Pre-announcement and Timing – The Effects of a Government Expenditure Shock*

Alexander Kriwoluzky¶
University of Bonn

February 8, 2012

Abstract

An econometric strategy to identify a pre-announced fiscal policy shock is proposed. I show that the reduced form innovations can be recovered by estimating a Vector-moving-average model using the Kalman filter. The structural effects are identified exploiting the shock's pre-announced nature, which leads to potentially different signs of the responses of some endogenous variables during the announcement and after the realization of the shock. I illustrate my strategy by identifying a pre-announced shock to government consumption expenditures. I find that the response of private consumption is significantly negative on impact, rises and becomes significantly positive two quarters after the realization of the policy shock.

JEL classification: C32, E62.

Keywords: Fiscal policy, Fiscal foresight, Vector Autoregressive Moving Average Process.

*I would like to thank Jon Faust, my discussant at the EER meeting in Philadelphia, and an anonymous referee, as well as Christian Bayer, Franceso Furlanetto, Holger Gerhardt, Wouter den Haan, Martin Kliem, Eric Leeper, Helmut Lütkepohl, James Nason, Morten Ravn, Harald Uhlig, and Todd Walker for their helpful comments. The paper has benefitted enormously from comments by conference and seminar participants at the EER conference in Philadelphia on Monetary and Fiscal Policy Interactions, Norges Bank, the EUI Florence, the University of Amsterdam, the Deutsche Bundesbank, and the Annual Meeting of the European Economic Association in Barcelona.

¶University of Bonn, Kaiserplatz 7-9, 53117 Bonn, Germany, email: a.kriwoluzky@uni-bonn.de.

1 Introduction

Fiscal policy is mostly pre-announced due to implementation lags or to government bills which are legislated much earlier than they take effect.[1] The pre-announced nature causes two difficulties for an econometrician investigating the effects of fiscal policy. First, as shown by Leeper, Walker, and Yang (2008), pre-announcement induces a non-invertible moving average representation of the data, i.e. it cannot be approximated by a Vector Autoregression (VAR) model. Second, it poses a challenge to derive the structural effects from the reduced form estimates employing standard identification schemes. I deal with the former issue by estimating a Vector Autoregression Moving-Average (VARMA) model instead of a VAR model. Using standard properties of the Kalman filter one can recover the innovations of the reduced form VARMA model. The latter issue is resolved by making use of the characteristic behavior of endogenous variables as a response to a pre-announced shock: the signs of their responses during the announcement period potentially differ from the signs after the realization of the shock.[2]

I illustrate the strategy by estimating the effects of a pre-announced increase in government consumption expenditures on private consumption which is (besides real wages) the decisive variable in determining the explanatory power of either the Keynesian view or the classic view on economics. The sequence of reduced form innovations is obtained from an estimated VARMA model for the US economy consisting of government consumption expenditures, private consumption, private investment, hours worked, GDP, and government debt. I use sign restrictions to identify the structural effects: while private consumption is left unrestricted in its behavior, the signs of the responses of the other endogenous variables are restricted. These sign restrictions can potentially differ during the pre-announcement period and after the realization of the shock.

The sign restrictions are derived from a dynamic stochastic general equilibrium (DSGE)[3] model laid out by Galí, López-Salido, and Vallés (2007). This model is well suited to resolving the debate because it addresses the arguments why the classic result should hold as well as the typical arguments why it might fail: households which cannot smooth consumption, imperfect labor markets and a certain degree of price stickiness. Depending on its parametrization, for example the fraction of rule-of-thumb consumers and the degree of price stickiness, the model features classic or Keynesian characteristics. In the limit, i.e. with no rule-of-thumb consumers and firms allowed to reset prices each period, it boils down to a neoclassical model. The sign restrictions are derived from the DSGE model from two points of view: from a classic perspective first, from a

[1]A recent example is the American Recovery and Reinvestment Act from 2009: only 2.6% of the total sum were spent in 2009.

[2]The existence of those differences was found by Yang (2005), House and Shapiro (2006) and Trabandt and Uhlig (2006) among others.

[3]This strategy is also employed by e.g. Enders, Müller, and Scholl (2011) and Peersman and Straub (2009).

Keynesian perspective afterwards. I find that the response of private consumption is in line with the Keynesian view: It is significantly negative on impact, rises and becomes significantly positive two quarters after the realization of the shock.

The remaining paper is organized as follows: After reviewing the related literature, I describe the econometric strategy. Section 4 lays out the DSGE model which is employed to derive the sign restrictions. The econometric strategy is applied in Section 5 to identify the effects of a pre-announced shock in government consumption expenditures. Section 6 concludes.

2 Related literature

Findings in the literature on the effects of an increase in government expenditures are twofold depending on the respective identification scheme of the government expenditure shock. On the one hand, researcher employing the narrative approach as Ramey and Shapiro (1998), Burnside, Eichenbaum, and Fisher (2004) and Edelberg, Eichenbaum, and Fisher (1999) find corroborative evidence for the classic view. More precisely, a rise in government expenditure leads to a decrease in private consumption (Ramey and Shapiro, 1998) and a short lived increase in investment (Burnside, Eichenbaum, and Fisher, 2004). On the other hand, Blanchard and Perotti (2002) choose a structural VAR (SVAR) approach and find evidence supporting the Keynesian view on economics, i.e. an increase in private consumption. Ramey (2011) shows that the difference of the findings can be due to misspecified timing assumption of the SVAR approach. In her paper, a neoclassic DSGE model including a pre-announced government expenditure shock is set up and used to simulate artificial data. It is then demonstrated that, if the pre-announcement of the shock is taken into account, a negative response of consumption is estimated. If not, consumption appears to react positively, a clearly misleading result.

However, the Monte Carlo experiment laid out by Ramey (2011) ignores the fact that the DSGE model used to simulate the artificial data features a non-invertible moving average process due to the announcement of the shock in advance. The importance and the consequences of pre-announced policy has recently been stressed by Leeper, Walker, and Yang (2008), building on work by Hansen and Sargent (1991). In light of their arguments, the Monte Carlo simulation by Ramey (2011) just points out the importance of taking pre-announcement into account, but does not necessarily imply that the SVAR approach is doomed from the start.

There exist two suggestions in the literature how to address the issue of a non-invertible moving average process. One is to augment the VAR model with variables capturing the news and its effects on the variables. Recent examples are Fisher and Peters (2009) and Tenhofen and Wolff (2010). Faust, Rogers, Swanson, and Wright (2003) and Faust, Swanson, and Wright (2004) use high frequency data to capture the news effects and to expand the information set of the econometrician. The second approach employs Blaschke matrices as put forward by Lippi and Reichlin (1993) and Lippi and Reichlin (1994) to construct an invertible moving average representation. This approach has been chosen by **?** recently.

3 Pre-announcement, non-invertibility and rotation matrices

In this section I describe in detail how pre-announcement leads to a non-invertible moving-average representation, how the innovation of the reduced form can be estimated using the Kalman filter and finally how the structural shocks can be recovered by sign restrictions.

3.1 Non-invertibility in a DSGE model

To illustrate the issue of non-invertibility, consider a standard classical growth model with government expenditures g. Denote the log-linear deviations of a variable x from the steady state by $\hat{x}$ and define η_{ij} as the recursive law of motion of the variable i to the state variable j. The shock to government expenditures is denoted by ϵ_t^g. It is standard normally distributed: $\epsilon_t^g \sim \mathcal{N}\left(0, \sigma_{\epsilon,g}^2\right)$. In the case of no pre-announcement, i.e. $\hat{g}_t = \epsilon_t^g$, the recursive solution of the only endogenous state variable, capital (k), of the DSGE model is given by:

$$(1 - \eta_{kk} L)\hat{k}_t = \eta_{kg}\hat{g}_t \tag{1}$$

If the government expenditure shock is announced, the recursive law of motion changes. In the case of a two period announcement, i.e. $\hat{g}_t = \epsilon_{t-2}$, the recursive law of motion for $\hat{k}_t$ becomes:

$$(1 - \eta_{kk} L)\hat{k}_t = \eta_{k,\epsilon,2}\epsilon_t^g + \eta_{k,\epsilon,1}\epsilon_{t-1}^g + \eta_{kg}\hat{g}_t \tag{2}$$

The immediate effect of a government expenditure shock (η_{kg}) is unchanged. But, additionally the shock exhibits pre-announcement effects represented by the term $\eta_{k,\epsilon,2}\epsilon_t^g + \eta_{k,\epsilon,1}\epsilon_{t-1}^g$. As pointed out among others by Ljungqvist and Sargent (2004) and Mertens and Ravn (2010) this term can be further simplified making use of the result that the news' terms are discounted by a constant anticipation rate θ.[4] It holds that $\eta_{k\epsilon,2} = \theta\eta_{k\epsilon,1}$ and equation (2) can be written as:

$$(1 - \eta_{kk} L)\hat{k}_t = \eta_{k\epsilon,1}(\theta + L)\epsilon_t^g + \eta_{kg}\hat{g}_t \tag{3}$$

[4]The anticipation rate is equal to the inverse of the unstable root of the characteristic polynomial when solving the rational expectations system. Thus: $|\theta| < 1$.

The non-invertibility occurring in DSGE models with fiscal foresight stems from the term $\eta_{k\epsilon,1}(\theta+L)\epsilon_t^g$ in equation (3): The root of the moving-average polynomial is equal to $-\theta$ and is therefore inside the unit circle.[5] The fact that the moving-average process is not invertible implies that equation (3) cannot be estimated by a VAR model. In the next section I will illustrate how the convergence result of the Kalman filter can be employed to derive an invertible MA representation.

3.2 Non-invertibility and the Kalman filter

In order to keep the following tedious analytical derivations as simple as possible, I concentrate on the part in equation (3) that is causing the non-invertibility of the moving-average process. I further normalize the impact of the shock to one by defining the new error term $\eta_{k\epsilon 2}\epsilon_t^g = \tilde{\epsilon}_t^g$. Equation (3) becomes:

$$(1-\eta_{kk}L)\hat{k}_t = \tilde{\epsilon}_t^g + \frac{1}{\theta}\tilde{\epsilon}_{t-1}^g, \quad \tilde{\epsilon}_t^g \sim \mathcal{N}\left(0, (\sigma_{\epsilon,g}\eta_{k\epsilon 2})^2\right) \tag{4}$$

Note that despite the simplifications equation (4) still exhibits the crucial characteristic of equation (3), the non-invertible moving-average process. Equation (4) can be written in the following state-space system:

$$\xi_t = F\xi_{t-1} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{bmatrix} \tilde{\epsilon}_t^g \\ 0 \end{bmatrix} \tag{5}$$

$$k_t = G'\xi_t \tag{6}$$

with $\xi_t = \begin{bmatrix} k_t \\ k_{t-1} \end{bmatrix}$, $F = \begin{bmatrix} \eta_{kk} & 0 \\ 1 & 0 \end{bmatrix}$ and $G' = \begin{bmatrix} 1 & \frac{1}{\theta} \end{bmatrix}$. F collects the recursive laws of motion of the endogenous variables with respect to the endogenous state variables, the part of equation (4) causing the non-invertibility is part of the G matrix. Additionally, $Q = \begin{bmatrix} (\sigma_{\epsilon,g}\eta_{k\epsilon 2})^2 & 0 \\ 0 & 0 \end{bmatrix}$ is the variance covariance matrix corresponding to the shock vector in equation (5).

Since the recursive laws of motion in F, i.e. $\eta_k k$, are chosen such that the system is stable, the eigenvalues of F are smaller than one. This property of F translates into convergence results for the Kalman filter gain (K_t) and the variance covariance matrix of ξ (Σ_ξ)[6]: If the eigenvalues of F are inside the unit circle, both matrices converge to time-invariant matrices $\Sigma_{\xi,\infty}$ and K_∞. The time-invariant variance covariance matrix $\Sigma_{\xi,\infty}$ solves the Riccati equation of the state-space system.[7] The corresponding time-invariant Kalman gain K_∞ has the characteristic that the eigenvalues of $F - K_\infty G'$ are all inside the unit circle.

[5] As shown by Mertens and Ravn (2010), this result generalizes to the class of larger DSGE models.
[6] Proposition 13.1 and 13.2 in Hamilton (1994).
[7] $\Sigma_{\xi,\infty} = F\Sigma_{\xi,\infty}F' + Q - F\Sigma_{\xi,\infty}G\left(G'\Sigma_{\xi,\infty}G\right)^{-1}G'\Sigma_{\xi,\infty}F'$

The convergence results of the Kalman Filter imply that the state-space system (5) - (6) has the following innovation representation:

$$u_t^g = k_t - G'\xi_{t|t-1} \quad (7)$$

$$\xi_{t+1|t} = F\xi_{t|t-1} + K_\infty u_t \quad (8)$$

where u_t is the innovation error with mean zero and variance $\Sigma_u = G\Sigma_{\xi,\infty}G'$. From the state-space representation (7) - (8) the Wold representation for k can be derived as:

$$k_t = [I + G'(I - FL)^{-1}K_\infty L]u_t^g$$

$$k_t = u_t^g + G'K_\infty u_{t-1}^g + G'FK_\infty u_{t-2}^g + G'F^2K_\infty u_{t-2}^g + G'F^3K_\infty u_{t-3}^g \cdots . \quad (9)$$

For the simple DSGE model and its simple state-space system (5) - (6) it is possible to solve for $\Sigma_{\xi,\infty}$ and K_∞ analytically.[8] The variance of u is equal to $\Sigma_u = \left(\frac{\sigma_{\epsilon,g}\eta_{k\epsilon 2}}{\theta}\right)^2 = (\sigma_{\epsilon,g}\eta_{k\epsilon 1})^2$. Furthermore, the Wold representation (9) is given by:

$$k_t = u_t^g + (\eta_{kk} + \theta)u_{t-1}^g + \eta_{kk}(\eta_{kk} + \theta)u_{t-2}^g \cdots \quad (10)$$

How is the innovation error u related to the underlying pre-announced shock ϵ^g? Consider the error term that would result from employing the Blasche factor $\frac{L+\theta}{1+\theta L}$: $\epsilon_t^{\star g} = \frac{L+\theta}{1+\theta L}\epsilon_t^g$. The Blaschke factor flips the root from inside to outside the unit circle. Equation (4) is then given by:

$$(1 - \eta_{kk}L)\hat{k}_t = \eta_{k\epsilon,1}(1 + \theta L)\epsilon_t^{\star g} \quad (11)$$

Equation (11) constitutes an invertible MA process. As in equation (4) I normalize the impact of the shock to one by defining the shock $u^\star = \eta_{k\epsilon,1}\epsilon^{\star g}$. This yields the following Wold representation of equation (11) :

$$k_t = u_t^{\star g} + (\eta_{kk} + \theta)u_{t-1}^{\star g} + \eta_{kk}(\eta_{kk} + \theta)u_{t-2}^{\star g} \cdots \quad (12)$$

with $u^\star \sim \mathcal{N}\left(0, (\sigma_{\epsilon,g}\eta_{k\epsilon,1})^2\right)$. Comparing equation (12) with equation (10) reveals that the innovation error u corresponds to the normalized error term obtained by employing the Blaschke factor to the underlying shock ϵ^g.

To summarize: Initializing the Kalman filter steps with the time-invariant variance covariance matrix, i.e. the matrix that solves the Riccati equation, yields an estimate of an invertible MA process. The innovation error corresponds to the error one would obtain employing the Blaschke factor. In contrast to the application of the Blaschke factor no knowledge about the anticipation rate is necessary.

[8] The expressions for $\Sigma_{\xi,\infty}$ and K_∞ are provided in Appendix A.2.

3.3 Sign restrictions and pre-announcement

In this section I provide details on how the structural shock is identified. Consider the multivariate version of Equation (9). The vector of observable variables additionally includes private consumption c: $y_t = \left[\begin{array}{cc} k_t & c_t \end{array}\right]'$. Define the reduced form MA coefficient matrices as $\Phi_i = G'F^{i-1}K_\infty$ for $i = 1 \ldots \infty$. The Wold representation of y is given by:

$$y_t = u_t + \Phi_1 u_{t-1} + \Phi_2 u_{t-2} \ldots, \quad u \sim \mathcal{N}\left(0, \Sigma_u\right) \tag{13}$$

The structural shocks ϵ of the model are related to the reduced form shocks u_t by the relationship $A\epsilon_t = u_t$.

$$y_t = A\epsilon_t + \Theta_1 \epsilon_{t-1} + \Theta_2 \epsilon_{t-2} \ldots, \quad \epsilon \sim \mathcal{N}\left(0, I\right), \tag{14}$$

where $\Theta_i = \Phi_i A$ for $i = 1 \ldots \infty$. The matrix A has the characteristic $\Sigma_u = AA'$. Since there exists no unique solution for A, additional identifying restrictions are needed. The key identification idea is to employ the fact that some variables (in the example it is capital) exhibit different signs during the announcement period and after the realization of the shock. The restriction is implemented by first decomposing the matrix A into an eigenvector Matrix and the square roots of the eigenvalues (the product of the two matrices is denoted $\tilde{A}$) and the product of rotation matrices.[9] In the bivariate case this decomposition is given by:

$$A = \tilde{A} \left[\begin{array}{cc} cos(\omega_1) & -sin(\omega_1) \\ sin(\omega_1) & cos(\omega_1) \end{array}\right]$$

To provide further insights, I conduct a computational experiment. I calibrate[10] the model of Section 3.1, and solve for the recursive laws of motion.[11] Capital responds positively for two periods and negatively in the third to a pre-announced government expenditure shock.

Given the recursive law of motion I set up the VARMA model and its corresponding state-space form. Afterwards, I compute the time-invariant variance covariance matrix and the corresponding time-invariant Kalman gain. Finally, I derive the reduced form Wold decomposition (13).

The sign restrictions for capital, i.e. a positive response for two quarters and a negative response in the third quarter, are fulfilled for the rotation parameter $\omega_1 = [1.4314, 1.5980]$. Figure 1 plots the associated structural impulse responses from Equation (14). Consumption responds indeed negatively.

In the following empirical analysis, I employ an additional identifying assumption: government consumption expenditures are restricted to be zero throughout the pre-announcement period. This assumption has been commonly made in the literature

[9] See Canova and de Nicoló (2003) for a detailed description and application.

[10] $\alpha = 0.3$, $\beta = 0.99$, $\delta = 0.025$, $\bar{n} = 1/3$.

[11] The analytical results are provided in Appendix A.1.

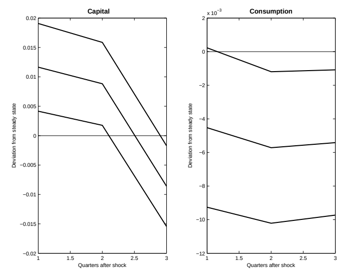

Figure 1: Impulse response function of capital and consumption. Identifying restrictions are that capital responds positively for two quarters and negatively in the third. Consumption is not restricted. Bands are 98% of the rotation parameter interval.

following Mountford and Uhlig (2009). Technically, i.e. in terms of rotation parameters, this assumption allows to determine one rotation parameter for every period in which government consumption expenditures are restricted to be zero. It has the drawback that it assumes an exogenous process for government consumption expenditures. This assumption might be too restrictive. In this paper I will employ it nevertheless. First, it is not clear how the endogenous policy rule should be specified.[12] Government consumption expenditures could respond positively as well as negatively. Second, in the subsequent empirical analysis this assumption will be of minor importance. The VARMA model will consist of six variables, implying a total of 15 rotation parameters. The benchmark pre-announcement horizon will be three periods, i.e. only three rotation parameters are determined by zero restrictions. One way to still include restrictions on government consumption expenditures into the identification scheme would be to employ additional shape restriction: the shape or slope of the response of government expenditures should be increasing in the period of the realization of the shock.

3.4 Determination of the VARMA model

So far the discussion has been based on the assumption that the parameters of the reduced form VARMA model are known. When the VARMA model is estimated, one has to bear in mind that the parameters of the reduced form state-space system (5)-(6) are not uniquely identified. One way to proceed is to find a sufficient number of restrictions and estimate the system (5)- (6). This was suggested by Hannan (1971) and applied among others by Hamilton (1985). I could not find a sufficiently large number of restrictions, even for the very simple bivariate model.

I therefore estimate the parameters of the reduced form model by estimating the echelon

[12]See Leeper, Plante, and Traum (2010) and Kliem and Kriwoluzky (2010) for attempts to determine and estimate simple fiscal feedback rules.

form[13] of the VARMA model. By doing so, I obtain a consistent estimate of the reduced form VARMA model. Afterwards, I transform the echelon form into the state-space form. The echelon form is specified by Kronecker indices. Poskitt (2011) describes an algorithm that allows to determine Kronecker indices independent of the order of variables.

4 The identifying DSGE model

In this section I discuss the choice of the model, briefly describe it and derive the identifying restrictions.

4.1 Choice of the DSGE model

To identify a pre-announced shock to government consumption expenditures and investigate its consequences for private consumption I derive sign restrictions from a DSGE model. The DSGE model employed here has originally been developed by Galí, López-Salido, and Vallés (2007).

I choose this DSGE model for it is well suited to sort through the debate how private consumption responds after a government expenditure shock for two reasons. First, it is possible to generate a negative as well as a positive response of private consumption to a shock in government consumption expenditures. Second, the nominal frictions and rigidities mirror the arguments why the classic result of a negative response of consumption might fail: credit constrained households, labor market imperfections and price stickiness. While other DSGE models have been laid out that generate a positive response of private consumption (Ravn, Schmitt-Grohé, and Uribe, 2007; Davig and Leeper, 2011; Kim, 2003), their positive response is not due to nominal rigidities.

I employ two different versions of the DSGE model. One version comprises the Keynesian view on economics. This version of the DSGE model includes rule-of-thumb households, a certain degree of price stickiness and labor unions. The other version is consistent with the classic view on economics, i.e. the DSGE model features neither rule-of-thumb households, nor price or labor market frictions. Since the DSGE model has been described Galí, López-Salido, and Vallés (2007) in depth, I only summarize the private sector briefly and present the slight change to the government sector, the introduction of pre-announcement. The log-linearized equations are presented in Appendix B.

[13] See Lütkepohl (2006) for an in-depth discussion of the echelon form of a VARMA model.

4.2 A brief description of the private sector

The DSGE model consists of two types of households, households with access to government bond and capital markets and households without. The latter are called rule-of-thumb households.

Goods are produced by perfectly competitive firms, using goods produced by intermediate firms as inputs. Intermediate good firms are monopolistic competitors and subject to a Calvo pricing mechanism, i.e. with a certain probability they receive a signal allowing them to reset their price which they are not allowed to change otherwise. Intermediate good firms have access to a production technology combining capital and labor.

As an additional friction an imperfect labor market is introduced. The introduction of wage-setting by unions has the effect that the amount of labor supplied by the households is equal across households.

4.3 Government sector

The government sector consists of a monetary authority setting nominal interest rates R and a fiscal authority setting lump sum taxes t and issuing nominal government bonds B. The monetary authority follows the simple interest rate rule in dependence of inflation. The fiscal authority has to balance the government budget constraint given by:

$$t_t + \frac{B_t}{p_t R_t} = g_t + \frac{B_{t-1}}{p_t}, \tag{15}$$

where p denote prices, and g government consumption expenditures. Log-linearized government expenditures are determined exogenously following an AR(1) process with shocks pre-announced q quarters in advance[14]:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \epsilon^g_{t-q} \tag{16}$$

4.4 The sign restrictions from the DSGE model

The DSGE model is employed to derive the identifying sign restrictions for the VARMA model: On the one hand sign restrictions in line with the Keynesian view on economics and on the other hand sign restrictions in line with the classic view. The classic perspective is represented by the share of rule-of-thumb consumers and the degree of price stickiness set to zero and no labor market imperfections. The remaining parameters are calibrated to standard values taken from Galí, López-Salido, and Vallés (2007).

[14]The log-linearized formulation is chosen since the discussion in section 5.4 is also in terms of the log-linearized form.

The Keynesian view comprises labor market imperfections, a positive share of rule-of-thumb consumers and price rigidities. As benchmark calibration I follow Galí, López-Salido, and Vallés (2007) and choose the elasticity of wages with respect to hours to $\nu = 0.2$, but set the share of rule-of-thumb consumers and the degree of price stickiness slightly lower: $\lambda = 0.4$ and $\vartheta = 0.7$. The benchmark calibration is an innocuous choice since the resulting qualitative implications of the DSGE model, the signs of the impulse response functions, are compatible with a wide variety of different parameter values.

The impulse response function of the Keynesian and the classic parametrization are plotted in Figure 2 and Figure 3. From those figures sign restrictions are derived as summarized in Table 1 .

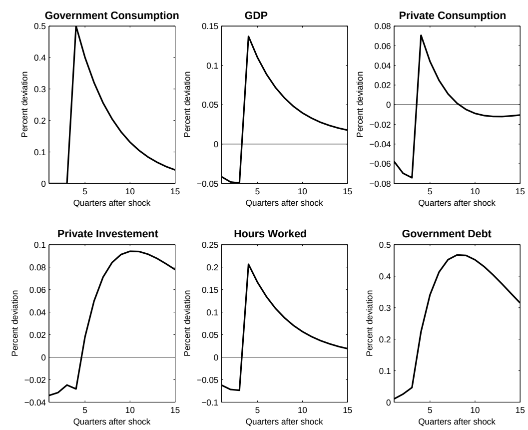

Figure 2: Impulse response function of the DSGE model with Keynesian parametrization. Pre-announcement three periods.

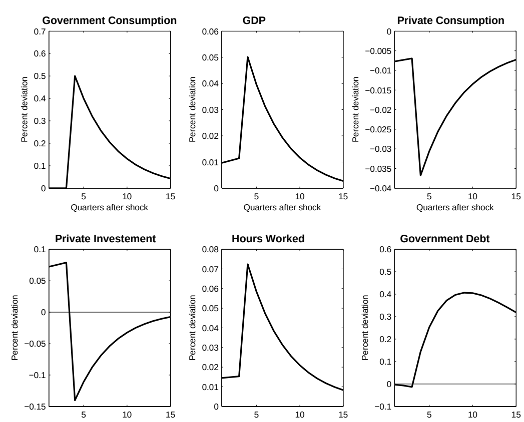

Figure 3: Impulse response function of the DSGE model with classic parametrization. Pre-announcement three periods.

	Keynesian Parametrization		Classic Parametrization	
	Announcement	Realization	Announcement	Realization
Government	0	+	0	+
Real gdp	-	+	+	+
Hours worked	?	+	?	+
Private Investment	-	-	+	-
Private Consumption	?	?	?	?
Government bonds	+	+	?	+

Table 1: Overview over sign restrictions for the Keynesian and classic parametrization respectively. The column Announcement denotes the restriction during the announcement period, the column Realization the restriction after the realization of the shock. $+,-$ denote the corresponding sign, ? stands for a left open response.

While in both parameterizations the sign restrictions after the realization of the shock are equivalent, they differ after the announcement and before the realization of the shock. For the classic parameterization investment increases first, before it becomes negative. This behavior is in line with the observation made by Ramey (2011): as firms expect the government spending shock to be prolonged, they build up their capital stock. In the Keynesian parameterization the variables respond differently during the announcement period. The government expenditure shock is assumed to increase demand after the realization, firms that can reset prices during the announcement period anticipate this and increase prices right away. This drives the economy into a recession during the announcement period. After the realization of the shock, output increases due to the demand effects. The key to identify the pre-announced government expenditure shock is the switch of the signs of the impulse response function of investment in the case of the classic parametrization and of output in the case of the Keynesian parametrization.

In order to control for the sensitivity of the sign restrictions with respect to the parameter values I conduct the following experiment: I take 50,000 draws from a wide multivariate distribution for all parameters[15] that fulfill the sign restriction in each parameterization and report the minimum and the maximum of each parameter in Table 2. The results indicate that the sign restrictions that I employ in the next step are not very sensitive to the choice of the parameter values.

[15]I include all parameters into the robustness exercise since Galí, López-Salido, and Vallés (2007) show that they all matter in some respect for the dynamics of the DSGE model.

Parameter	Description	*Keynesian interval* min	max	*Classic interval* min	max
ρ_g	autocorrelation g	0.01	0.99	0.003	0.965
ϕ_g	policy rule coefficient	0.001	0.499	0.001	0.91
ϕ_b	policy rule coefficient	0.032	1.416	0.03	1.80
λ	share rule-of-thumb	0.001	0.999	-	-
ϑ	Calvo parameter	0.001	0.999	-	-

Table 2: Interval of structural parameter values compatible with the sign restrictions in each parametrization. Pre-announcement three quarters. ($-$ denotes fixed parameter values.)

5 Results

This section describes the time series and details of the estimation of the VARMA model.[16] Afterwards the estimated impulse response functions are presented. Further sensitivity analysis with respect to crucial assumptions is conducted. Finally the findings are juxtaposed to the literature.

5.1 Data

The VARMA model consists of quarterly time series for government consumption expenditures, output, private consumption, private investment, hours worked and government debt. The data ranges from the first quarter 1948 to the fourth in 2009. Prior to the estimation the data is de-trended by removing a linear quadratic trend. The data has been obtained from NIPA, FRED II and the Federal reserve bank of Dallas. A detailed description can be found in Appendix C.

5.2 Estimation

First, I determine the restrictions necessary to estimate the reduced form VARMA model, i.e. the Kronecker indices of the echelon form. I choose the maximum number of Kronecker indices to be 7 and compute the error terms and their variances of all possible combinations of Kronecker indices. The best combination is then determined according to the Schwarz criterion. The estimated Kronecker indices are $p^k = \{1, 1, 1, 1, 1, 1\}$ yielding VARMA(1,1) model in state-space form. Kronecker indices determined this way can depend on the order of the variables. I therefore perform a robustness check

[16]The Matlab code that sets up the VARMA model, estimates it and computes the impulse response functions can be downloaded from my webpage at: *http://www.mwpweb.eu/AlexanderKriwoluzky*.

with respect to the place of government consumption expenditures in the VARMA model.

I denote the vector collecting the restricted coefficients of the VARMA model as well as the vectorized variance covariance matrix of the reduced form error $vech(\Sigma_u)$ as Θ and the likelihood estimate by $\tilde{\Theta}$. When applying the sign restrictions to identify the structural impulse response functions I take a Bayesian perspective. I aim at describing the posterior distribution of Θ and the impulse matrix A. In order to approximate this distribution I first compute the inverse of the Hessian $\tilde{\Sigma}_{\tilde{\Theta}}$ at the mode of the likelihood. I then take draws from the distribution $\mathcal{N}(\tilde{\Theta}, \tilde{\Sigma}_{\tilde{\Theta}})$. For every $i-th$ draw Θ^i I go through the steps described in Section 3.1 to compute the reduced form Wold decomposition. I then search for the rotation parameters which lead to a structural Wold decomposition fulfilling the sign- and zero restrictions.

5.3 Structural impulse response functions

I identify two shocks, a business cycle shock ordered first and the government expenditure shock ordered second. As in Mountford and Uhlig (2009) the business cycle shock is included to absorb the strong co-movements of output, private consumption, hours worked and investment and is defined such that it provokes a positive response of these variables.

As benchmark pre-announcement horizon I choose 3 quarters following Yang (2007). In both identification schemes the sign restrictions have to be fulfilled for five periods in total. For the classic identification I do not find rotation parameters that fulfill the sign restrictions. I therefore reduce the pre-announcement horizon to two quarters. The results are shown in Figure 4. The sign restrictions to be fulfilled are the initial rise in investment and its negative response after the realization of the shock as well as the positive response of debt, output, and hours worked three quarters after the realization of the shock. Except for output, which is restricted to respond positively, the signs of those variables are not restricted during the announcement period. The response of private consumption is not estimated significantly different from zero for the first five quarters. It becomes significantly positive after six quarters and stays positive. The DSGE model employed suggests a negative response throughout the quarters after the shock for a classic parametrization. The estimated impulse response is thus not in line with the prediction of the DSGE model.

The results for the Keynesian identification scheme are displayed in Figure 5. The sign restrictions to be fulfilled are a negative response of output and investment during the announcement period. After the realization of the shock output and hours worked are restricted to be positive for two quarters. Investment is restricted to stay negative two quarters after the realization of the shock. Government debt is restricted to be positive throughout the first five quarters. The impulse response of private consumption is

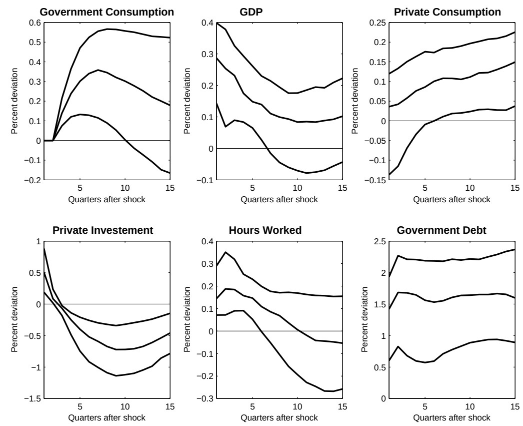

Figure 4: Impulse response function of the VARMA model identified by sign restrictions derived from the classic parameterization of the DSGE model. Pre-announcement two quarters. 68% probability bands.

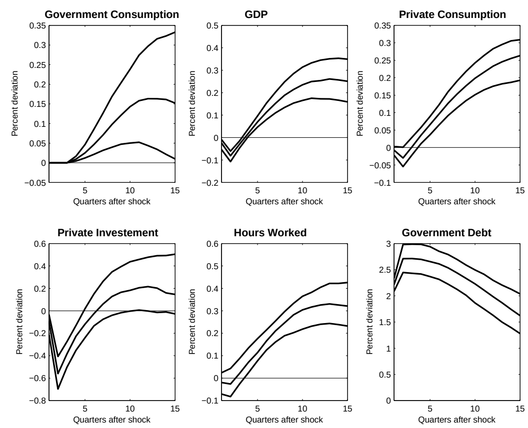

Figure 5: Impulse response function of the VARMA model identified by sign restrictions derived from the Keynesian parameterization of the DSGE model. Pre-announcement three quarters. 68% probability bands.

found to be significantly negative on impact. Afterwards it is increasing and becomes significantly positive eight quarters after the announcement of the shock. This response is in line with the impulse response theory would suggest. In the remaining part of this section I therefore concentrate on its interpretation and implication.

The identifying DSGE model with a Keynesian parametrization provides the following explanation for the estimated impulse response function of private consumption. Firms anticipate higher inflation after the realization of the shock and increase prices immediately after the announcement. Monetary authorities increase nominal interest rates as a response to the rise in inflation. The increase in prices leads to an initial drop in output, private consumption and investment. The result is stagflation during the announcement period. The increase in government consumption expenditures then leads to a rise in output, hours worked and private consumption for two reasons: a rise in income for the rule-of-thumb households and a drop in prices due to the negative response of output so far - prices overshoot.

5.4 Sensitivity analysis

In this section I conduct a sensitivity analysis of important assumptions of the shock process.

To control for the length of the assumed announcement horizon I estimate the VARMA model with two and four quarters of announcement. The results for the Keynesian identification scheme are displayed in Figure 6 and Figure 7 respectively. Both figures show similar results. The response of private consumption is negative on impact and increases afterwards. For a pre-announcement horizon of two quarters this response is weaker than in the case of four periods.

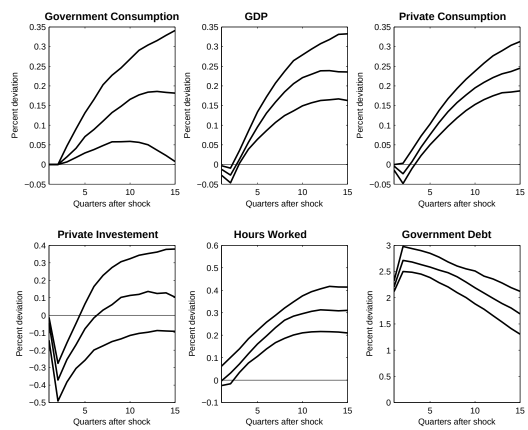

Figure 6: Impulse response function of the VARMA model identified by sign restrictions derived from the Keynesian parameterization of the DSGE model. Pre-announcement two quarters. 68% probability bands.

A second sensitivity analysis concerns the shock process. An important assumption is that it is serially uncorrelated, i.e. the announcement today determines government consumption expenditures in two or three quarters. Another way to think of pre-announcement, put forward by Leeper, Walker, and Yang (2008) and discussed in more detail by Leeper and Walker (2011), is that the news process is temporally correlated. Leeper, Walker, and Yang (2008) and Leeper and Walker (2011) capture this by a weighted moving average formulation and interpret the weights as the relative importance of the news at different horizons. The shock process (16) with pre-announcement horizon q is then given by:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \zeta_1 \epsilon_t^g + \ldots \zeta_q \epsilon_{t-q}^g \tag{17}$$

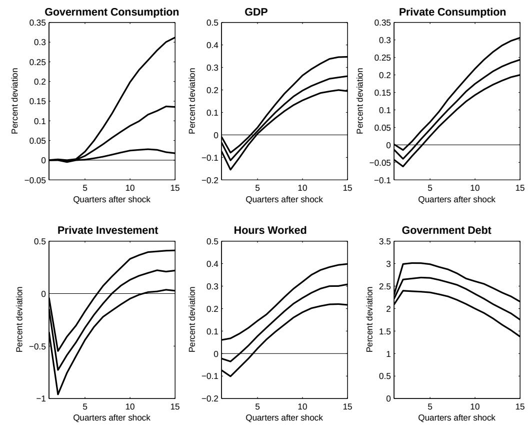

Figure 7: Impulse response function of the VARMA model identified by sign restrictions derived from the Keynesian parameterization of the DSGE model. Pre-announcement four quarters. 68% probability bands.

with $\sum_j \zeta_j = 1$. Modifying the shock process that way reduces the pre-announcement horizon and introduces a kink in the shock process and in the responses of the endogenous variables. The sign restrictions derived from the DSGE model are therefore robust as long as most of the weight is put on the older news. Otherwise the process mirrors a shorter pre-announcement period. Since the main result is robust with respect to the pre-announcement horizon, higher weights on more recent news do not cause a problem.

5.5 Comparison with other studies

The main result, i.e. the significant negative response of private consumption on impact followed by an increase and a significant positive response, is in line with the findings of recent studies by **?** and Fisher and Peters (2009). While the latter augment the VAR model with stock prices to capture the news effects, the former also aim at addressing the issue of a non-invertible MA process explicitly. The study by **?** is therefore closely related to this paper and I thus highlight the main differences in the assumptions.

To achieve identification of a pre-announced shock in government consumption expenditures, **?** have to make three assumptions: one concerning the announcement horizon, one concerning the size of the Blaschke factor and one on the nature of the change in government expenditures. The first assumption also has to be made in this paper. The second assumption is not necessary here. Using the third assumption the authors look at anticipated and unanticipated changes. In this paper, I have considered pre-announced changes only. Despite the different assumptions, however, the effect of an pre-announced shock on private consumption in both studies is similar.

5.6 Limitations and discussion of the results

Even though the sign restrictions derived from the DSGE model are robust with respect to different assumptions concerning the shock process one might want to be careful at this stage before drawing strong policy conclusions. For one, fiscal policy is modeled exogenously. Therefore, government consumption expenditures can be restricted to be zero throughout the announcement periods. This assumption allows to determine as many rotation parameters as there are periods of pre-announcement.

Furthermore, this paper tackles the issue of a non-invertible MA process stemming from pre-announced fiscal policy. Non-invertibility can also arise if an incomplete set of variables is employed. An additional assumption which is implicitly present throughout the paper is that the information set of the government is identical to the information set of the private sector. In the case that the government has superior information about the state of the economy, it can employ government spending as a signaling device to the agents in the economy. Agents would learn from the government's decision of the recession and would cut consumption for precautionary savings. This would constitute a different channel, associated with a different set of sign restrictions, which is not considered in this paper.

Moreover, sign restrictions in general also include linear combinations of shocks that yield similar signs. For instance, it is difficult to identify a pre-announced shock in government consumption expenditures if at the same time the agents have foresight about further shocks in technology and taxes.

All those limitations are not of minor importance. Thus, the results are best viewed as an illustration of the importance of foresight and the methodology proposed in the paper are an initial step in allowing us to deal with this important issue in a reasonable way.

6 Conclusion

In this paper I have demonstrated an econometric strategy to identify pre-announced policy shocks, i.e. to estimate the effects of structural shocks if the underlying MA process is not invertible due to pre-announcement of fiscal policy. The strategy consist of first recovering the reduced form innovations by estimating a VARMA model using the Kalman filter. Second, the structural effects are estimated by exploiting the pre-announcement effects explicitly, i.e. considering qualitative differences in the response of investment and output during the announcement period and after the realization of the shock.

As an application I have investigated the effects of a pre-announced shock in government consumption expenditures on private consumption. The sign restrictions have been derived from a DSGE model. The model has been parameterized to mirror the Keynesian view on economics on the one hand and the classic view on the other hand. The structural impulse response functions have been estimated for both types of sign restrictions. I find that the response of private consumption to a pre-announced shock in government consumption expenditure is in line with the Keynesian view on economics, i.e. it is significantly negative on impact, rises and becomes significantly positive two quarters after the realization of the shock.

References

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*, 117(4), 1329–1368.

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

Canova, F., and G. de Nicoló (2003): "On the sources of business cycles in the G-7," *Journal of International Economics*, 59(1), 77–100.

Davig, T., and E. M. Leeper (2011): "Monetary-fiscal policy interactions and fiscal stimulus," *European Economic Review*, 55(2), 211–227.

Edelberg, W., M. Eichenbaum, and J. D. Fisher (1999): "Understanding the Effects of a Shock to Government Purchases," *Review of Economic Dynamics*, 2(1), 166–206.

Enders, Z., G. J. Müller, and A. Scholl (2011): "How do fiscal and technology shocks affect real exchange rates?: New evidence for the United States," *Journal of International Economics*, 83(1), 53–69.

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

Faust, J., E. T. Swanson, and J. H. Wright (2004): "Identifying VARS based on high frequency futures data," *Journal of Monetary Economics*, 51(6), 1107–1131.

Fisher, J. D. M., and R. Peters (2009): "Using stock returns to identify government spending shocks," Discussion paper.

Galí, J., J. López-Salido, and J. Vallés (2007): "Understanding the Effects of Government Spending on Consumption," *Journal of the European Economic Association*, 5(1), 227–270.

Hamilton, J. D. (1985): "Uncovering Financial Market Expectations of Inflation," *Journal of Political Economy*, 93(6), pp. 1224–1241.

——— (1994): *Time Series Analysis*. Princeton University Press.

Hannan, E. J. (1971): "The Identification Problem for Multiple Equation Systems with Moving Average Errors," *Econometrica*, 39(5), pp. 751–765.

Hansen, L. P., and T. J. Sargent (1991): "Two Difficulties in Interpreting Vector Autoregressions," in *Rational Expectations Econometrics*, ed. by L. P. Hansen, and T. J. Sargent. Westview Press.

House, C. L., and M. D. Shapiro (2006): "Phased-In Tax Cuts and Economic Activity," *American Economic Review*, 96(5), 1835–1849.

Kim, S. (2003): "Structural Shocks and the Fiscal Theory of the Price Level," *Macroeconomic Dynamics*, 7(05), 759–782.

Kliem, M., and A. Kriwoluzky (2010): "Toward a Taylor rule for fiscal policy," Discussion Paper Series 1: Economic Studies 2010,26, Deutsche Bundesbank, Research Centre.

Leeper, E., and T. Walker (2011): "Information Flows and News Driven Business Cycles," *Review of Economic Dynamics*, 14(1), 55–71.

Leeper, E. M., M. Plante, and N. Traum (2010): "Dynamics of fiscal financing in the United States," *Journal of Econometrics*, 156(2), 304–321.

Leeper, E. M., T. B. Walker, and S.-C. S. Yang (2008): "Fiscal Foresight: Analytics and Econometrics," NBER Working Papers 14028, National Bureau of Economic Research, Inc.

Lippi, M., and L. Reichlin (1993): "The Dynamic Effects of Aggregate Demand and Supply Disturbances: Comment," *American Economic Review*, 83(3), 644–52.

——— (1994): "VAR analysis, nonfundamental representations, blaschke matrices," *Journal of Econometrics*, 63(1), 307–325.

Ljungqvist, L., and T. J. Sargent (2004): *Recursive Macroeconomic Theory, 2nd Edition*, vol. 1 of *MIT Press Books*. The MIT Press.

Lütkepohl, H. (2006): *New Introduction To Multiple Time Series Analysis*.

Mertens, K., and M. Ravn (2010): "Measuring the Impact of Fiscal Policy in the Face of Anticipation: A Structural VAR Approach," *Economic Journal*, 120(544), 393–413.

Mountford, A., and H. Uhlig (2009): "What are the effects of fiscal policy shocks?," *Journal of Applied Econometrics*, 24(6), 960–992.

Peersman, G., and R. Straub (2009): "Technology Shocks And Robust Sign Restrictions In A Euro Area Svar," *International Economic Review*, 50(3), 727–750.

Poskitt, D. S. (2011): "Vector Autoregresive Moving Average Identication for Macroeconomic Modeling: A New Methodology," Discussion paper, Monash University.

Ramey, V. A. (2011): "Identifying Government Spending Shocks: It's all in the Timing," *The Quarterly Journal of Economics*, 126(1), 1–50.

Ramey, V. A., and M. D. Shapiro (1998): "Costly capital reallocation and the effects of government spending," *Carnegie-Rochester Conference Series on Public Policy*, 48, 145–194.

Ravn, M. O., S. Schmitt-Grohé, and M. Uribe (2007): "Explaining the Effects of Government Spending Shocks on Consumption and the Real Exchange Rate," NBER Working Papers 13328, National Bureau of Economic Research, Inc.

Tenhofen, J., and G. B. Wolff (2010): "Does anticipation of government spending matter? The role of (non-) defense spending," Discussion Paper Series 1: Economic Studies 2010,12, University of Bonn, Graduate School.

Trabandt, M., and H. Uhlig (2006): "How Far Are We From The Slippery Slope? The Laffer Curve Revisited," SFB 649 Discussion Papers SFB649DP2006-023, Sonderforschungsbereich 649, Humboldt University, Berlin, Germany.

Yang, S.-C. S. (2005): "Quantifying tax effects under policy foresight," *Journal of Monetary Economics*, 52(8), 1557–1568.

——— (2007): "A Chronology Of Postwar U.S. Federal Income Tax Policy," Caepr Working Papers 2007-021, Center for Applied Economics and Policy Research, Economics Department, Indiana University Bloomington.

Appendix

A A simple DSGE model

A.1 Description and Solution

Utility of the household:

$$max_{c_t,n_t,k_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t \left[log(c_t) + log(1-n_t)\right],$$

The capital accumulation equation:

$$k_t = x_t + (1-\delta)k_{t-1} \tag{18}$$

Production function:

$$y_t = k_{t-1}^{\alpha} n^{1-\alpha} \tag{19}$$

The feasibility constraint

$$c_t + x_t + g_t \;=\; y_t \tag{20}$$

The solution of the log-linearized model with a two period pre-announced shock to government expenditures:

$$\hat{k}_t \;=\; \eta_{kk}\hat{k}_{t-1} + \eta_{k\epsilon,2}\epsilon_t^g + \eta_{k\epsilon,1}\epsilon_{t-1}^g + \eta_{kg}\hat{g}_t \tag{21}$$

$$\hat{c}_t \;=\; \eta_{ck}\hat{k}_{t-1} + \eta_{c\epsilon,2}\epsilon_t^g + \eta_{c\epsilon,1}\epsilon_{t-1}^g + \eta_{cg}\hat{g}_t \tag{22}$$

where the recursive laws of motion are functions of the deep parameters (α, β, δ) and the normalization $\bar{n}$.

Define the steady state of the model: $\frac{\bar{y}}{\bar{k}} = \frac{(\frac{1}{\beta}-1+\delta)}{\alpha}$, $\bar{k} = \frac{\bar{y}}{\bar{k}}^{\frac{1}{(\alpha-1)}}\bar{n}$, $\bar{c} = \bar{y} - \delta\bar{k} - \bar{g}$. Further, define $\bar{C}_1 = 1 + \alpha\beta(1-\alpha)(1-\bar{n})\frac{\bar{y}}{\bar{k}(-\alpha\bar{n}+\bar{n}+\alpha)}$, $\bar{C}_2 = \alpha^2\beta\frac{\bar{y}}{(\bar{k}(-\alpha\bar{n}+\alpha+\bar{n})} - \alpha\beta\frac{\bar{y}}{\bar{k}}$, $C3 = -(\frac{\bar{c}}{\bar{y}} + \frac{(1-\alpha)(1-\bar{n})}{(-\alpha\bar{n}+\alpha+\bar{n})})$, $\bar{C}_4 = \frac{\bar{k}}{\bar{y}}$, $\bar{C}_5 = -(\frac{\alpha}{(-\alpha\bar{n}+\alpha+\bar{n})} + (1-\delta)\frac{\bar{k}}{\bar{y}})$, $\bar{C}_6 = \frac{\bar{g}}{\bar{y}}$.

Then, $\eta_{kk} = \left(\frac{(\bar{C}_4+\bar{C}_2\bar{C}_3-\bar{C}_1\bar{C}_5)}{2(\bar{C}_1\bar{C}_4)}\right) - \left(\left(-\frac{(\bar{C}_4+\bar{C}_2\bar{C}_3-\bar{C}_1\bar{C}_5)}{2(\bar{C}_1\bar{C}_4)}\right)^2 + \frac{\bar{C}_5}{\bar{C}_1\bar{C}_4}\right)^{(1/2)}$, and correspondingly : $\frac{1}{\theta} = \left(\frac{(\bar{C}_4+\bar{C}_2\bar{C}_3-\bar{C}_1\bar{C}_5)}{2(\bar{C}_1\bar{C}_4)}\right) + \left(\left(-\frac{(\bar{C}_4+\bar{C}_2\bar{C}_3-\bar{C}_1\bar{C}_5)}{2(\bar{C}_1\bar{C}_4)}\right)^2 + \frac{\bar{C}_5}{\bar{C}_1\bar{C}_4}\right)^{(1/2)}$.

The remaining recursive laws of motion are: $\eta_{ck} = \frac{\bar{C}_4}{\bar{C}_3}\eta_{kk} + \frac{\bar{C}_5}{\bar{C}_3}$, $\eta_{kg} = \frac{-\bar{C}_6}{\bar{C}_3(\frac{\bar{C}_4}{\bar{C}_3}-\bar{C}_1\eta_{ck}+\bar{C}_2)}$, $\eta_{cg} = \frac{\bar{C}_4}{\bar{C}_3}\eta_{kg} + \frac{\bar{C}_6}{\bar{C}_3}$, $\eta_{k\epsilon,1} = \frac{\bar{C}_1\eta_{cg}}{(\frac{\bar{C}_4}{\bar{C}_3}+\bar{C}_2-\bar{C}_1\eta_{ck})}$, $\eta_{k\epsilon,2} = \theta\eta_{k\epsilon,1}$, $\eta_{c\epsilon,1} = \frac{\bar{C}_4}{\bar{C}_3}\eta_{k\epsilon,1}$, $\eta_{c\epsilon,2} = \theta\eta_{c\epsilon,1}$

A.2 Root flipping via the Kalman Filter

For the simple example:

$$(1-\eta_{kk}L)\hat{k}_t = \tilde{\epsilon}_t^g + \frac{1}{\theta}\tilde{\epsilon}_{t-1}^g$$

The time-invariant Variance Covariance matrix of the state-space system (5) - (6) that solves the Ricatti equation is given by:

$$\Sigma_\infty = \begin{bmatrix} \frac{\sigma^2(\eta_k k^2+2\theta\eta_{kk}+1)}{(\eta_{kk}\theta+1)^2} & -\frac{(\eta_{kk} sigma^2(\theta^2-1))}{(\eta_{kk}\theta+1)^2} \\ -\frac{(\eta_{kk} sigma^2(\theta^2-1))}{(\eta_{kk}\theta+1)^2} & \frac{(\sigma^2-\sigma^2\theta^2)}{(\eta_{kk}^2\theta^2+2\eta_{kk}\theta+1)} \end{bmatrix}$$

The corresponding Kalman gain $K_\infty = ...$ is:

$$K_\infty = \begin{bmatrix} \frac{(\eta_{kk}\theta(\eta_{kk}+\theta))}{(\eta_{kk}\theta+1)} \\ \frac{(\theta^2-1)}{(\eta_{kk}\theta+1)} + 1 \end{bmatrix}$$

B Log-linearized Equations of the identifying DSGE model

The log-linearized identifying DSGE model consists of the following equations:

$$\hat{c}_t^o = \hat{c}_{t+1}^o - \hat{R}_t + \hat{\pi}_{t+1} \tag{23}$$

$\hat{c}^o$ consumption of intertemporal optimizing households, $\hat{R}$ nominal interest rate, $\hat{\pi}$ inflation

$$\hat{q}_t = -\hat{c}_{t+1}^o + \hat{c}_t^o + (1-\beta(1-\delta))\hat{R}_{t+1}^k + \beta\hat{q}_{t+1} \tag{24}$$

$\hat{q}$ Tobin's q

$$\hat{i}_t^o - \hat{k}_{t-1}^o = \varsigma\hat{q}_t \tag{25}$$

$\hat{i}^o$ private investment intertemporal optimizing households, $\hat{k}^o$ capital intertemporal optimizing households.

$$\hat{k}_t^o = (1-\delta)\hat{k}_{t-1}^o + \delta\hat{i}_t^o \tag{26}$$

$$\hat{c}_t^r = \frac{\bar{y}}{\bar{c}}\frac{(1-\alpha)}{\mu_p}(\hat{w}_t + \hat{n}_t) - \frac{\bar{t}^r}{\bar{c}}(\phi_b\hat{b}_{t-1} + \phi_g\hat{g}_t) \tag{27}$$

$$\hat{c}_t + \nu \hat{n}_t = \hat{w}_t \tag{28}$$

$\hat{c}$ aggregate consumption, $\hat{w}$ aggregate wages, $\hat{n}$ hours worked

$$\hat{c}_t = \lambda \hat{c}_t^r + (1-\lambda)\hat{c}_t^o \tag{29}$$

$\hat{c}^r$ consumption rule-of-thumb households

$$\hat{k}_t = \hat{k}_t^o \tag{30}$$

$\hat{k}$ aggregate capital

$$\hat{i}_t = \hat{i}_t^o \tag{31}$$

$\hat{i}$ aggregate private investment

$$\hat{y}_t = \alpha \hat{k}_{t-1} + (1-\alpha)\hat{n}_t \tag{32}$$

$\hat{y}$ output

$$\hat{y}_t = \frac{\bar{c}}{\bar{y}}\hat{c}_t + \frac{\bar{i}}{\bar{y}}\hat{i}_t + \frac{\bar{g}}{\bar{y}}\hat{g}_t \tag{33}$$

$$\hat{\pi}_t = \beta E_t[\hat{\pi}_{t+1}] - \lambda_p \hat{mc}_t \tag{34}$$

$\hat{mc}$ marginal costs intermediate good firm

$$\hat{mc}_t = \hat{y}_t - \hat{n}_t - \hat{w}_t \tag{35}$$

$$\hat{R}_t^k = \hat{c}_t + (1+\varphi)\hat{n}_t - \hat{k}_{t-1} \tag{36}$$

$\hat{R}^k$ return on capital

$$\frac{\bar{b}}{\bar{y}\beta}\hat{b}_t - \frac{\bar{b}}{\bar{y}\beta}\hat{R}_t + \frac{\bar{b}}{\bar{y}}\hat{\pi}_t = (\frac{\bar{b}}{\bar{y}} - \frac{\bar{t}}{\bar{y}}\phi_b)\hat{b}_{t-1} + (\frac{\bar{g}}{\bar{y}} - \frac{\bar{t}}{\bar{y}}\phi_g)\hat{g}_t \tag{37}$$

$$\hat{R}_t = \phi_\pi \hat{\pi}_t \tag{38}$$

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \epsilon_{g,t-q} \tag{39}$$

C Data description

The frequency of all data used is quarterly.

Real GDP: This series is *BEA NIPA table 1.1.6 line 1*. It is measured in billions of dollars, chained 2005.

Nominal GDP: This series is *BEA NIPA table 1.1.5 line 1*. It is measured in billions of dollars.

Implicit GDP Deflator: The implicit GDP deflator is calculated as the ratio of **Nominal GDP** to **Real GDP**.

Government Debt: This series is taken from the Federal Reserve Bank of Dallas. It is the market value of government debt measured in Billions of Dollars. *http://www.dallasfed.org/data/data/natdebt.tab.htm*.

Government Consumption Expenditures: Government consumption expenditures is the series *BEA NIPA table 3.1 line 16* (Billion of Dollars).

Private Consumption: Nominal consumption expenditures for non-durables and services is the sum of the respective values of the series *BEA NIPA table 1.1.5 line 5* and *BEA NIPA table 1.1.5 line 5*. Both series are measured in billions of dollars.

Private Investment: Total private investment is the sum of the series *BEA NIPA table 1.1.5 line 7* and durable consumption goods *BEA NIPA table 1.1.5 line 5*. Measured in Billions of Dollars.

Hours worked: This series is downloadable from the website of the Bureau of Labor Statistics at *http://data.bls.gov/cgi-bin/srgate*. The series' identification number is: *PRS84006033*. It is an index (1992=100).

Civilian Population: This is a quarterly measure for the population given by the respective average of the monthly values of the series *CNP16OV, Civilian Non-institutional Population* at the Federal Reserve Board of St. Louis' website *http://research.stlouisfed.org/fred2/*. The numbers have been converted from thousands to billions.