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Abstract

This paper investigates the transmission mechanism of government spending shocks in an estimated dynamic general equilibrium model. I construct a New Keynesian model with distortionary labour and capital taxes and with preferences that allow the wealth effect on labour supply to vary in strength. I show that the interaction of these two features crucially affects the response of the economy to a government spending shock. The model's parameters are therefore estimated (including the tax policy rules) for the United States. I show that the estimated model can match the positive empirical response of key variables including output, consumption and the real wage — a challenge for many New Keynesian models. I find that the estimated importance of the wealth effect is small; that sticky prices, variable capital utilisation, investment adjustment costs and habits all play an important role; and that whilst tax rates rise following the shock, their small magnitude crucially reduces the distortions involved.

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1 Introduction

The effectiveness of government spending in stimulating the economy became a central policy question during the 2008 financial crisis. Whilst proponents and critics argued about the mechanisms determining policy success, it has been often noted that standard macroeconomic models can generate a wide range of theoretical predictions depending on the assumptions made about how the spending increase is financed[1] and assumptions about how consumers respond to implied future tax increases.

In this paper I construct and estimate a New Keynesian dynamic general equilibrium model focusing on the endogenous response of tax rates to government spending shocks and the strength of the so-called 'wealth effect' on labour supply — both of which are shown to crucially affect the predictions of standard macroeconomic models. This paper therefore contributes directly to the literature on the transmission mechanism of government spending shocks. The model is shown to match key aspects of the empirical evidence with a realistic set of tax instruments and transmission channels.

For all their complexity, many standard models of fiscal policy often rely on a very simple fiscal policy instrument, the lump sum tax, to finance an expenditure shock. This includes state of the art policy models such as that of Smets and Wouters (2007) and recent papers, for example by Cogan et al. (2009), who analyse the size of fiscal multipliers in the U.S.

However, the lump sum tax assumption is far from innocuous. Lump sum tax-finance implies a 'wealth' effect as (expected) income falls. Consumption falls but, assuming leisure and consumption are normal goods, labour supply and consequently output rise. This allows the neoclassical model, and others based on it, to match empirical evidence that GDP increases following a discretionary government spending stimulus.

There are, however, several issues with this mechanism. Firstly, the output rise relies both on the strength of the wealth effect and the lack of distortions associated with the instrument. Consider using a labour income tax instead. The labour supply decision is now distorted, producing strong negative substitution effects. Generally this substitution effect dominates, lowering labour supply and output. Secondly, even if the wealth effect channel can explain the output response, it generates consumption and the real wage responses that are at odds with the empirical Structural Vector Autoregression (SVAR) literature.[2] Thirdly, there is the practical realism of the assumption. Lump

[1] See, for example, Baxter and King (1993) or Alesina et al. (2002).

[2] For example see Perotti (2007) for a review of this evidence. Papers employing the narrative approach to identification sometimes find a fall in consumption. Perotti (2007) shows that this is largely due to the Korean War.

sum taxes are rarely, if ever, used as primary instruments of tax policy. Cloyne (2011) and Romer and Romer (2010) illustrate that most tax actions in the U.K. and U.S. respectively were changes in distortionary taxes.[3]

Since there is no a priori reason to assume that a particular mix of tax instruments finances a spending increase, my first goal in this paper is to estimate the endogenous response of tax rates for the United States and construct a New Keynesian model which replicates these.

The second goal is then to examine the strength of the wealth effect on labour supply itself. The wealth effect channel is still potentially important even after modelling and estimating the distortionary tax rules. This is because the government's budget constraint must hold each period. In several models (such as Burnside et al. (2004)), this is done using a lump sum tax. Furthermore, even if the budget constraint is satisfied by issuing debt, Ricardian equivalence with respect to lump sum taxes implies the same wealth effect on labour supply. It is therefore important to jointly consider the strength of the wealth effect on labour supply *and* the endogenous tax responses to the spending shock.

Following Monacelli and Perotti (2009), I use Jaimovich and Rebelo (2009) (JR) preferences which allow for a variable wealth effect on labour supply. Following Schmitt-Grohe and Uribe (2010) (who do not investigate fiscal policy issues), I estimate the size of this effect. As shown by Monacelli and Perotti, a useful feature of these preferences is that, when the wealth effect on labour supply is limited, consumption and the real wage can increase. This further motivates estimating the importance of the channel.

To evaluate the importance of other potential transmission mechanisms I include a range of more standard features such as sticky prices, variable capital utilisation and habits. I show that the estimated model can match the positive empirical response of key variables including output, consumption and the real wage, which is a challenge for many New Keynesian models. These results arise for a number of reasons. Firstly, the importance of the wealth effect on labour supply is small. Secondly, mechanisms such as sticky prices, variable capital utilisation, investment adjustment costs and habits all play an important role in matching the evidence. Thirdly, distortionary tax rates rise following the expenditure shock but their small magnitude crucially reduces the distortions involved. This explains why the positive output and consumption responses prevail.

The results in this paper contribute, and are related, to several branches of the current literature. First, I directly contribute to the literature which seeks to explain the empirical effects

[3]This includes, for example, both tax changes to directly fund spending measures and tax changes to deal with a budget deficit.

of discretionary shocks to government expenditure. In recent years, work has been focused on matching the sign of the consumption (and real wage) response — see, for example, Monacelli and Perotti (2009), Ravn et al. (2007),[4] Linnemann and Schabert (2003). Few papers in this specific branch of the literature have considered distortionary taxes or included empirically realistic tax policy rules (Burnside et al. (2004) is one exception and Reis (2008) who explicitly argues that it is necessary). To my knowledge, no papers have *empirically* evaluated the importance of the wealth effect channel as a transmission mechanism of fiscal policy.[5]

Secondly, by estimating tax policy rules, the results in this paper have a relationship with the wider literature estimating different fiscal policy rules. For example, both Leeper et al. (2010) and Zubairy (2010) perform Bayesian estimation of DSGE models that include feedback rules for tax rates from output and debt (but not spending). However, Leeper et al. (2010) does not focus on the effects of spending shocks and Zubairy (2010) is more concerned with estimating fiscal multipliers using a DSGE model rather than matching other empirical evidence on the effects of spending shocks.

The remainder of the paper is structured as follows. Section 2 estimates the empirical effects of government spending shocks using a SVAR. Section 3 sets up the theoretical model. Section 4 illustrates key features of the model with respect to the tax policy rules and their interaction with the wealth effect channel. Section 5 estimates the model using a minimum distance estimator. Section 6 concludes that the estimated model matches the empirical evidence well, that shocks appear largely debt-financed, that the wealth effect is relatively small and that sticky prices play an important role, as do the other common mechanisms.

2 The empirical effects of fiscal policy

2.1 Identification

The parameters of the model will be chosen to match the estimated empirical impulse response functions. The empirical effects of a government spending shock are identified using the method of Blanchard and Perotti (2002). Consider the following reduced form VAR:

$$\mathbf{X}_t = \alpha_0 + \alpha_1 t + B(L)\mathbf{X}_{t-1} + \mathbf{u}_t. \tag{1}$$

[4] Zubairy (2009), as I do, follows a minimum distance approach, estimating how well a 'deep habits' model of the form of Ravn et al. (2007) (with lump sum taxes) can explain a government spending shock.

[5] Although, as noted above, Monacelli and Perotti (2009) do show how varying the strength of this effect has useful implications.

$\mathbf{X} = [g_t\ \tau^k\ \tau^n\ y\ c\ n\ w\ i\ b]'$ where g is government spending, τ^k capital taxes, τ^n labour taxes, y output, c consumption, n employment, w the real wage and i investment. For later reference, I also include government debt, b. $B(L)$ is a lag polynomial of order P.

The reduced form residuals $\mathbf{u}_t$ are likely to be correlated. For example, a shock to government spending is likely to imply contemporaneous effects on taxes, debt and so on. Pre-multiplying (1) by the square matrix $\mathbf{A}$ (and ignoring the constant and trend for presentation) yields:

$$\mathbf{A}\mathbf{X}_t = \mathbf{A}B(L)\mathbf{X}_{t-1} + \mathbf{e}_t \tag{2}$$

where $\mathbf{A}\mathbf{u}_t = \mathbf{e}_t$ and $\mathbf{e}_t$ are the structural shocks.[6]

Identification proceeds by making assumptions about the contemporaneous correlation between variables. Identification is achieved by restricting $n(n-1)/2$ parameters. The Blanchard–Perotti assumptions justify certain restrictions. The key assumption is that policy decision variables are unaffected contemporaneously (within the same quarter) by changes in the other endogenous variables. This is justified by the institutional delays involved in policy decision-making. It is therefore assumed that government spending is not affected contemporaneously by any other variable.

The original Blanchard–Perotti approach made use of tax revenues as the measure of taxes, from which they had to work out how much of the change in revenues was due to cyclical movements (in income, for example) and how much was due to genuine policy shocks. External information on tax elasticities was used to disentangle the two effects. In my empirical setup I follow Perotti (2007) and directly construct, and use, tax *rates* so that the theoretical model's policy rules can be directly estimated. The consequence of using rates rather than revenues is that they are policy decision variables. Under the Blanchard–Perotti timing assumptions, these should also be unaffected by other endogenous variables within the quarter. However, I allow them to be affected by spending (in other words, I assume that spending decisions are taken first and then taxes can respond).

To illustrate the identification scheme, consider a smaller set of variables: government spending g, a distortionary tax rate τ, a non-fiscal variable such as output or consumption, y, and debt, b. The relationship between the reduced form residuals and the structural shocks can be written as:

[6] Sometimes this is written as $\mathbf{A}\mathbf{u}_t = \mathbf{B}\mathbf{e}_t$. I am therefore assuming $\mathbf{B} = \mathbf{I}$, which is common. It is worth noting that assumptions on $\mathbf{A}$ will replicate having some non-zero off-diagonal elements in $\mathbf{B}$. Since I only consider structural government spending shocks, all other elements of $\mathbf{e}_t$ will be 0 and only the first column of $\mathbf{B}$ is relevant. Suppose that the second element of this column was non-zero. This would imply that the structural government spending shock affects the tax (where tax is the second equation) reduced form residual. However, since $u^g = e^g$ by the Blanchard–Perotti timing assumptions, nothing is lost by setting this element of $\mathbf{B}$ to zero but ensuring that the relevant element of $\mathbf{A}$, the effect of u^g on other elements of $\mathbf{u}_t$, is correctly accounted for.

$$
\begin{bmatrix} 1 & -\alpha_{g\tau} & -\alpha_{gy} & -\alpha_{gb} \\ -\alpha_{\tau g} & 1 & -\alpha_{\tau y} & -\alpha_{\tau b} \\ -\alpha_{yg} & -\alpha_{y\tau} & 1 & -\alpha_{yb} \\ -\alpha_{bg} & -\alpha_{b\tau} & -\alpha_{by} & 1 \end{bmatrix} = \begin{bmatrix} u_t^g \\ u_t^\tau \\ u_t^y \\ u_t^b \end{bmatrix} = \begin{bmatrix} e_t^g \\ e_t^\tau \\ e_t^y \\ e_t^b \end{bmatrix} \tag{3}
$$

The timing assumptions discussed above allow us to set $\alpha_{g\tau} = \alpha_{gy} = \alpha_{gb} = \alpha_{\tau y} = \alpha_{\tau b} = 0$. However, it seems reasonable to assume that taxes, output and debt may respond to the structural spending shock. Output and debt may also respond to taxes contemporaneously.

In the example above, these assumptions leave us one restriction short. We need to restrict either α_{yb} or α_{by}. With the variable ordering above, setting $\alpha_{yb} = 0$ implies a lower triangular matrix for $\mathbf{A}$. Following Perotti (2007) I adopt this procedure. The most contentious assumption is therefore that debt is ordered last. Ordering the debt series last implies that debt has no contemporaneous effect on output within the quarter (or that the level of debt in period t is the outcome of the changes to the other variables and not the other way around). Ordering debt before output assumes that output has no effect on debt ($\alpha_{by} = 0$) within the quarter. The latter assumption here would appear unrealistic and so I opt for the former specification.[7]

2.2 The data

The data are for the United States over the period 1955:1 to 2007:4. I exclude the Korean War because it is, to some extent, a unique event and can disproportionately drive the results (see Perotti (2007)).

With the exception of the tax rates and debt, all data are taken directly from the relevant sources (and appropriately deflated). The tax rates are constructed using the method outlined in Jones (2002). This approach is also adopted by Burnside et al. (2004).

The debt series would ideally be 'Debt Held by the Public', as used by Favero and Giavazzi (2007). However, this quarterly series does not go back far enough. I therefore construct a debt series from old editions of the U.S. Treasury Bulletin. The resulting series is very close to 'Debt Held by the Public', see Appendix A for details. This improves on the Favero–Giavazzi method of simulating the debt series back to 1947 using annual data.

[7] In the full specification I tested alternative variable orderings. Not placing debt last, despite the above discussion, generated identical impulse response functions to three decimal places, with the standard errors only marginally affected. I switched the two tax rates around and this made little difference. I also used different combinations of the non-fiscal variables (which all appear in place of y in the shorter example), again with very little effect.

All variables, except the tax rates, are the log of real per capita variables. The tax rates are percentages. All real series are the nominal series deflated by its own implicit price deflator, with the exception of government spending and debt which are deflated by the GDP deflator. Appendix A sets out the specific details of each series.

2.3 Results

The figures below report the baseline results for $P = 4$. The impulse response functions are simulations to a one percent structural shock to government spending. The point estimates are shown together with standard 68 percent non-parametric bootstrapped confidence intervals using 10,000 replications.

Figure 1 shows the response of the fiscal policy variables to the shock. The response of the labour and capital tax rates, although positive (as one might expect) are relatively modest.[8] Given the modest increase in taxes, it is useful to consider the response of debt. To the extent that lump sum taxes are rarely used to satisfy the government budget constraint, modest tax rate increases would imply a larger increase in debt. This is what is observed in the fourth panel of figure 1.

Figure 2 shows the responses of the other variables in the SVAR. The top two panels show the familiar SVAR result that output and consumption rise following a government spending shock. The output response on impact is 0.224. Note that this is $\log y_t - \log y$ and $\log g_t - \log g = 1$ by definition. This means that the ratio of the percentage deviations can be written as $\frac{\Delta y_t}{\Delta g_t}\frac{g}{y}$. The multiplier, $\frac{\Delta y_t}{\Delta g_t}$, is therefore the product of this ratio and average government spending to GDP ($\frac{g}{y}$), which is 0.22 in the sample. These estimates imply an output multiplier of about one.

Consumption exhibits the hump-shaped response often seen in SVAR results. Interestingly the labour market responses are weaker, although the point estimates are generally still positive. The investment response is generally negative, again a feature often found in other SVAR studies. For comparable findings see, among others, Perotti (2007) and Monacelli and Perotti (2009).

3 The model

To directly address the issues raised earlier, the model includes distortionary capital and labour tax rates, allowing for endogenous tax rate responses to government spending shocks. I also employ Jaimovich and Rebelo (2009) preferences which allow the strength of the wealth effect on labour supply to vary. Finally, the model includes a range of more standard features such as sticky prices,

[8] These responses are very similar including and excluding the debt series.

variable capital utilisation and habits.

3.1 Households

Households derive utility from consumption (C) and leisure ($1 - N$). The household maximises lifetime utility

$$\max_{C_t, N_t, I_t, z_t, K_{t+1}, B_{t+1}} \mathbb{E}_t \sum_{t=s}^{\infty} \beta^{t-s} u(C_{t+s}, 1 - N_{t+s}), \tag{4}$$

subject to a budget constraint (in real terms)

$$C_t + I_t + \frac{B_{t+1}}{R_t} = B_t + w_t N_t (1 - \tau_t^N) + r_t^K(z_t)(1 - \tau_t^K) K_t - T_t. \tag{5}$$

The capital stock evolves according to

$$K_{t+1} = (1 - \delta(z_t)) K_t + I_t \left(1 - \phi\left(\frac{I_t}{I_{t-1}} - 1\right)\right), \tag{6}$$

which incorporates adjustment costs employed by Christiano et al. (2005), among others. The utility function, $u : \mathbf{R^2} \to \mathbf{R}$, is assumed to be concave and twice continuously differentiable. The function ϕ satisfies $\phi = \phi' = 0$ and $\phi'' > 0$.

K_{t+1} denotes capital held by households at the end of period t and B_{t+1} are real holdings of government bonds, also at the end of period t. C_t is consumption, I_t is investment, R_t is the aggregate real interest rate (gross), w_t is the aggregate real wage and r_t^K is the real return on capital. τ_t^K and τ_t^N are the tax rates on capital and labour income respectively. T_t are lump sum taxes. δ is the rate of depreciation.

The parametric specification for the utility function $u(\cdot)$ follows Jaimovich and Rebelo (2009), Schmitt-Grohe and Uribe (2010) and Monacelli and Perotti (2009).

$$U(C_t, N_t) = \frac{(C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{1-\sigma}}{1 - \sigma} \tag{7}$$

where

$$X_t = (C_t - h\tilde{C}_{t-1})^{\gamma} X_{t-1}^{1-\gamma}. \tag{8}$$

For $\gamma = 1$ and $h = 0$ these preferences become those considered by King et al. (1988). For $\gamma = 0$ and $h = 0$ they become the preferences considered by Greenwood et al. (1988) (henceforth GHH).[9]

[9] One reason against simply using GHH preferences is that they fail to satisfy the conditions for balanced growth, see King and Rebelo (1999) and Jaimovich and Rebelo (2009).

The latter preferences exhibit no wealth effect on labour supply. In other words, labour supply is solely affected by the real wage (net of taxes) and not by the level of consumption.

I have modified the Jaimovich–Rebelo preferences to include habits. $\tilde{C}_{t-1}$ is aggregate consumption in the previous period and the consumer takes this as given. Below I show that internal habits, where consumers explicitly consider C_{t-1} in their optimisation decisions, would reintroduce the wealth effect on labour supply when $\gamma = 0$.

The model also features variable capital utilisation. High utilisation by firms implies greater depreciation of a given stock of capital. For this reason both the return on capital and the depreciation are functions of utilisation, captured by the variable z_t.

3.1.1 First order conditions

The first order conditions for the household's problem, with respect to C_t, X_t, B_{t+1}, N_t, I_t, K_{t+1} and z_t are:

$$\lambda_t = (C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{-\sigma} + \mu_t \gamma (C_t - h\tilde{C}_{t-1})^{\gamma-1} X_{t-1}^{1-\gamma} \tag{9}$$

$$(C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{-\sigma} \psi N_t^{\xi} + \mu_t = \beta \mathbb{E}_t (\mu_{t+1}(1-\gamma)(C_t - h\tilde{C}_{t-1})^{\gamma} X_t^{-\gamma} \tag{10}$$

$$\mathbb{E}_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) = \frac{1}{R_t \beta} \tag{11}$$

$$\psi N_t^{\xi-1} \xi X_t (C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{-\sigma} = \lambda_t w_t (1 - \tau_t^n) \tag{12}$$

$$1 - q_t \left(\left(1 - \phi \left(\frac{I_t}{I_{t-1}} \right) \right) - \phi' \left(\frac{I_t}{I_{t-1}} \right) \left(\frac{I_t}{I_{t-1}} \right) \right) = \mathbb{E}_t \left(q_{t+1} \frac{\lambda_{t+1}}{\lambda_t} \beta \left[\frac{I_{t+1}^2}{I_t^2} \phi' \left(\frac{I_{t+1}}{I_t} \right) \right] \right) \tag{13}$$

$$q_t = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left(r_{t+1}^K (1 - \tau_{t+1}^K) + q_{t+1}(1 - \delta(z_t)) \right) \tag{14}$$

$$r_t'^K(z_t) = q_t \delta'(z_t) \tag{15}$$

where r'^K is the derivative of the return on capital with respect to utilisation. μ_t is the Lagrange multiplier on the evolution of X_t (equation (8)) and q_t is the multiplier on the capital accumulation equation and reflects Tobin's marginal q.

3.1.2 The variable wealth effect

Consider the extreme case where $\gamma = 0$. The preferences are then of the GHH-form and the marginal rate of substitution between consumption and leisure is independent of consumption. To see this, combine the first order condition with respect to consumption with the first order condition with respect to labour supply:

$$\psi N_t^{\xi-1}\xi X_t(C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{-\sigma} = (C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{-\sigma} w_t(1-\tau_t^n) \tag{16}$$

noting

$$\lambda_t = (C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi} X_t)^{-\sigma}. \tag{17}$$

This implies that

$$\psi\xi N_t^{\xi-1} = w_t(1-\tau_t^n). \tag{18}$$

At an unchanged real wage and tax rate, hours do not change. In a simple graphical representation without capital, this implies that the labour supply curve does not shift outwards as consumption falls (the key neoclassical channel, raising labour supply and lowering the real wage following an increase in lump sum taxes). Under Jaimovich–Rebelo preferences, increasing γ from zero raises the strength of the wealth effect on labour supply.

3.1.3 Habits and the wealth effect

An important feature of the preferences is the lack of wealth effect on labour supply as γ tends towards zero. This feature is preserved under the habits specification introduced above. To see this consider again equation (16). This was obtained because the marginal utility of consumption is equal to λ_t, cancelling on both sides of equation (16). Note that this would not be true with internal habits. For $\gamma = 0$, λ_t would be:

$$\lambda_t = (C_t - h\tilde{C}_{t-1} - \psi N_t^{\xi})^{-\sigma} - \mathbb{E}_t\lambda_{t+1}h\beta(C_{t+1} - h\tilde{C}_t - \psi N_{t+1}^{\xi})^{-\sigma}. \tag{19}$$

The first order condition for labour supply is unchanged. λ_t no longer cancels in equation (16) and labour supply once again depends on consumption.

3.2 Firms

There are a continuum of monopolistically competitive firms producing final output indexed on the unit interval. The consumer's problem can still be formulated as above but note that each individual actually purchases a bundle of differentiated goods $\int_0^1 P_t(i)C_t(i)$ where i refers to a particular firm. For each variety of goods the consumption demand function is:

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} C_t, \tag{20}$$

where

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}} \tag{21}$$

and ϵ is the elasticity of substitution between varieties of goods.

The minimum expenditure required to purchase a bundle of goods resulting in C_t units of the composite good is given by $P_t C_t$ and so the consumer's budget constraint can be written as before.[10]

The demand for the i^{th} product (the output of firm i) is given by

$$Y_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\epsilon} Y_t^d, \tag{22}$$

where Y_t^d is aggregate demand. The resource constraint is

$$Y_t = C_t + I_t + G_t. \tag{23}$$

Cost minimization with respect to $N_t(i),\ K_t(i)$ and $z_t(i)$ subject to firm i's production function $Y_t(i) = [z_t(i)K_t(i)]^\alpha N_t(i)^{(1-\alpha)}$ implies

$$w_t = mc_t(i)(1-\alpha)\frac{Y_t(i)}{N_t(i)} \tag{24}$$

$$r_t^K = mc_t(i)\alpha\frac{Y_t(i)}{K_t(i)}, \tag{25}$$

and

$$mc_t(i)\alpha\frac{Y_t(i)}{z_t(i)} = \frac{q_t\delta'(z_t(i))k_t(i)}{(1-\tau_t^K)} \tag{26}$$

where $mc_t(i)$ is real marginal cost and equation (26) makes use of equation (15).

When firms are able to reset their price they choose $P_t^*(i)$ to maximize expected profits

$$\max \mathbb{E}_t \sum_{s=0}^{\infty} Q_{t,t+j}\left[(1-\tau^P)P_{t+j}^*(i)Y_{t+j}(i) - MC_{t+s}(i)Y_{t+s}(i) + T_{t+j}^P\right] \tag{27}$$

subject to

$$Y_{t+j}(i) = \left(\frac{P_{t+j}(i)}{P_{t+j}}\right)^{-\epsilon} Y_{t+j}^d,$$

where MC_t is nominal marginal cost. τ^P and T^P are a tax and lump sum subsidy, which removes the steady state markup distortion.

[10] The consumer's problem technically also includes non-zero profits Π_t which I assume are equally distributed lump sum to all consumers. This does not affect the first order conditions.

The first order condition for firm i's price setting problem is the familiar New Keynesian optimal reset price:

$$P_t^*(i) = \frac{\mathbb{E}_t \sum_{j=0}^{\infty} \eta^j Q_{t,t+j} MC_{t+1} Y_{t+j}(i)}{\mathbb{E}_t \sum_{j=0}^{\infty} \eta^j Q_{t,t+j} Y_{t+j}(i)}. \tag{28}$$

Finally, the price index is an aggregate of firms who reset their price today and those who must retain last period's prices

$$P_t = \left[\eta P_{t-1}^{1-\epsilon} + (1-\eta) P_t^{*(1-\epsilon)}\right]^{\frac{1}{1-\epsilon}}. \tag{29}$$

3.3 Government

The government can finance spending, G, through a mixture of bond supply B, labour and capital income taxes τ^N, τ^K or lump sum taxes T, such that the government budget constraint is satisfied

$$\frac{B_{t+1}}{R_t} = B_t + G_t - \tau_t^N N_t w_t - \tau_t^K K_t r_t^K - T_t. \tag{30}$$

Tax rules are necessary to specify how the government splits its financing between the various tax instruments. I assume tax rates respond to a proportion of the spending increase. Writing $\hat{\tau}$ as the percentage point deviation from steady state, and all other lower case letters as percentage deviation from steady state, the tax rules for the linearized model are of the form:

$$\hat{\tau}_t^N = \theta^{\tau^N,1} \hat{\tau}_{t-1}^N + \theta^{\tau^N,2} \hat{\tau}_{t-2}^N + \theta^{ng} g_t \tag{31}$$

$$\hat{\tau}_t^K = \theta^{\tau^K,1} \hat{\tau}_{t-1}^K + \theta^{\tau^K,2} \hat{\tau}_{t-2}^K + \theta^{kg} g_t \tag{32}$$

I follow Reis (2008) in making government spending ARMA(1,1)

$$g_t = \phi_1 g_{t-1} + \phi_2 a_t, \tag{33}$$

where a_t is an AR(1) process with a white noise shock and the persistence is governed by parameter ρ.

3.4 Monetary policy

Monetary policy follows a simple rule relating the nominal interest rate ($nomi_t$) to inflation. In percentage deviations from steady state (linearized form), and using the Fisher relation, the real interest rate is related to inflation by

$$nomi_t = r_t - \mathbb{E}_t \pi_{t+1} = \phi_\pi \pi_t. \tag{34}$$

where $\phi_\pi > 1$.

3.5 Equilibrium and model solution

The equilibrium is defined by an allocation $\{K_t, C_t, N_t, Y_t, B_t, I_t, z_t, X_t\}_{t=0}^{\infty}$, a price system $\{w_t, R_t, q_t, r_t^k, P_t(i), P_t, mc_t, \lambda_t, \mu_t)\}_{t=0}^{\infty}$, a fiscal policy $\{\tau_t^N, \tau_t^K, G_t\}_{t=0}^{\infty}$ and an exogenous process $\{a_t\}_{t=0}^{\infty}$ such that the allocation $\{K_t, C_t, N_t, Y_t, B_t, I_t, z_t, X_t\}_{t=0}^{\infty}$ solves:

1. the households' problem, maximizing (4) subject to (5), (6), (8) and a no-ponzi condition, given prices, thus satisfying (9), (10), (11), (12), (13), (14) and (15);
2. the firms' problem (27) subject to (22) and minimizing costs so that equations (24), (25), (26), (28) and (29) are satisfied.
3. All markets clear and equations (30), (31), (32), (33) and (34) and the resource constraint $Y_t = C_t + I_t + G_t$ are satisfied.

The equilibrium system is therefore defined by equations (6), (8), (9), (10), (11), (12), (13), (14), (15), (28), (29), (30), (31), (32), (33), (34), the production function, the aggregates of equations (24), (25) and (26) and an exogenous process for $a_{t+1} = \rho a_t + \varepsilon_{t+1}$. The set of predetermined variables is $\{B_t, K_t, a_t\}$.

The model is linearized around a deterministic steady state where all firms set the same price. The collection of linearized conditions can be written in recursive form:

$$\mathbf{A}\mathbb{E}_t \begin{bmatrix} x_{t+1} \\ y_{t+1} \end{bmatrix} = \mathbf{B} \begin{bmatrix} x_t \\ y_t \end{bmatrix} \tag{35}$$

where x is the vector of state variables, $x_{t+1} = \{k_{t+1}, b_{t+1}, a_{t+1}\}$. y is the vector of control variables. The solution to this linear rational expectations model is then of the form:

$$y_t = \mathbf{Q} x_t \tag{36}$$

$$x_{t+1} = \mathbf{P} x_t. \tag{37}$$

To solve for matrices P and Q in the policy functions, I employ the Klein (2000) algorithm *solab*.

Details of the linearized system and the steady state are given in the Appendices B and C respectively. Of particular interest are the linearized equations governing price evolution, utilisation and investment (recall, lower case letters represent percentage deviations from steady state). The first is the New Keynesian Phillips Curve. Note that the degree of price stickiness, η, appears in this expression and will be estimated.

$$\pi_t = \frac{(1-\beta\eta)(1-\eta)}{\eta} mc_t + \beta \mathbb{E}_t \pi_{t+1}. \tag{38}$$

The degree of capital utilisation, z_t, is described by

$$(1+\kappa) z_t = y_t - k_t - q_t + mc_t - \tau_t^K \frac{1}{1-\tau^K}, \tag{39}$$

where $\kappa = \frac{\delta''}{\delta'}$ is the elasticity of depreciation to utilisation, and will also be estimated. Investment evolves according to

$$\frac{q_t}{\phi''} = (1+\beta) i_t - i_{t-1} - \beta \mathbb{E}_t i_{t+1} \tag{40}$$

and $\frac{1}{\phi''} = \mu$ will be estimated.

4 Key features of the model

In this section I consider some important mechanisms in the model. Before considering how the choice of tax policy instruments affect the results, I first consider how the model's more standard features interact with the strength of the wealth effect on labour supply under lump sum taxes. Table 1 presents the initial baseline calibration for this section.

4.1 The strength of the wealth effect on labour supply

Figures (3) to (7) illustrate the effect of turning on each mechanism one at a time while still assuming that lump sum taxes fund the spending shock.

In Figure (3), the model has flexible prices ($\eta = 0$), no variable capital utilisation ($\kappa = \infty$) and no habit formation ($h = 0$). $\gamma = 1$, so there is a standard wealth effect on labour supply. This case can therefore be regarded as a simple baseline neoclassical model. Figure (3) shows the familiar neoclassical result. The higher lump sum taxes that accompany the spending shock lower lifetime wealth, lower consumption, lower savings and hence investment, but boost labour supply. The real wage therefore falls. Figure (4), however, illustrates the effect of turning off the wealth effect on labour supply, i.e. setting $\gamma = 0$. Labour supply now does not respond to the lower lifetime wealth. Consumption and investment are lower than before, reflecting the decrease in lifetime wealth and the lack of increased earnings from supplying more labour. All these forces cause output to fall over time. Importantly, the neoclassical model can no longer match the empirical output response.

In fact the neoclassical model without a wealth effect on labour supply fails to qualitatively match any of the output, consumption, real wage or hours responses estimated in section 2.

It is worth emphasising that if the shock were funded with debt rather than lump sum taxes, Ricardian equivalence implies that the result will be the same. To the extent that governments rarely, if ever, use lump sum taxes (Cloyne (2011) and the associated long appendix documents this for the United Kingdom and see Romer and Romer (2010) for the U.S.), increased borrowing will be needed to satisfy the government's budget constraint (assuming no distortionray taxes). It is therefore an important empirical question whether debt-finance — which raises expectations about future tax increases — generates a wealth effect on labour supply today.

Figure (5) shows the result of adding sticky prices to the previous model ($\gamma = 0$). As Figure (5) illustrates, government spending now has a positive effect on demand which boosts output, labour demand (and hence hours), the real wage, hours worked and consumption. The figure illustrates the Monacelli and Perotti (2009) result that consumption can rise following the shock. Two features of the model produce this result. Firstly, there is no wealth effect on labour supply. This means that the real wage does not fall on impact because the labour supply curve does not shift with the increase in the marginal utility of wealth. Secondly, in response to the shock, the sticky price demand effect induces an outward shift of the labour demand curve. For sufficiently sticky prices the result is a rise in the real wage and hours — raising income enough that consumption also increases. This effect lowers the amount of dis-saving, lessening the negative effect on investment.

Adding variable capital utilisation to the model serves to increase the persistence of these effects, as can be seen from figure (6). Finally, the inclusion of habits adds persistence to the consumption profile, with additional implications for overall demand. This can be seen from figure (7).

This section has shown that all the mechanisms in the model interact to produce positive consumption, output, real wage and hours responses, as found empirically in section 2, when the wealth effect on labour supply is small enough. This contrasts with the standard neoclassical model. The empirical relevance of the wealth effect on labour supply is therefore of great importance.

4.2 The effect of different tax instruments

The previous section illustrated the importance of the wealth effect on labour supply under lump sum taxes. This section now evaluates the effect of adding distortionary taxes to the model and explores varying the tax instruments used to finance the shock.

In the above examples, by using lump sum taxes, there were no substitution effects. This is not true when distortionary taxes finance the spending shock. Figure (8) illustrates the effect of assuming that the two distortionary tax rates increase following the spending shock. For this exercise I arbitrarily choose $\theta^{gn} = \theta^{gk} = 0.6$. The figure illustrates the strong negative effect on output and consumption of using distortionary taxes. In short, the results in the previous section depend not only on the strength of the wealth effect on labour supply, but also — quite dramatically — on the instruments used to finance the shock. I now consider the two types of taxes individually.

4.2.1 Labour income taxes

Consider the supply side effects of a rise in the labour income tax rate. There are two substitution effects. First, the intra-temporal decision is distorted and labour supply falls. In other words, it is more costly to supply labour today as the worker pays higher taxes per hour. Second, the inter-temporal decision is distorted if the tax rate is changing over time (as it may be when the tax rules are estimated). For a rising (falling) tax profile the worker may still prefer (dislike) to work today as it will be relatively less (more) costly than tomorrow. These substitution effects work to offset the wealth effect on labour supply. In the simulations below, labour supply falls considerably following a rise in government spending.

To illustrate the effect, I calibrate the coefficient on g_t in the labour tax rule to be 0.95, leaving the equivalent parameter zero in the capital tax rule. Figure 9 shows the strong negative effect of this change in the tax policy rule. The positive effects on output, consumption and hours in the previous section are now reversed in the presence of labour income tax-finance. Note that saving becomes more attractive which, over time, raises investment.

4.2.2 Capital income taxes

Figure 10 shows the effect of calibrating the coefficient on g_t in the capital tax rate rule to 0.95, leaving the equivalent coefficient zero in the labour tax rule.

Interestingly, the use of capital taxes raises consumption and output on impact but lowers the persistence. This effect is a combination of substitution effects and sticky prices (and habits). Taxing capital makes consumption relatively more attractive than saving. As a result, ceteris paribus, the balance between consumption and saving tilts towards consumption. This increase in demand, given sticky prices, boosts output in the short run. With flexible prices the increase in capital taxes tends to lower consumption and output as the capital stock declines.

Another key determinant of the size of this response is the presence of capital adjustment costs. The distortions introduced by taxing capital are not fully felt immediately but become apparent over time as the capital stock adjusts. This explains the decline in output over time.

4.2.3 Summary

The previous subsections have analysed the interactions between debt finance/lump sum taxes, the use of distortionary taxes and the wealth effect channel. Debt finance (or lump sum taxes) minimizes the contemporaneous distortions associated with labour and capital taxes. Labour income taxes produce a strong negative effect on all the key variables. If the objective is a stimulus to output (rather than a concern with welfare), this suggests labour income taxes should be avoided. The use of capital income taxes may raise the impact stimulus by boosting consumption but will lower the persistence of the effect on output as the capital stock declines faster.

I also showed that under debt-finance (or lump sum taxes) the model's predictions rest on the strength of the wealth effect on labour supply and the degree of price stickiness (and, to a lesser extent, habits and variable capital utilisation, which reinforce the results). A low degree of wealth effect on labour supply allows the sticky price effects to jointly raise output, consumption, the real wage and hours. However, for stronger degrees of wealth effect, consumption will fall. Conversely, if the wealth effect is small, but prices are flexible, output and consumption both fall.

In short, this section has shown that the choice of tax policy instruments matters, as does the strength of the wealth effect on labour supply. In fact, the model's results are highly dependent on these parameters. However, there is no a priori reason to calibrate either the tax policy rules in a particular way, or to assume a particular strength of wealth effect on labour supply. To properly evaluate the ability of the model to explain the effects of a government spending shock, arbitrarily calibrating these key parameters will not be enlightening. Estimation is therefore the most appropriate strategy to follow.

5 Estimation

I estimate the model using a minimum distance approach as discussed by, for example, Christiano et al. (2005). Key parameters of the model are chosen to minimize the distance between the model's impulse responses and the empirical impulse responses.

The model's parameters are partitioned into two blocks. The first block includes a set of parameters which are calibrated. The second block includes parameters to be estimated. I estimate all the parameters of the fiscal policy rules. I also estimate the parameters of the key mechanisms in the model: γ governing the size of the wealth effect, κ determining the degree of variable capital utilisation, μ determining the strength of the investment adjustment costs, η the degree of price stickiness and the habit persistence parameter h. The parameter vector to be estimated is therefore[11]

$$\zeta = [\phi_1\ \phi_2\ \theta^{gn}\ \theta^{n1}\ \theta^{n2}\ \theta^{gk}\ \theta^{k1}\ \theta^{k2}\ \eta\ \kappa\ \gamma\ h\ \mu].$$

Let the empirical impulse responses be stacked in a vector $\bar{\mathbf{x}}$. The model produces impulse responses conditional on a set of parameters. Let the parameter vector be ζ as above. Let the output of the model given the set of parameters be $\mathbf{x}(\zeta)$. The objective is to choose parameters to minimize the loss function

$$\zeta = \arg\min_{\zeta} [\bar{\mathbf{x}} - \mathbf{x}(\zeta)] V^{-1} [\bar{\mathbf{x}} - \mathbf{x}(\zeta)]', \tag{41}$$

where V is a weighting matrix which includes the variances of the empirical impulses along the diagonal and zeros elsewhere. The purpose of this matrix is to down-weight observations with larger standard errors. As such, I ensure that the estimated model's responses lie as far inside the empirical confidence intervals as possible.

I match the model's impulse responses to the first 16 periods of the nine empirical impulse responses. Dropping any observation with zero variance from the loss function (the first element of the government spending series) leaves the $\mathbf{x}$ vectors $((9 \times 16) - 1) \times 1$ and the V matrix $((9 \times 16) - 1) \times ((9 \times 16) - 1)$ in dimension.

The standard errors are calculated following Hall et al. (2010). Specifically the variance-covariance matrix of the estimated parameters is found as the solution to:

$$V_\zeta = \left[\frac{\partial \mathbf{x}(\zeta)'}{\partial \zeta} W^{-1} \frac{\partial \mathbf{x}(\zeta)}{\partial \zeta} \right]^{-1} \tag{42}$$

where W is the variance-covariance matrix of the impulse response functions and $\frac{\partial \mathbf{x}(\zeta)}{\partial \zeta}$ is the $((9 \times 16) - 1) \times 9$ Jacobian of the theoretical impulse responses with respect to the parameter vector.

5.1 Results

The estimated parameter values are given in table (2). The tax rate responses to the government spending shock are estimated to be small, although the response builds over time — as can be seen from the coefficients on the lagged tax rates. Figure 11 displays the matched policy responses implied by the estimated model, together with the confidence intervals from the SVAR. The estimated fiscal policy parameters in table (2) generate responses within the empirical confidence intervals and are thus a decent replication of the empirical policy response. For reference, I also plot the

[11]For a list of parameter definitions see table 1.

simulated debt path from the model given the spending and tax rate changes. Interestingly, based on the model's estimated parameters, these tax rate changes are consistent with the empirically estimated response of debt from section 2. This suggests that spending shocks are typically funded more through debt than through contemporary tax changes.

Table 2 also reports the other estimated parameter values and their standard errors. It is worth comparing these with values discussed elsewhere. King and Rebelo (1999) take $\kappa \in [0.1, \infty]$ and the value in table 2 is close to the value of 0.15 used by Jaimovich and Rebelo (2009). η is of the order of magnitude usually used in New Keynesian models and is similar to the value of 0.83 estimated by Altig et al. (2004). It is, however, slightly too high, which may suggest other amplification mechanisms could be included in the model to lower the required degree of price stickiness. The estimate for γ implies a very small wealth effect on labour supply and not statistically significant from zero. This reinforces the results of Schmitt-Grohe and Uribe (2010). h is similar to the value of 0.7 used by Monacelli and Perotti (2009) and is a fairly standard figure found in the wider literature.

Figure 12 displays the responses of the other key macroeconomic variables. Again, the estimated model produces responses largely within the confidence intervals. It is noteworthy that the estimated model jointly replicates the output and consumption responses, which is often a problem for New Keynesian models. Although the hours response is slightly too strong, most of the real wage response is well matched. The investment response is too shallow to start with and too strong over time; however this reflects the investment adjustment cost mechanism. The parameter less well estimated is μ, which governs the investment adjustment costs. The estimate is well below the value of 1/8 estimated by Mertens and Ravn (2011), which itself is lower than in other studies. However, raising the value of μ would produce too great a decline in investment. All this suggests interesting scope for considering more complicated investment dynamics in the transmission of fiscal shocks.

5.2 Robustness

I now examine the robustness of the parameter estimates when each of the main mechanisms discussed earlier are turned off or directly calibrated.[12] Table (3) displays the results from these experiments.

First consider the fiscal policy parameters. Estimates of the persistence of the government spending process (ρ and ϕ_1) are very similar across all specifications. So too is the impact response

[12] Parameter values used in table (3) reflect commonly chosen values elsewhere in the literature.

of the tax rates following the spending shock (θ^{gk} and θ^{gn}). The persistence coefficients in the tax rules do vary somewhat, although these estimates still produce impulse responses generally within the empirical confidence intervals.

In all cases the strength of the wealth effect on labour supply is estimated to be low. This mirrors findings by Schmitt-Grohe and Uribe (2010). Furthermore, note that the loss increases significantly when γ is forced to be one, the case of King-Plosser-Rebelo-type preferences. The degree of price stickiness is estimated to be high across all specifications, suggesting an important role for short-run demand effects. However, when other mechanisms are turned off — notably variable capital utilisation — the degree of price stickiness becomes implausibly high. It is also interesting to note that the flexible price model (where $\eta = 0$) does not perform too badly (in terms of loss). This, however, relies on an implausibly high level of variable capital utilisation and strong habit persistence. Similarly, estimates of the habit persistence parameter increase significantly when sticky prices or variable capital utilisation are turned off. In general, the parameter estimates governing variable capital utilisation and the investment adjustment costs, κ and μ, are far too low. These experiments did not, therefore, resolve the issues with the investment response discussed earlier.

These exercises confirm several important results. Firstly, that the strength of wealth effect on labour supply is robustly low across all specifications. Secondly, that the strength of the tax rate response to government spending shocks is limited. And, thirdly, all the model's mechanisms appear important for matching the empirical evidence: the baseline case achieves the smallest loss.

6 Conclusion

In this paper I have empirically investigated the importance of the endogenous tax response to government spending shocks and the strength of the wealth effect channel in the United States. The estimated model matches well the empirical effects of an increase in government spending, with parameter estimates largely in line with those estimated elsewhere in the literature.

The mix of tax policy instruments matters greatly for the sign and magnitude of key responses. For example, greater use of labour income taxes causes a contraction in output, consumption, the real wage and hours, all contrary to the empirical evidence presented in section 2.

Furthermore, the degree of distortionary tax finance interacts with the strength of the wealth effect on labour supply, which can partially offset any negative substitution effects. By employing Jaimovich and Rebelo (2009) preferences, I showed that the neoclassical model with a low wealth effect on labour supply fails to match the output, consumption, real wage or hours responses found in the data. The presence of sticky prices, however, allows the model to qualitatively match all the empirical responses. The model also contains more standard features such as variable capital utilisation, investment adjustment costs and habits. All these played a role in replicating the empirical evidence. I showed how these mechanisms interact and this motivated estimation of the parameters governing their strength. This is particularly important given that there is little, if any, a priori information for calibrating the tax rules or the strength of the wealth effect.

The key findings that allow the estimated model to replicate the empirical impulse responses are, first, that the wealth effect on labour supply is estimated to be small. This casts further doubt on whether a simple neoclassical model can replicate the empirical evidence. Second, sticky prices, variable capital utilisation, investment adjustment costs and habits were all found to play an important role, with parameter values generally in line with those found in the wider literature. One exception is the parameter governing the investment adjustment costs. Typical calibrations of this parameter would have implied a larger fall in investment than was observed in the empirical results. My results suggest that further work should be done to investigate the response of investment following a government spending shock. Third, I find that while distortionary tax rates rise following the spending shock, their magnitudes are modest. Importantly, capital tax rates increase more than labour tax rates, limiting the contractionary effect on output and consumption. The model also implies a realistic debt path on the basis of these tax rate changes, implying that government spending shocks — at least over the short to medium-term horizon — tend to be debt-financed.

To the extent that nominal rigidities allow for short-run demand effects and, to the extent that the wealth effect on labour supply is small, my results suggest that debt-financed (or lump sum tax financed) government spending shocks will stimulate output, consumption, hours and the real wage over the short term. The output multiplier was around one. However, the decline in investment is important as it lowers the economy's longer-term output and wealth. Furthermore, the required current and future tax increases place a welfare cost on the economy, even if consumption and output rise initially. The short-term gain of a spending stimulus then has to be traded-off against the long-term costs. Striking this balance clearly remains hugely topical in the current climate.

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7 Tables and Figures

Table 1: Baseline calibration

Parameter	Value	Description
β	0.99	Discount factor
α	0.3	Capital share
δ	0.025	Steady state depreciation
τ^K	0	Steady state capital tax rate (from sample)
τ^N	0	Steady state labour tax rate (from sample)
N	0.2	Steady state labour
$\frac{G}{Y}$	0.2	Steady state share of government spending
$\frac{B}{Y}$	1.6	Steady state debt to GDP ratio (quarterly)
σ	1	Inverse of elasticity of intertemporal substitution ($\gamma = 1$)
ξ	1.8	Parameter governing Frisch elasticity of labour supply ($\gamma = 0$)
ϕ_π	1.5	Coefficient on inflation in the monetary policy rule
ρ	0.8	Autoregressive parameter on a_t shock
η	0.75	Probability of having a fixed price
κ	0.15	Parameter governing capital utilisation
μ	1/3	Parameter governing the investment adjustment costs
γ	0.01	Parameter governing the wealth effect
h	0.5	Parameter governing habit persistence

Table 2: Estimated parameter values

Parameter	Estimation	Description
ρ	0.94 (0.02)	Persistence of shock process
ϕ_1	0.00 (0.08)	Persistence of spending process
ϕ_2	-0.14 (0.06)	Effect of shock on spending
θ^{gn}	0.0043 (0.02)	Contemporaneous response of the labour tax rate
θ^{gk}	0.0046 (0.002)	Contemporaneous response of the capital tax rate
$\theta^{\tau^{N,1}}$	0.19 (0.1)	Labour tax rate AR(1) coefficient
$\theta^{\tau^{K,1}}$	1.87 (0.07)	Capital tax rate AR(1) coefficient
$\theta^{\tau^{N,2}}$	0.038 (0.1)	Labour tax rate AR(2) coefficient
$\theta^{\tau^{K,2}}$	-0.91 (0.07)	Capital tax rate AR(2) coefficient
γ	0.0023 (0.003)	Strength of the wealth effect
h	0.58 (0.06)	Strength of habits
η	0.86 (0.04)	Probability of a fixed price
κ	0.16 (0.33)	Governs capital utilisation
μ	0.032 (0.03)	Governs investment adjustment costs
Loss	51.52	

Table 4: Data sources

Series	Source	Description
Gov. spending	BEA	Gov. cons. expenditures and gross inv. (CVM)
Capital taxes	BEA	Constructed as above
Labour taxes	BEA	Constructed as above
Output	BEA	Gross domestic product (CVM)
Real wage	BLS	BLS Series ID: PRS85006153
Hours	Unpublished BLS	Francis-Ramey “Measures of Hours per Capita”
Consumption	BEA	Personal consumption expenditures (CVM)
Investment	BEA	Gross private domestic investment (CVM)
Debt	Treasury Bulletin	Close to ‘Debt Held by the Public’

Table 3: Robustness

	ρ	ϕ_1	ϕ_2	θ^{gn}	θ^{gk}	$\theta^{\tau^{N,1}}$	$\theta^{\tau^{K,1}}$	$\theta^{\tau^{N,2}}$	$\theta^{\tau^{K,2}}$	γ	h	η	κ	μ	Loss
Baseline	0.94	0.00	-0.14	0.0043	0.0046	0.19	1.87	0.038	-0.91	0.0023	0.58	0.86	0.16	0.032	51.52
	(0.02)	(0.08)	(0.06)	(0.02)	(0.002)	(0.1)	(0.07)	(0.1)	(0.07)	(0.003)	(0.06)	(0.04)	(0.3)	(0.03)	
Fixed habits ($h = 0.6$)	0.92	0.0003	-0.010	0.0021	0.0034	0.077	1.94	-0.093	-0.97	0.027	-	0.88	0.00	0.050	60.25
	(0.02)	(0.07)	(0.06)	(0.02)	(0.002)	(0.1)	(0.07)	(0.1)	(0.07)	(0.01)		(0.03)	(0.03)	(0.05)	
No habits ($h = 0$)	0.93	0.0002	-0.012	0.021	0.039	0.012	-0.063	-0.041	0.81	0.0042	-	0.91	0.00	0.0019	96.04
	(0.01)	(0.06)	(0.05)	(0.02)	(0.01)	(0.07)	(0.06)	(0.07)	(0.07)	(0.01)		(0.02)	(0.08)	(0.02)	
Fixed utilisation ($\kappa = 0.15$)	0.92	0.0024	-0.014	0.013	0.0043	0.029	1.89	0.16	-0.93	0.0044	0.55	0.85	-	0.029	56.16
	(0.02)	(0.07)	(0.06)	(0.02)	(0.002)	(0.1)	(0.06)	(0.1)	(0.07)	(0.004)	(0.04)	(0.03)		(0.03)	
No utilisation ($\kappa = \infty$)	0.93	0.011	-0.10	0.025	0.0016	0.054	2.00	0.0090	-1.00	0.069	0.94	0.97	-	0.014	80.29
	(0.01)	(0.07)	(0.05)	(0.01)	(0.001)	(0.005)	(0.001)	(0.002)	(0.001)	(0.0002)	(0.0005)	(0.007)		(0.009)	
Fixed adj. costs ($\mu = 1/3$)	0.93	0.00	-0.042	0.030	0.0027	-0.34	1.97	0.35	-1.00	0.041	0.86	0.97	0.087	-	54.96
	(0.01)	(0.07)	(0.05)	(0.02)	(0.001)	(0.07)	(0.09)	(0.08)	(0.09)	(0.02)	(0.07)	(0.08)	(0.09)		
Fixed $\eta = 0.75$	0.92	0.00	0.0094	0.010	0.026	-0.10	-0.020	0.20	0.93	0.061	0.89	-	0.0024	0.0077	60.64
	(0.02)	(0.07)	(0.05)	(0.02)	(0.01)	(0.08)	(0.04)	(0.06)	(0.08)	(0.02)	(0.03)		(0.04)	(0.007)	
Flexible prices ($\eta = 0$)	0.92	0.0016	0.016	0.027	0.022	0.012	0.042	-0.021	0.92	0.061	0.88	-	0.00	0.010	64.93
	(0.02)	(0.07)	(0.06)	(0.02)	(0.01)	(0.1)	(0.03)	(0.1)	(0.09)	(0.02)	(0.05)		(0.04)	(0.008)	
Fixed $\gamma = 0.01$	0.92	0.00	-0.024	0.0054	0.0036	0.076	1.91	0.0051	-0.94	-	0.56	0.87	0.00	0.032	53.98
	(0.02)	(0.07)	(0.06)	(0.02)	(0.001)	(0.1)	(0.06)	(0.1)	(0.06)		(0.08)	(0.03)	(0.05)	(0.03)	
$\gamma = 1$	0.91	0.00	0.041	0.024	0.0023	0.026	1.97	0.14	-1.0	-	0.18	0.92	0.00	0.11	125.42
	(0.01)	(0.07)	(0.06)	(0.02)	(0.001)	(0.2)	(0.06)	(0.2)	(0.06)		(0.3)	(0.02)	(0.04)	(0.2)	

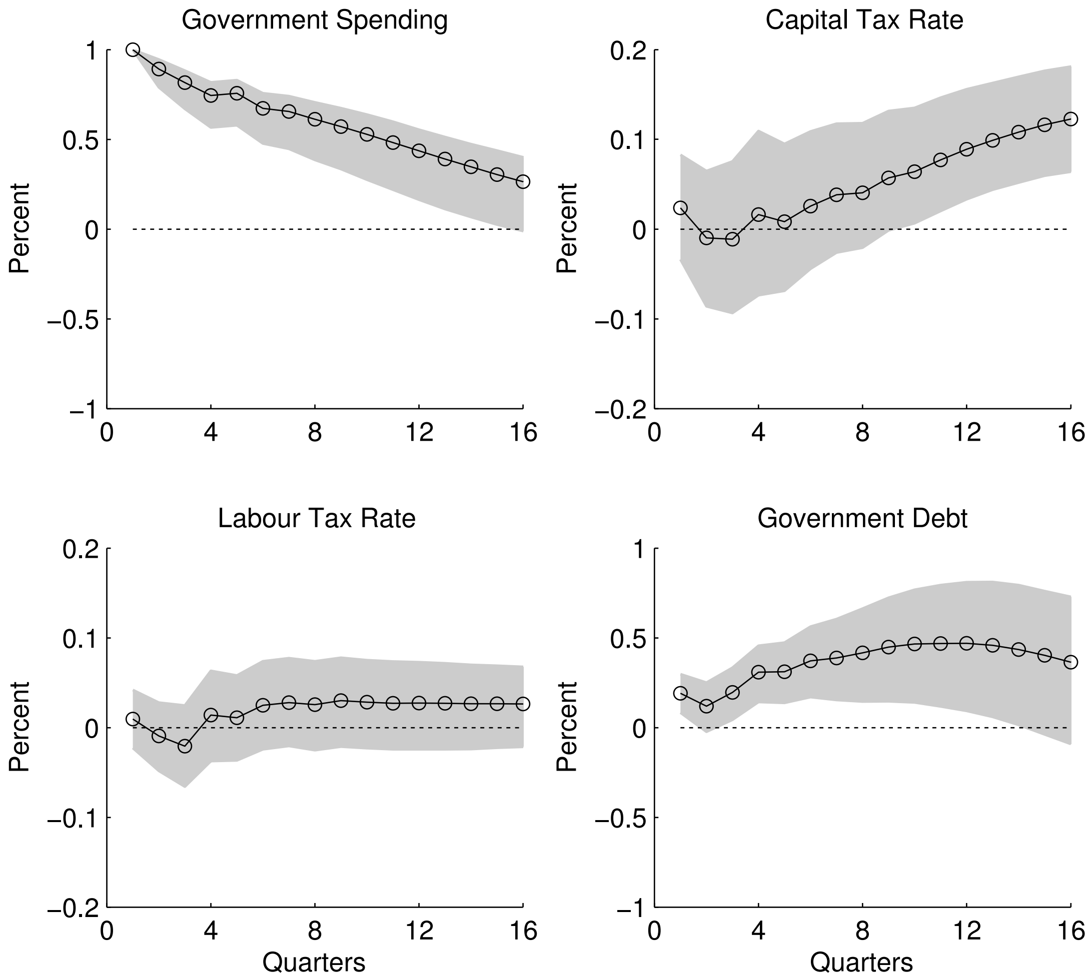

Figure 1: *Impulse responses for the fiscal policy variables*

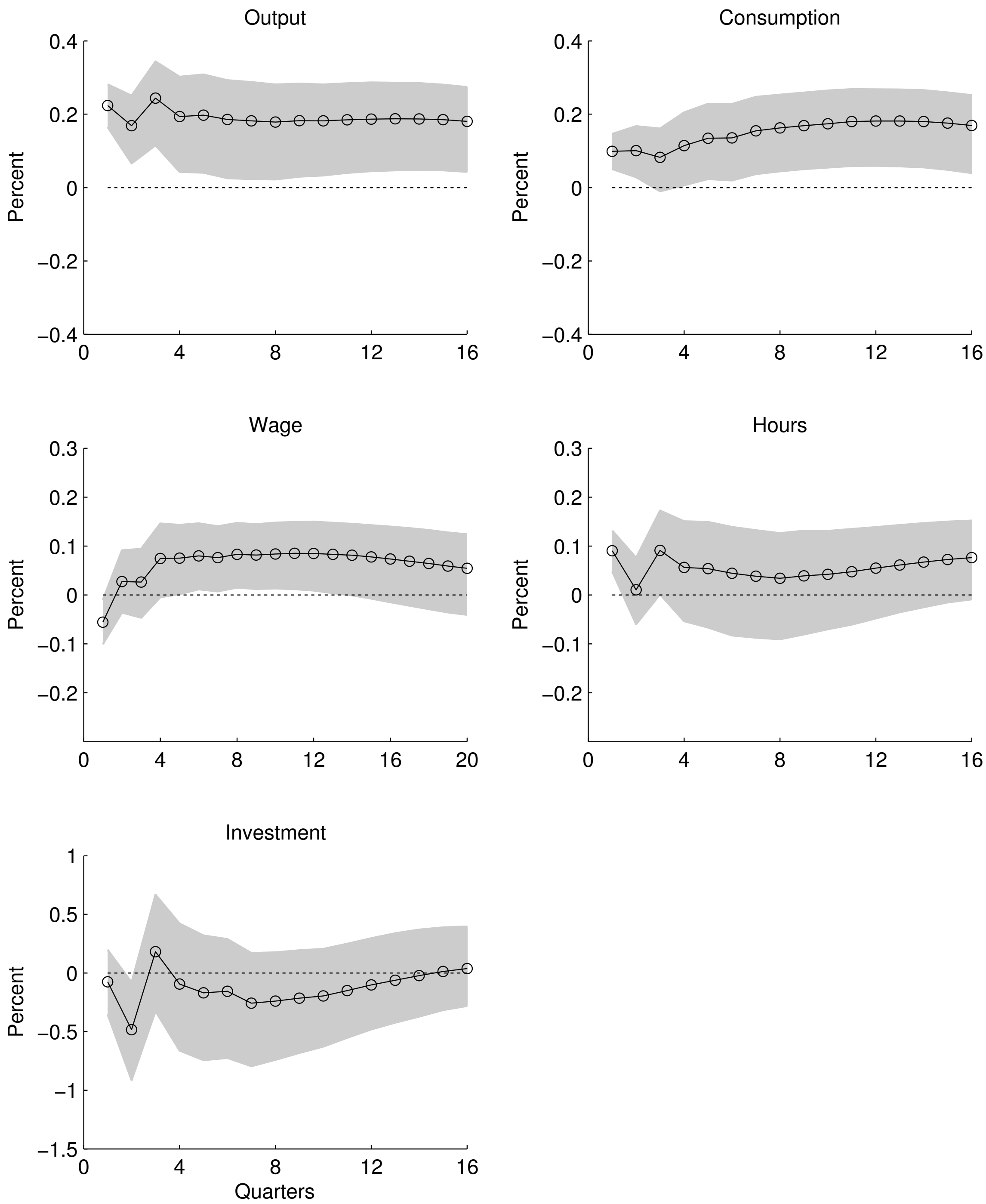

Figure 2: *Impulse responses for key macroeconomic variables*

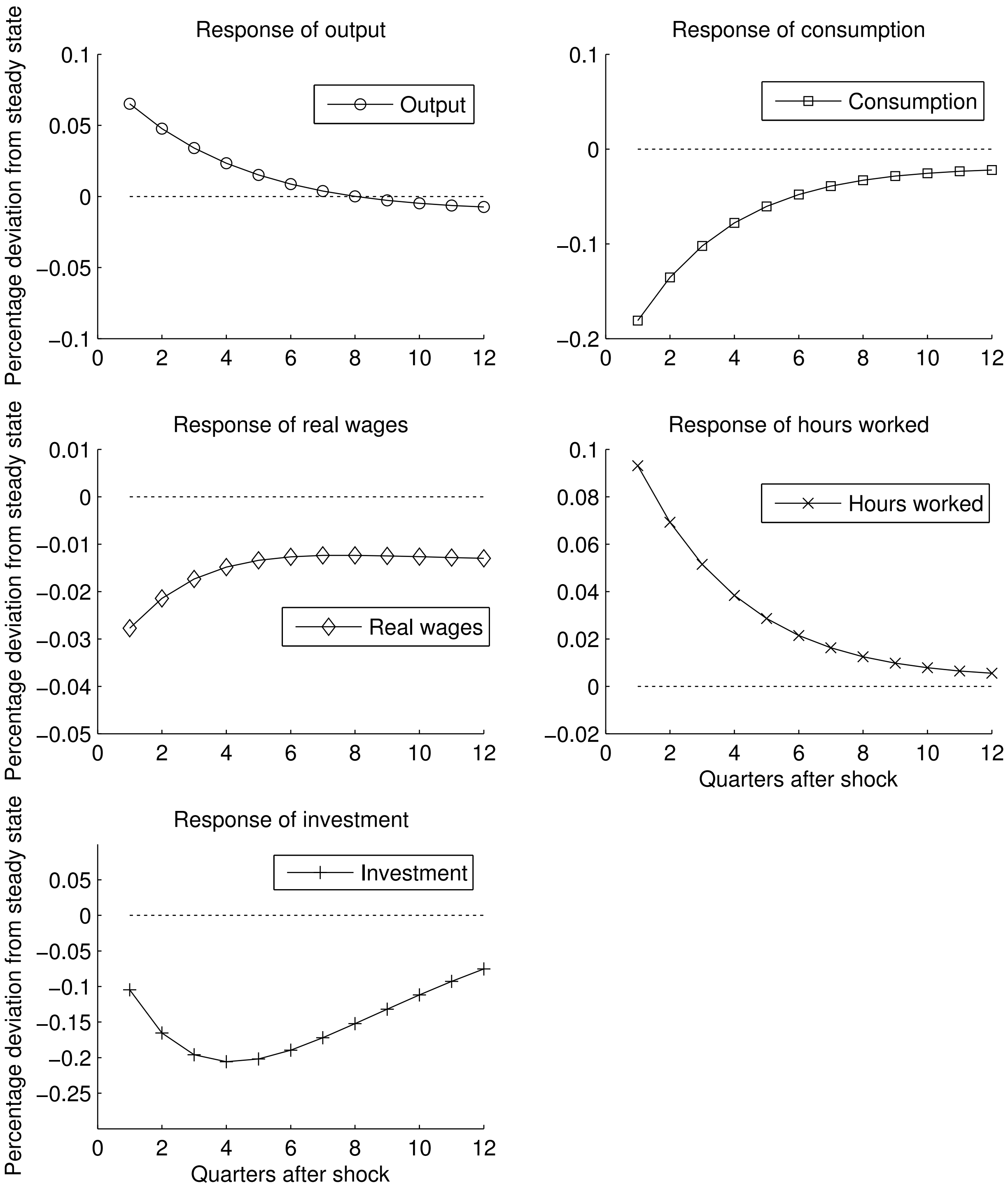

Figure 3: *A simple Neoclassical model:* $\eta = 0$, $\gamma = 1$, $\kappa = \infty$, $h = 0$

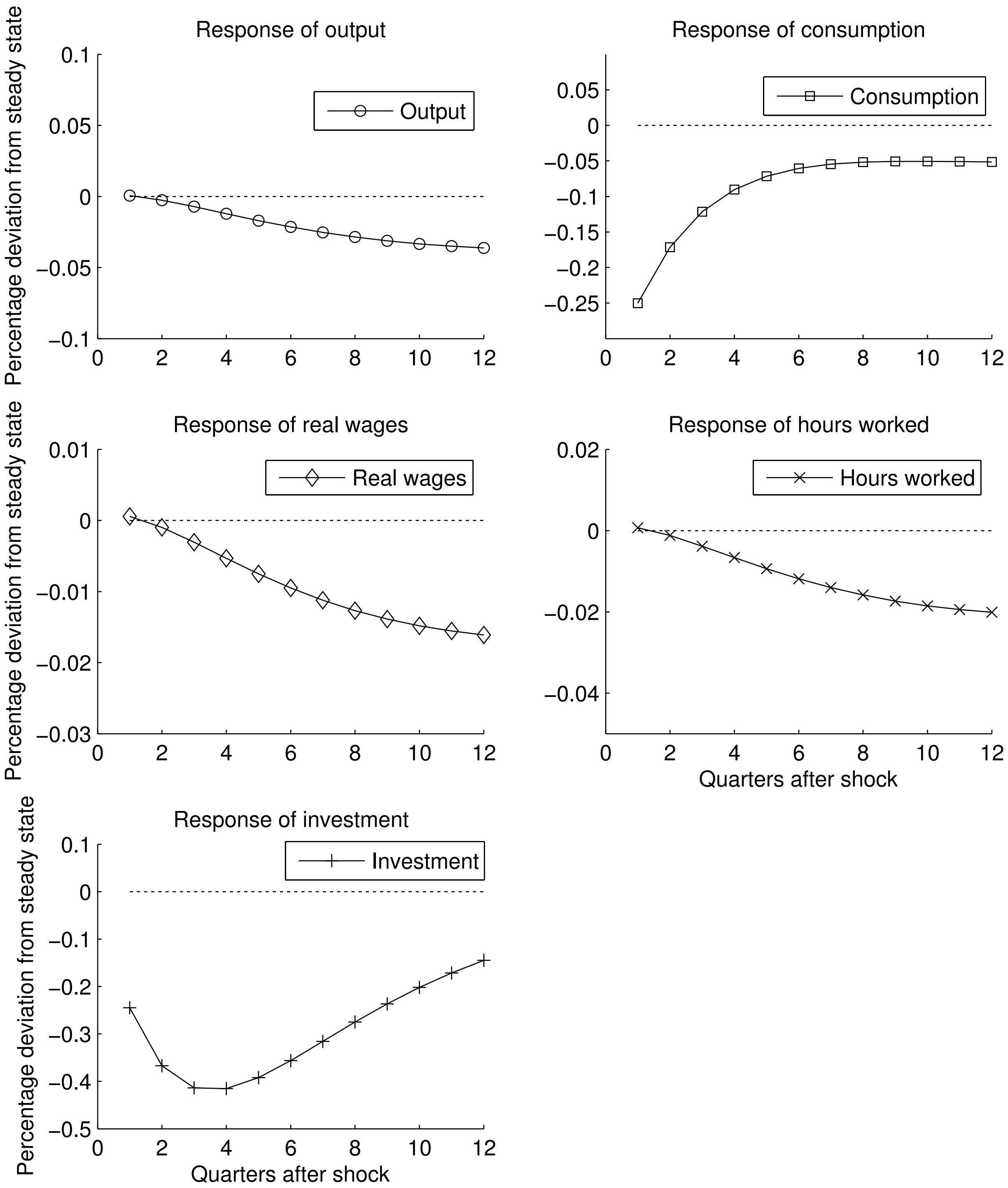

Figure 4: *A simple Neoclassical model (but no wealth effect):* $\eta = 0$, $\gamma = 0$, $\kappa = \infty$, $h = 0$

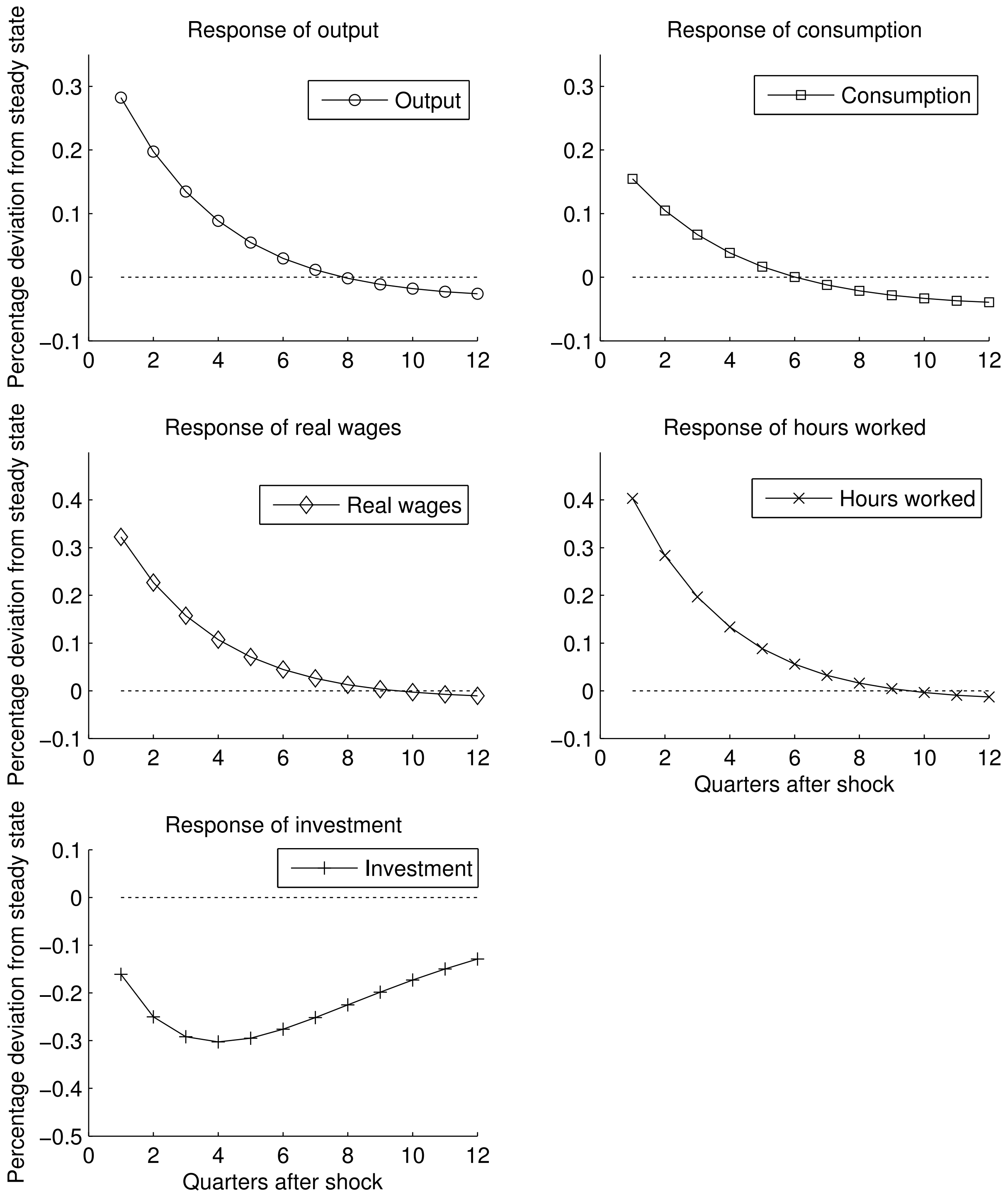

Figure 5: *Including sticky prices:* $\eta = 0.7$

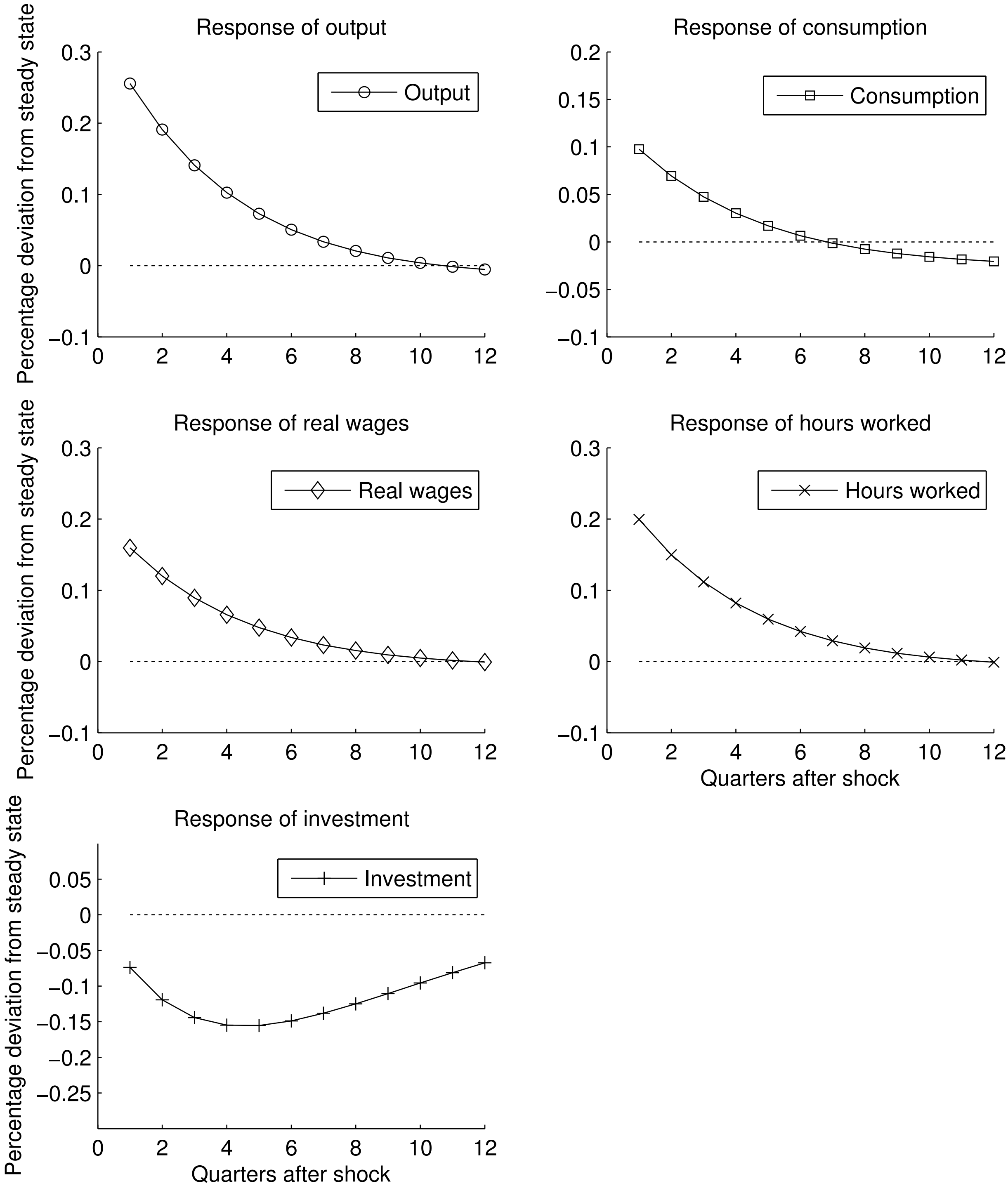

Figure 6: *Including variable capital utilization:* $\kappa = 0.15$

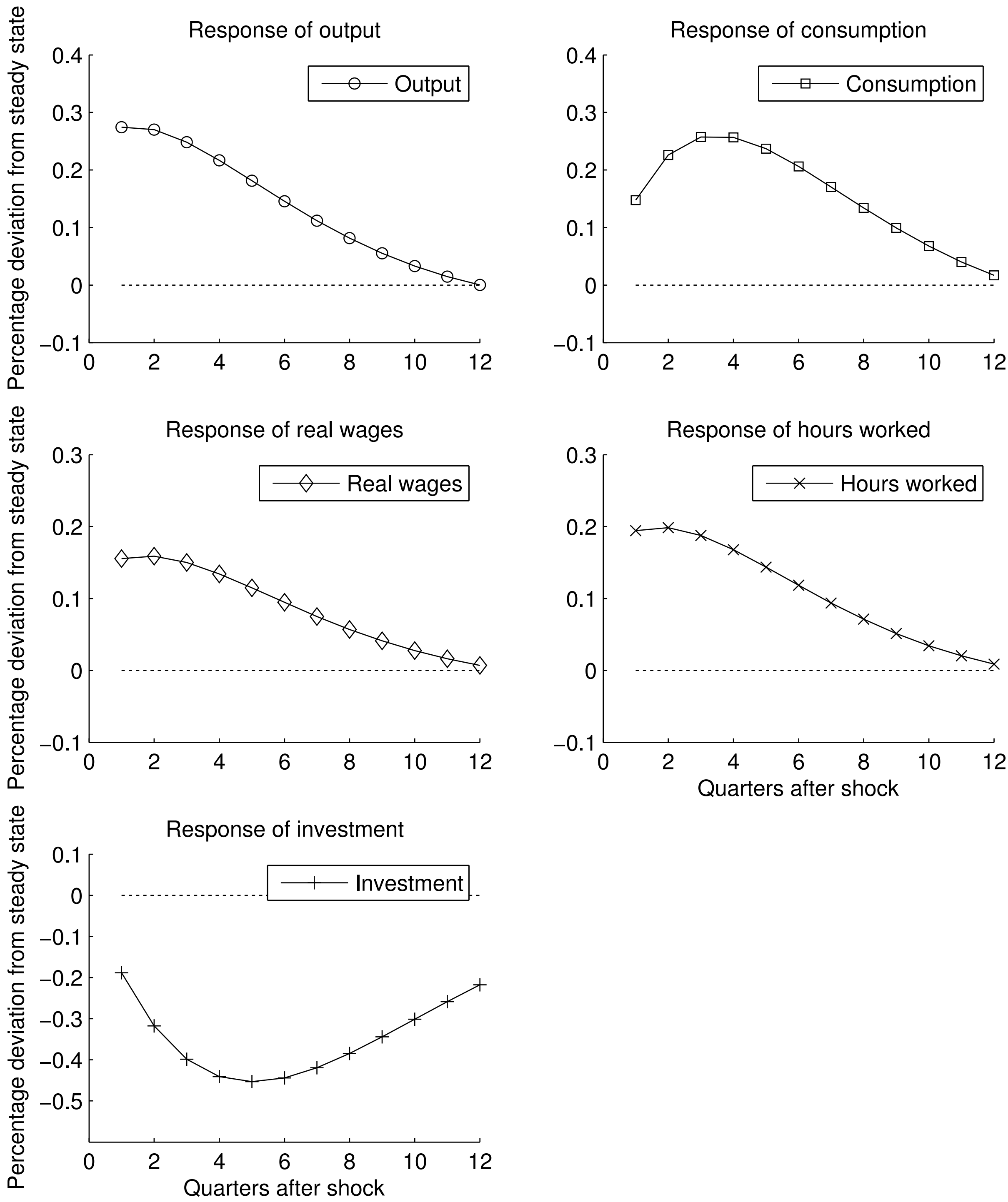

Figure 7: *Including habits:* $h = 0.5$

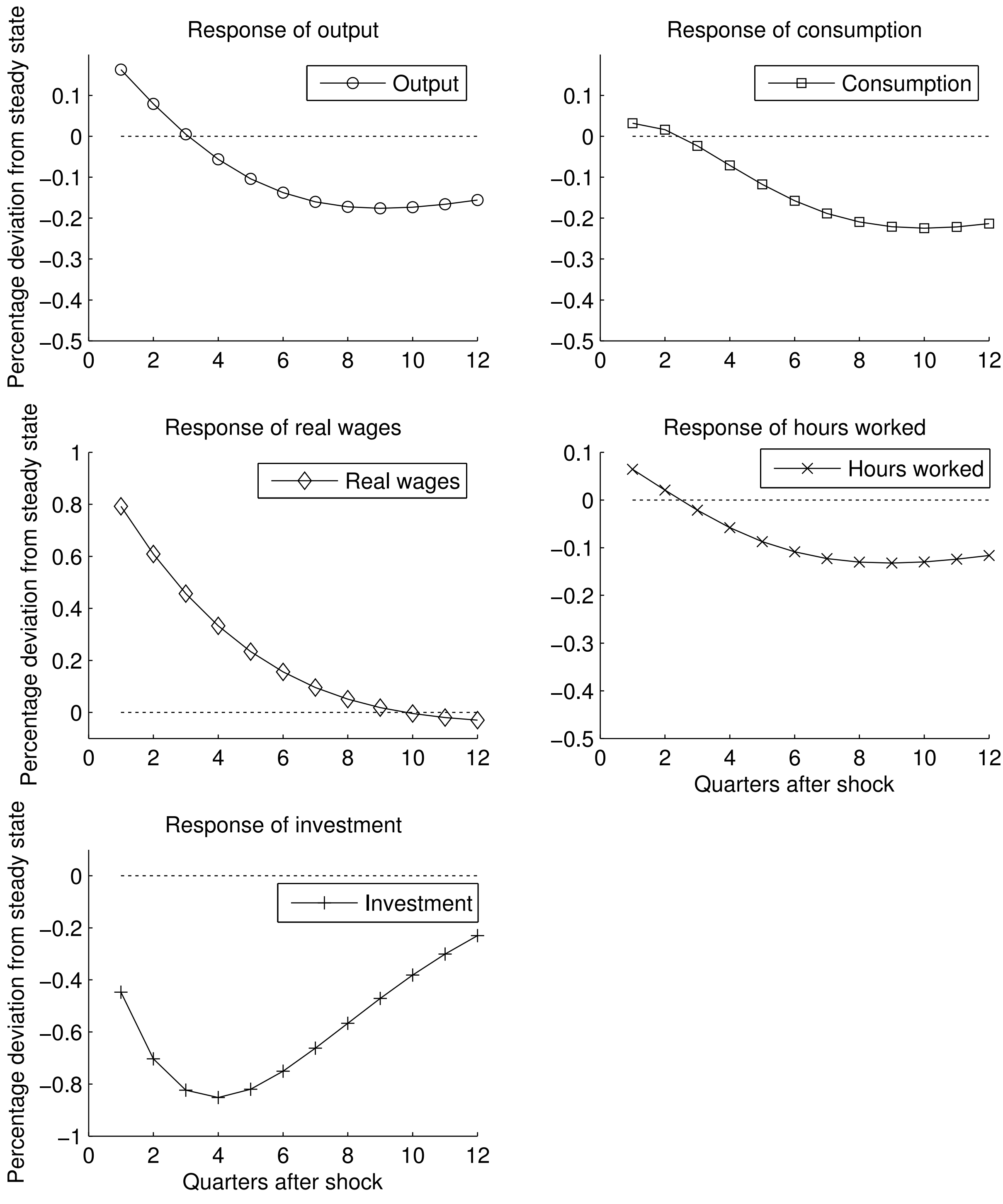

Figure 8: *Distortionary labour and capital tax rates respond*

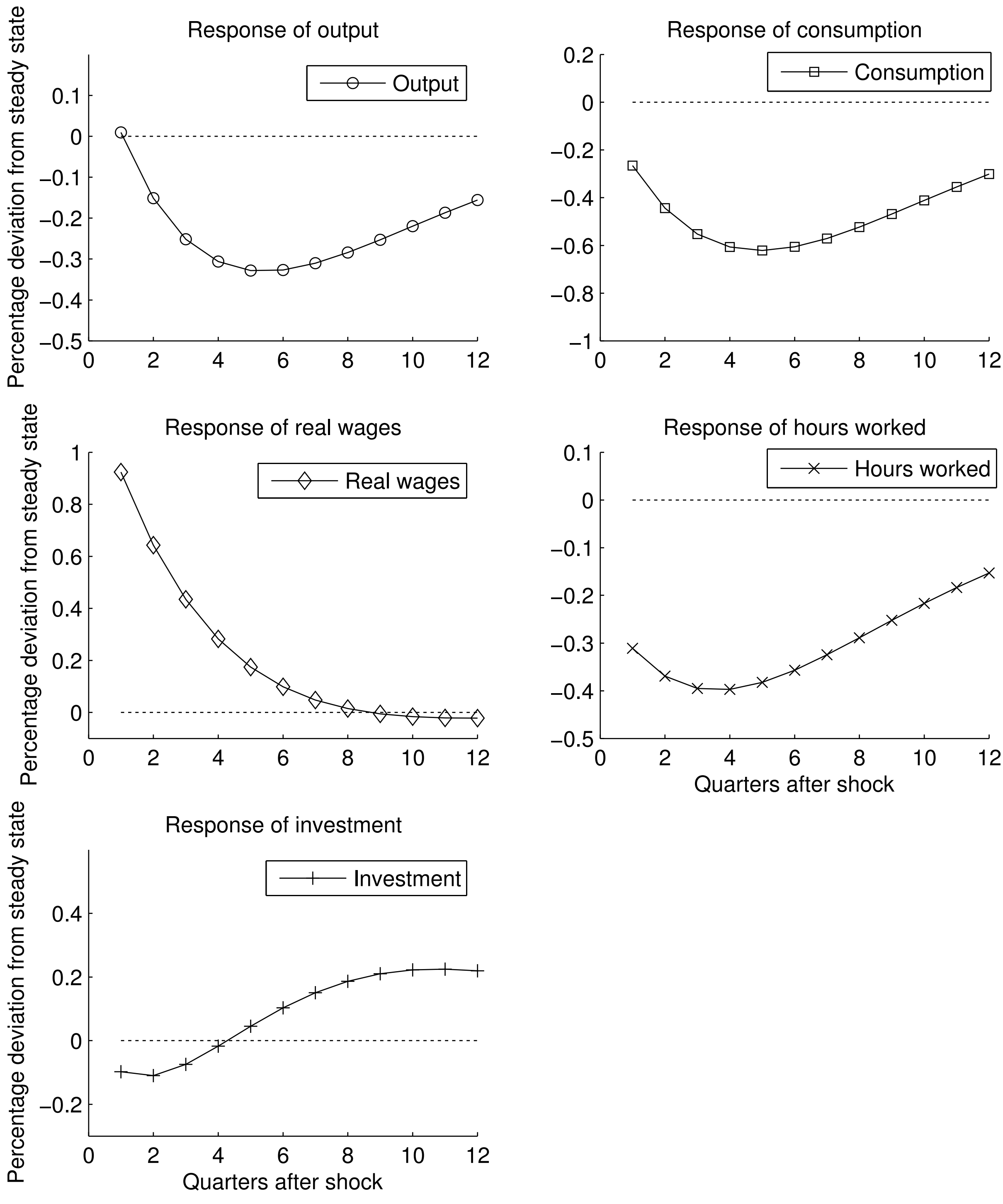

Figure 9: *Only the labour income tax rate responds*

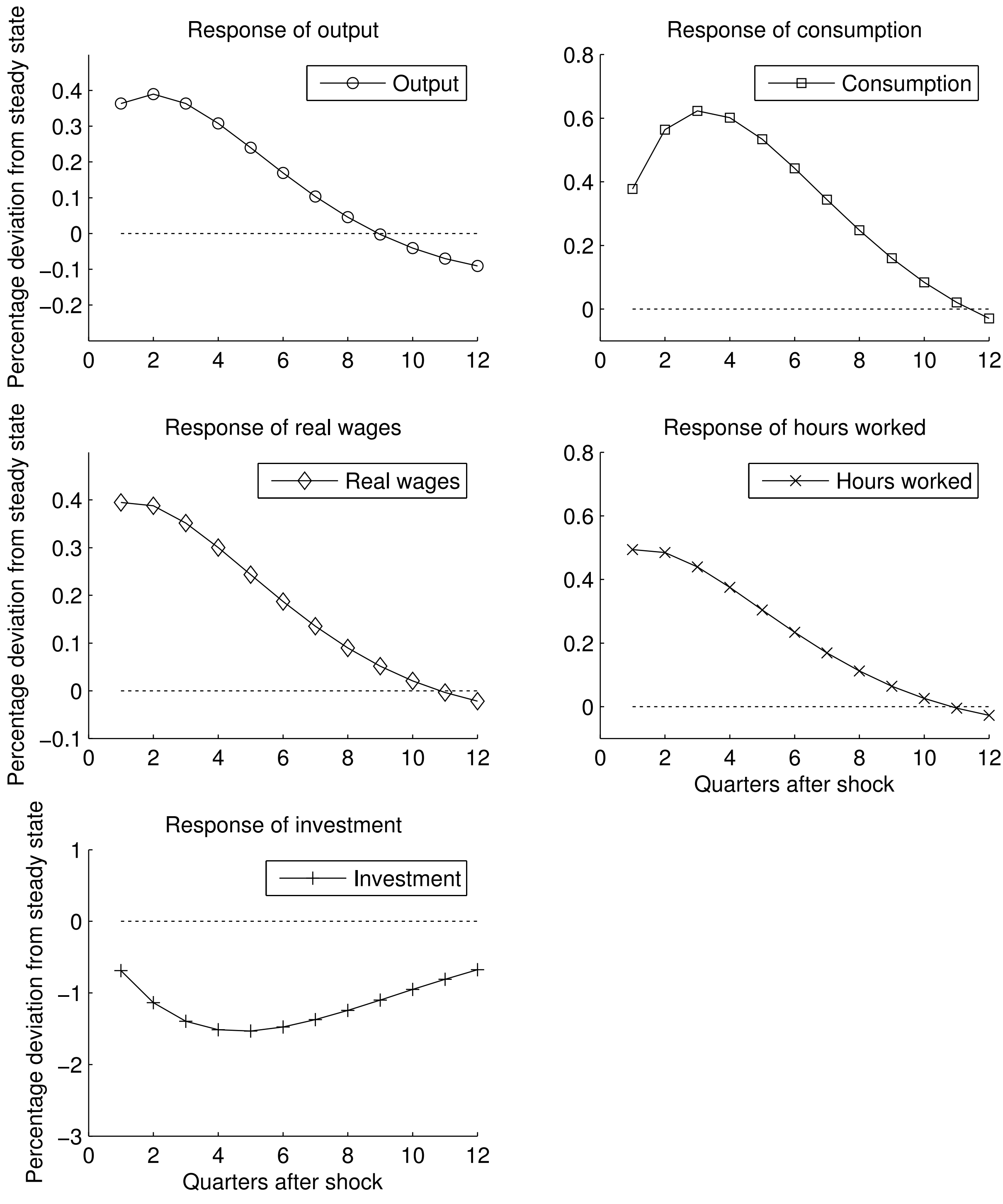

Figure 10: *Only the capital tax rate responds*

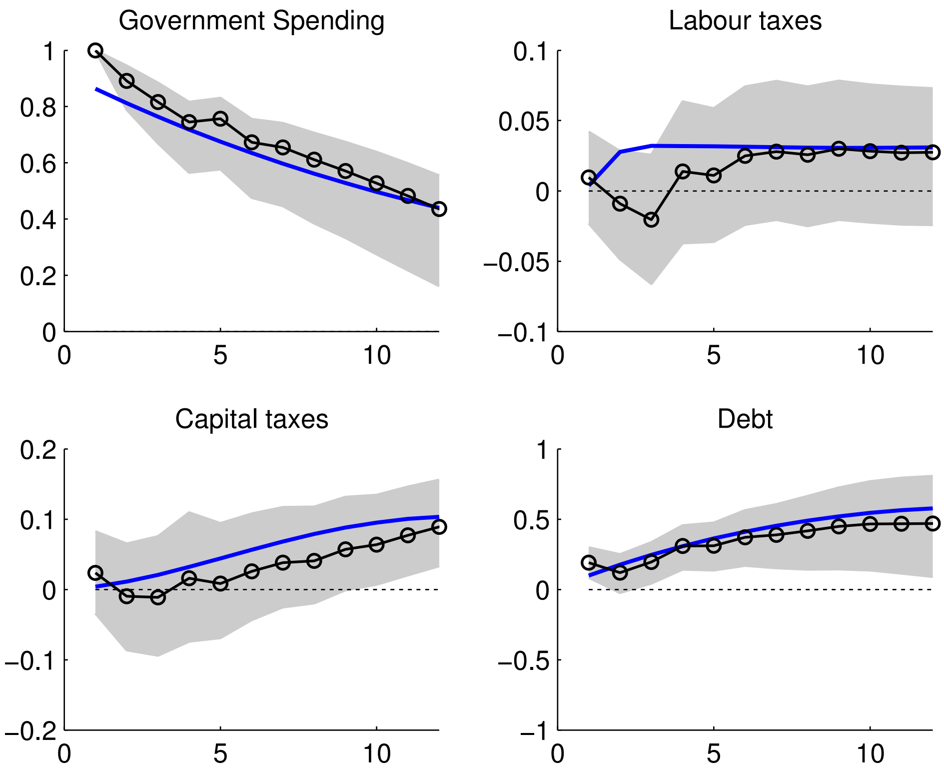

Figure 11: *Responses of the fiscal variables given the parameter estimates*

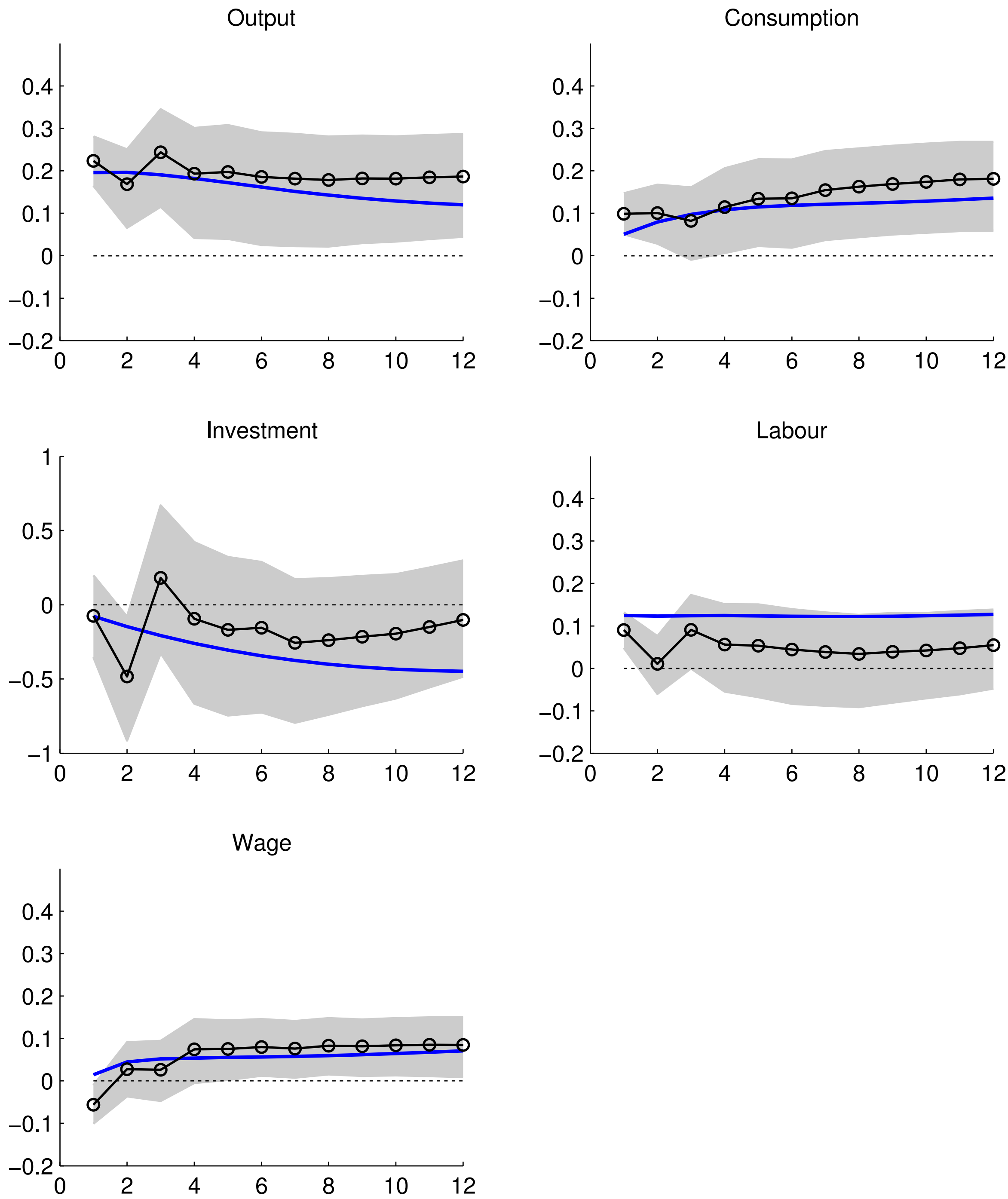

Figure 12: *Responses of the other variables given the parameter estimates*

Appendices

A Data Appendix

The data span the period 1955:1 to 2007:4. Real government spending, real consumption, real investment and real GDP come directly from the Bureau of Economic Analysis NIPA tables. All variables are the log of real per capita variables. Nominal variables are deflated by their own implicit price deflators with the exception of government spending which is deflated by the GDP deflator. Real hours are an unpublished Bureau of Labor Statistics (BLS) series, downloadable from Valerie Ramey's website. The real wage is real hourly compensation, non-farm business, in logs from the BLS. Population is total civilian population also from the BLS.

Real per capita debt is the log of my constructed debt measure divided by the total population and the GDP deflator. The debt measure is very close the 'Debt Held by the Public'. This series is only available from 1970, so I construct a proxy from old editions of the United States Treasury Bulletin back to 1947. For the pre-1974 period this is the 'Total Public Issues' series. After 1974, for consistency, I have to construct the 'Total Public Issues' series from the Monthly Statement of Public Debt by combining 'Total Interest Bearing Debt' minus the 'Government Accounts Series' plus 'Total Treasury Deposit Funds'. Because this is not an exact match to 'Debt Held by the Public' I check how close the two measures are (for the common part of the series, 1970 onwards) — the R squared is 0.999, so I am confident that my constructed series reflects changes in 'Debt Held By the Public'.

The capital and labour income tax rates are constructed following Jones (2002). I reconstruct the series, extend it back to 1947 following Burnside et al. (2004) and forward to 2008. As a check, I reproduce the narrative Vector Autoregression results in Burnside et al. (2004), the results are very similar. These extra results are available on request.

B Linearized models

B.1 Notation

Lower case letters represent the percentage deviation of each variable from its steady state value. The only exceptions are the tax rates τ_t^N and τ_t^K which are expressed as percentage point deviations to match the variable definition in the VAR.

B.2 The consumer's conditions

B.2.1 Households

$$a_1 c_t + a_2 n_t + a_3 x_t + a_4 x_{t-1} + a_5 \mu_t - a_6 \lambda_t + a_7 c_{t-1} = 0 \tag{43}$$

$$\lambda_t + w_t - \frac{1}{1-\tau^N}\tau_t^N = b_1 c_t + b_2 n_t + b_3 x_t + b_4 c_{t-1} \tag{44}$$

$$c_1 c_t + c_2 n_t + c_3 x_t + c_6 c_{t-1} + \mu \mu_t = c_4 \mu_{t+1} + c_5 c_{t+1} \tag{45}$$

$$\mathbb{E}_t \lambda_{t+1} = \lambda_t - r_t \tag{46}$$

$$(1-h)x_t = (1-h)(1-\gamma)x_{t-1} + \gamma c_t - h\gamma c_{t-1} \tag{47}$$

$$\mu q_t - (1+\beta)i_t + i_{t-1} - \beta \mathbb{E}_t i_{t+1} = 0 \tag{48}$$

where $\mu = \frac{1}{\phi''}$.

$$q_t + r_t = r^K(1-\tau^K)\beta \mathbb{E}_t r_{t+1}^K - \beta r^K \mathbb{E}_t \tau_{t+1}^K + \beta(1-\delta)\mathbb{E}_t q_{t+1} - \beta \delta'(z) z \mathbb{E}_t z_{t+1} \tag{49}$$

where the coefficients are given at the end of this appendix.

B.3 Firms

Up to a first order approximation the aggregate production function is given by

$$y_t = \alpha z_t + \alpha k_t + (1-\alpha) n_t \tag{50}$$

and factors are paid

$$r_t^K = mc_t + y_t - k_t \tag{51}$$

$$w_t = mc_t + y_t - n_t. \tag{52}$$

Utilisation is described by

$$(1+\kappa) z_t = y_t - k_t - q_t + mc_t - \frac{1}{1-\tau^K}\tau_t^K \tag{53}$$

where $\xi = \frac{\delta''}{\delta'}$.

Price evolution is determined by the New Keynesian Phillips Curve

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \frac{(1-\eta)(1-\beta\eta)}{\eta} mc_t. \tag{54}$$

B.4 Policy rules

$$r_t - \mathbb{E}_t \pi_{t+1} = \phi_\pi \pi_t \tag{55}$$

$$\tau_t^n = \theta^{gn} g_t + \theta^{bn} b_t + \theta^{n1} \tau_{t-1}^n + \theta^{n2} \tau_{t-2}^n \tag{56}$$

$$\tau_t^k = \theta^{gk} g_t + \theta^{bk} b_t + \theta^{k1} \tau_{t-1}^k + \theta^{k2} \tau_{t-2}^n \tag{57}$$

$$g_t = \phi_1 g_{t-1} + \phi_2 a_t \tag{58}$$

$$\frac{T}{Y}\hat{T}_t = \frac{B}{Y}\frac{1}{R}(b_{t+1} + r_t) - \frac{B}{Y} b_t = \frac{G}{Y} g_t - \alpha \tau^n (\tau_t^n + n_t + w_t) - (1-\alpha)\tau^k (\tau_t^k + r_t^k + k_t). \tag{59}$$

B.5 Identities

$$\delta i_t = k_{t+1} - (1-\delta) k_t \tag{60}$$

$$y_t = \frac{C}{Y} c_t + \frac{I}{Y} i_t + \frac{G}{Y} g_t. \tag{61}$$

B.6 Stochastic processes

$$a_{t+1} = \rho a_t + \epsilon_{t+1} \tag{62}$$

The 3 predetermined variables are:

$$\{b_t, k_t, a_t\}$$

and the control variables are:

$$\{c_t, \pi_t, w_t, n_t, x_t, y_t, r_t^k, mc_t, q_t, z_t, \lambda_t, \mu_t, r_t, \tau_t^K, \tau_t^N, g_t, i_t\}$$

B.7 Coefficients from the linearized Jaimovich–Rebelo preferences

$$a_1 = (\gamma - 1)\mu\gamma X^{1-\gamma}(C(1-h))^{\gamma-2} C - \sigma C \chi (C - hC - \psi N^\xi X)^{-1}$$

$$a_2 = \xi \psi N^\xi X \sigma (C - hC - \psi N^\xi X)^{-\sigma-1}$$

$$a_3 = \psi N^\xi X \sigma (C - hC - \psi N^\xi X)^{-\sigma-1}$$

$$a_4 = (1-\gamma)\mu\gamma X^{1-\gamma}(C(1-h))^{\gamma-1}$$

$$a_5 = \mu\gamma X^{1-\gamma}(C(1-h))^{\gamma-1}$$

$$a_6 = \mu\gamma X^{1-\gamma}(C(1-h))^{\gamma-1} + \chi$$

$$a_7 = -h a_1$$

$$b_1 = -(\sigma\psi N^{\xi-}\xi X((C - hC - \psi N^{\xi} X)^{-\sigma-1})C)/(a_6 W(1-\tau^N))$$

$$b_2 = ((\xi-1)\psi X N^{\xi-1}\xi\chi + \sigma\psi^2 N^{2\xi-1}\xi^2 X^2 (C - hC - \psi N^{\xi} X)^{-\sigma-1})/(a_6 W(1-\tau^N))$$

$$b_3 = X(\psi N^{\xi-1}\xi\chi + \psi N^{\xi-1}\xi X(\sigma((C - hC - \psi N^{\xi} X)^{-\sigma-1})\psi N^{\xi}))/(a_6 W(1-\tau^N))$$

$$b_4 = -hb_1$$

$$c_1 = -\sigma\psi N^{\xi}(C - hC - \psi N^{\xi} X)^{-\sigma-1} C + h(1-\gamma)\mu\beta\gamma(C(1-h))^{\gamma-1} X^{-\gamma} C$$

$$c_2 = \psi^2\xi X\sigma N^{2\xi}(C - hC - \psi N^{\xi} X)^{-\sigma-1} + \xi\psi N^{\xi}\chi$$

$$c_3 = \sigma\psi^2 N^{2\xi}(C - hC - \psi N^{\xi} X)^{-\sigma-1} X + \gamma\mu\beta(1-\gamma)(C(1-h))^{\gamma} X^{-\gamma}$$

$$c_4 = \mu\beta(1-\gamma)(C(1-h))^{\gamma} X^{-\gamma}$$

$$c_5 = \gamma\mu\beta(1-\gamma)(C(1-h))^{\gamma-1} X^{-\gamma} C$$

$$c_6 = \sigma h\psi N^{\xi}(C - hC - \psi N^{\xi} X)^{-\sigma-1} C$$

$$\chi = (C - hC - \psi N^{\xi} X)^{-\sigma}$$

C Steady state

Our assumptions of $\phi(I/K)$ imply that

$$\frac{I}{K} = \delta$$

therefore

$$\frac{I}{Y} = \frac{I}{K}\frac{K}{Y} = \delta\frac{K}{Y}.$$

Given the tax and subsidy on revenue ($mc = 1$), the state version of the return on capital implies

$$r^K = \alpha\frac{Y}{K}.$$

From equation (14)

$$r^K = \frac{R - 1 + \delta}{1 - \tau^K} \tag{63}$$

therefore

$$\frac{K}{Y} = \frac{\alpha}{r^K} \tag{64}$$

and

$$\frac{I}{Y} = \frac{\delta\alpha}{r^K}. \tag{65}$$

The share of consumption can be written

$$\frac{C}{Y} = 1 - \delta\frac{K}{Y} - \frac{G}{Y}, \tag{66}$$

This follows from the resource constraint, equation (23).

ψ can be found by solving the household's steady state first order conditions

$$\psi = \left(N^{\xi}\left[\frac{\xi X}{W(1-\tau^{N})N} - \frac{\gamma X^{1-\gamma}(C(1-h))^{\gamma-1}}{\beta(1-\gamma)(C(1-h))^{\gamma}X^{-\gamma}-1}\right]\right)^{-1} \tag{67}$$

where N is steady state hours and is calibrated.

From the production function and the marginal product of capital is

$$K = \left(\frac{r^{K}}{\alpha}\right)^{\left(\frac{1}{\alpha-1}\right)} N, \tag{68}$$

and dividing the resource constraint by K gives an expression for CK. Using this together with equation (68) yields an expression for steady state consumption. The steady state real wage follows from

$$W = (1-\alpha)\left(\frac{K}{N}\right)^{\alpha}. \tag{69}$$

μ is the steady state Lagrange multiplier

$$\mu = \frac{\psi N^{\xi}\chi}{\beta(1-\gamma)(C(1-h))^{\gamma}X^{-\gamma}-1}. \tag{70}$$

From equation (8), steady state X is given by:

$$X = C(1-h). \tag{71}$$

The steady state gross real interest rate is related to the discount factor

$$R = \frac{1}{\beta}. \tag{72}$$

From the first order condition for z_t

$$\delta'(z)z = (1-\tau^{K})\alpha\frac{Y}{K}. \tag{73}$$

$\frac{B}{Y}$ is calibrated.