelmo, T. (1945). Multiplier effects of a balanced budget. *Econometrica 13*, 311–318. 24

Hall, P. (1992). *The Bootstrap and Edgeworth Expansion*. New York: Springer. 23

Hoover, K. D., S. Demiralp, and S. J. Perez (2009). Empirical identification of the vector autoregression: The causes and effects of U.S. M2. In J. Castle and N. Shephard (Eds.), *The Methodology and Practice of Econometrics: A Festschrift in Honour of David F. Hendry*, pp. 37–58. Oxford: Oxford University Press. 12

Ilzetzki, E., E. G. Mendoza, and C. A. Végh (2013). How big (small?) are fiscal multipliers? *Journal of Monetary Economics 60*, 239–254. 2

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control 12*, 231–254. 14, 15, 16

Johansen, S. (1995). *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press. 12, 14, 19

Juselius, K. (2006). *The cointegrated VAR model*. Oxford: Oxford University Press. 12, 19

Keynes, J. M. (1936). *The General Theory of Employment, Interest and Money*. London: Macmillan. 24

Krolzig, H.-M. (2001). General-to-specific reductions in vector autoregressive processes. In R. Friedmann, L. Knüppel, and H. Lütkepohl (Eds.), *Econometric Studies - A Festschrift in Honour of Joachim Frohn*, pp. 129–157. Münster: LIT Verlag. 13, 19

Krolzig, H.-M. (2003). General-to-specific model selection procedures for structural vector autoregressions. *Oxford Bulletin of Economics and Statistics 65*, 769–801. 12, 14

Krolzig, H.-M. and D. F. Hendry (2001). Computer automation of general-to-specific model selection procedures. *Journal of Economic Dynamics and Control 25*, 831–866. 12, 19

Krolzig, H.-M. and I. Sserwanja (2014a). Corporate bond yields in the transmission mechanism of monetary policy. *University of Kent at Canterbury*. 15, 21, 34

Laubach, T. (2009). New evidence on the interest rate effects of budget deficits and debt. *Journal of the European Economic Association 7*(4), 858–885. 4

Laubach, T. (2011). Fiscal policy and interest rates: The role of sovereign default risk. *NBER International Seminar on Macroeconomics*. 4

Marattin, L., P. Paesani, and S. Salotti (2011). Fiscal shocks, public debt, and long-term interest rate dynamics. *Quaderni DSE Working Paper No. 740*. 4

Matthiessen, L. (1966). A note on the haavelmo theorem. *The Swedish Journal of Economics 98 (4)*, 261–280. 23

Mountford, A. and H. Uhlig (2009). What are the effects of fiscal policy shocks? *Journal of Applied Econometrics 24*, 960–992. 16

Pearl, J. (2000). *Causality: Models, Reasoning, and Inference*. Cambridge: Cambridge University Press. 13, 14, 17

Perotti, R. (2004). Estimating the effects of fiscal policy in oecd countries. *Bocconi University*. 3, 4

Perotti, R. (2007). In search of the transmission mechanism of fiscal policy. *NBER Working Paper 13143*. 16

Ramey, A. V. and S. Zubairy (2014). Government spending multipliers in good times and in bad times: Evidence from u.s. historical data. *University of California, San Diego and Texas A&M University*. 3

Ramey, V. (2011). Identifying government spending shocks: It is all in the timing. *Quarterly Journal of Economics 126*, 1–50. 16

Ramey, V. and M. Shapiro (1998). Costly capital reallocation and the effects of government spending. *Carnegie Rochester Conference on Public Policy*. 16

Ricco, G. (2014). A new identification of fiscal shocks based on the information flow. *Lonond Business School*. 3, 16

Romer, D. C. and D. H. Romer (1989). Does monetary policy matter? a new test in the spirit of friedman and schwartz. *Olivier J. Blanchard & Stanley Fischer, NBER macroeconomics annual 4*, 121–184. 16

Romer, D. C. and D. H. Romer (2010). The macroeconomic effects of tax changes: Estimates based on a new measure of fiscal shocks. *American Economic Review 100(3)*, 763–801. 16

Rossi, B. and S. Zubairy (2011). What is the importance of monetary and fiscal shocks in explaining us macroeconomic fluctuations? *Journal of Money, Credit and Banking 43(6)*. 3, 4

Spirtes, P. and C. Glymour (1991). A fast algorithm for discovering sparse causal graphs. *Social Science Computer Review 9*, 62–72. 17

Spirtes, P., C. Glymour, and R. Scheines (2000). *Causation, Prediction, and Search*. Cambridge, MA: MIT Press. 14, 17

Spirtes, P., C. Glymour, and R. Scheines (2001). *Causation, Prediction, and Search* (2nd ed.). Cambridge, MA: MIT Press. 12, 13

Spirtes, P., R. Scheines, J. Ramsey, and C. Glymour (2005). Tetrad 4.3.3-0. Technical report, Carnegie Mellon University, http://www.phil.cmu.edu/tetrad. 13

Spirtes, P., R. Sheines, J. Ramsey, and C. Glymour (2010). Tetrad v. *Laboratory for Symbolic and Educational Computing, Department of Philosophy, Carnegie Mellon University*. 17

Appendix

Measuring the 30-Year Government Bond Yield

We replicate the splicing technique in Krolzig and Sserwanja (014a) to approximate missing data in the government bond yield series. Data is available for all series from 1960$M1$ except for the GS30 series which starts in 1977$M2$. GS30 data is also missing between 2002$M3$ and 2006$M1$, during which no new 30-year maturity Treasuries were issued. To match maturity with corporate bonds, splicing is used to approximate the missing data points in the 30-year Treasury series with 20-year Treasuries. Monthly data is used for splicing so as to capture at as close a frequency as possible data details at the start and end dates for which data is missing than would otherwise be possible were quarterly data to be used. Changes in the two yields should be close at lower frequencies. Due to the location of the missing data, the splicing implemented here takes two forms. For the 1959$M1$ – 1977$M2$ period, equation (26) is used. Crucially, (26) approximates the month-on-month change in the 30-year Treasury yield by the month-on-month change in the 20-year Treasury yield. Looking at the lower panel in Figure 13, this assumption is justifiable. For the period 2002$M3$ – 2006$M1$, (27) equates the growth rate in the 30-year Treasury yield to the sum of the growth rate of the 20-year Treasury yield and the difference in the two growth rates over the period data is missing, weighted by the number of periods for which data is missing.

Backward interation:

$$GS30_t = GS30_{t+1} - \Delta GS20_{t+1} \tag{26}$$

Forward interation:

$$GS30_t = \Delta GS30_{t-1} + \Delta GS20_t + \Delta_{t_1-t_0} \frac{(GS30_{t_1} - GS20_{t_1})}{t_1 - t_0} \tag{27}$$

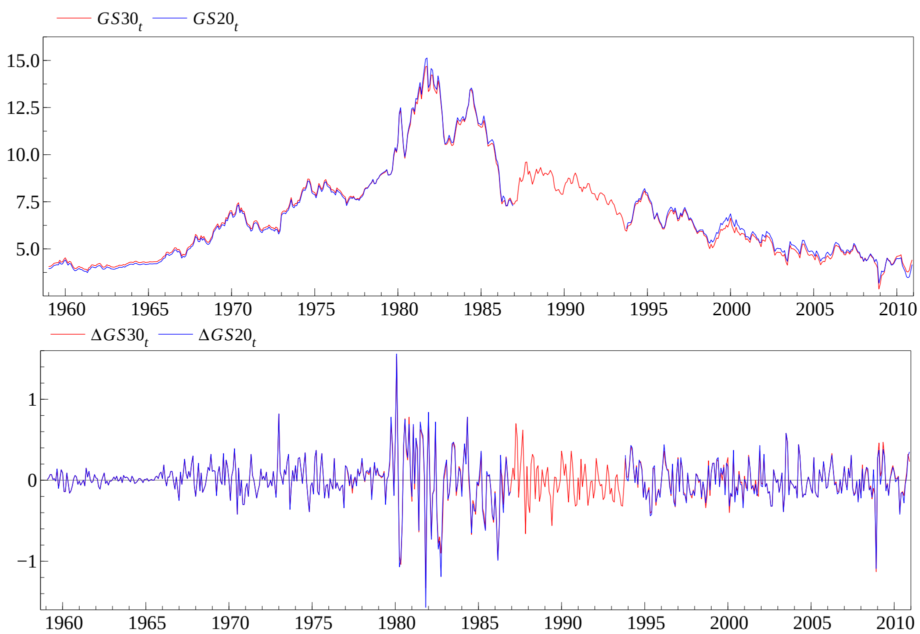

Figure 13 *$GS20_t$ and $GS30_t$ series compared*

The long-term behaviour of the $GS20_t$ and $GS30_t$ series lend credence to the assumption that these two series are linked. Their graphs below confirm this close relationship. Looking at the ranges $1977M2 - 1986M12$, and $1993M10 - 2002M2$ in Figure 13 for which both $GS20_t$ and $GS30_t$ data is available, it is evident that these two series closely track each other. Their first-difference plots in the bottom panel of Figure 13 is further support for this argument. The full $GS30_t$ series is then transformed to quarterly frequency by evaluating the simple average for the three months making up a quarter for quarters 1-4.