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ABSTRACT

Understanding the Aggregate Effects of Anticipated and Unanticipated Tax Policy Shocks

We evaluate the extent to which a dynamic stochastic general equilibrium model can account for the impact of "surprise" and "anticipated" tax shocks estimated from U.S. time-series data. In U.S. data, surprise tax cuts have expansionary and persistent effects on output, consumption, investment and hours worked. Anticipated tax liability tax cuts give rise to contractions in output, investment and hours worked before their implementation while thereafter giving rise to an economic expansion. A DSGE model with changes in tax rates that may be anticipated or not, is shown to be able to account for the empirically estimated impact of tax shocks. The important features of the model include adjustment costs, variable capacity utilization and consumption habits. We derive Hicksian decompositions of the consumption and labor supply responses and show that substitution effects are key for understanding the impact of tax shocks. When allowing for rule-of-thumb consumers, we find that the estimate of their share of the population is only around 10-11 percent.

JEL Classification: E20, E32, E62 and H30
Keywords: anticipation effects, fiscal policy, structural estimation and tax liabilities

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1 Introduction

This paper studies the aggregate dynamic effects of tax liability changes. A key aspect of our analysis is that we investigate both the impact of implemented tax changes and the impact of news about future tax changes and we confront a DSGE model with empirical evidence on both types of fiscal policy shocks. Studying post World War II U.S. time series data, we show that implemented tax cuts provide a major stimulus to the economy while pre-announced but not yet implemented tax cuts lead to decline in output, investment and hours worked until the tax cut is eventually implemented. Consumption, in contrast, is approximately unaffected by tax announcements until their implementation. We demonstrate that a DSGE model can account for the aggregate dynamic effects of tax changes. We use the model to provide a Hicksian decomposition of the response of hours worked and consumption to tax changes and show that substitution effects are key.

Our empirical analysis builds upon Mertens and Ravn (2009). The measurement of tax changes rests upon Romer and Romer's (2007, 2008) narrative account of federal U.S. tax liability changes for the postwar period since 1947. We study the impact of those changes in tax liabilities that Romer and Romer (2007, 2008) classify as exogenous and introduce a timing convention to distinguish between anticipated and unanticipated tax changes. This timing convention accomplishes the distinction between anticipated and unanticipated tax changes by reference to the implementation lag, the difference between the date at which the tax liability change was implemented and the date that it became law, associated with each tax liability change. When this implementation lag exceeds (is shorter than) 90 days, we define the tax liability change as anticipated (unanticipated).

These tax shocks are embedded in a vector autoregressive analysis in order to derive estimates of the dynamic effects of tax policy shocks. We study the impact of tax shocks on aggregate output, consumption of nondurables and services, purchases of durable consumption goods, investment, and on hours worked. We find that unanticipated tax cuts give rise to significant increases in output, consumption, and investment, and a gradual increase in hours worked. Assuming that anticipated tax shocks are announced 6 quarters before their implementation, the median anticipation horizon in the data, we find that an anticipated tax cut is associated with a pre-implementation drop in output, investment and hours worked, while consumption remains roughly constant during the pre-implementation period. Once the tax change is implemented, its impact on these variables becomes similar to the effects of an unanticipated tax change. Thus, we find significant responses to tax news.

We then construct a dynamic stochastic general equilibrium model in which variations in distortionary tax rates on capital and labor income give rise to changes in tax liabilities. We allow for unanticipated as well as anticipated tax changes. The benchmark model allows for features such as habit formation, variable capacity utilization, and adjustment costs that have been shown in the business cycle literature to be important for accounting for other structural shocks, and for consumer durables. Key parameters are estimated by indirect inference.

We show that the DSGE model accounts very well for the shapes and sizes of the response of the observables to changes in taxes. Interestingly, tax news effects can be accounted for in a model with standard preferences. This is an important finding because the literature on "news shocks" to technology, c.f. Beaudry and Portier (2004, 2006, 2007) and Jaimovich and Rebelo (2006), has shown that wealth effects on labor supply must be weak in order to generate an "anticipation expansion" of the economy in response to current good news about future productivity. This literature, however, provides no direct empirical evidence on such news effects in the data. Our empirical results show that good news about future taxes leads to a pre-implementation decline in aggregate activity and that this effect can be accounted for by standard preference models. On the other hand, consistent with the technology news literature, we find that adjustment costs and variable capacity utilization are pertinent to account for the impact of tax shocks, as also stressed by Auerbach (1989).

Another important insight relates to the anticipation effects on consumption of nondurables and services. Our empirical results agree with earlier studies of the consumption response to anticipated tax changes. Poterba (1988) tests whether aggregate U.S. consumption reacts to announcements of future tax changes and fails to find robust evidence in favor of this hypothesis.[1] Similarly, Heim (2007) studies announcements effects of state tax rebates on household consumption using Consumer Expenditure Survey (CEX) data. Like Poterba (1988), Heims finds no response of consumption to tax announcements. Parker (1999) and Souleles (1999, 2002) also study CEX data and show that consumption responds to the implementation of tax changes rather than to their announcements. These results are often interpreted as evidence of lack of forward looking behavior or the presence of binding

[1] Poterba (1988) identifies five such episodes: February 1964, June 1968, March 1975, August 1981, and August 1986. We exclude the second and third of these episodes because Romer and Romer (2007a) categorize these tax changes as endogenous.

liquidity constraints.

We challenge these views. The significant impact of tax news on investment and hours worked seems inconsistent with the idea that agents are not forward looking. But, even more importantly, we show that the idea that the lack of the consumption response imply that a large proportion of the population are rule-of-thumb consumers does not square well with the responses of other macroeconomic aggregates. We show this formally by reestimating the DSGE model allowing for a share of the population to be described by rule-of-thumb behavior. Following Galí, López-Salido and Vallés (2007) we combine the introduction of rule-of-thumb consumers with the imperfect competition in the labor market. We estimate the share of liquidity constrained agents to be 10.5 percent, much smaller than the share of 50 percent typically assumed in the literature.

Our results also extends the literature in terms of understanding the impact of tax changes. Yang (2005) builds a simple DSGE model and shows that in response to an anticipated cut in the labor tax rate, consumption rises during the pre-implementation period while output, investment and hours worked contract; in response to an anticipated cut in the capital income tax rate instead, the opposite pattern is implied. We demonstrate that, in an economy with a more rigorous modeling of production and preference structures and with reasonable degrees of adjustment costs, the anticipation effects of capital income and labor income tax changes are quite similar.

We derive a Hicksian decomposition of the hours worked and consumption responses to changes in taxes. We decompose these responses into wealth effects, substitution effects that derive from changes in wages and interest rates, and a "wedge" which arises because of adjustment costs. The response of hours worked and consumption to changes in taxes are dominated by the substitution effects, while the wealth effects which derive from Harberger triangles are very small. We show that the key to understanding why hours worked responds sluggishly to surprise changes in taxes is the opposing effects of the substitution effects due to wages and due to changes in interest rates.

The remainder of this paper is structured as follows. The next section describes our estimation approach and discusses the dynamic effects of tax shocks. Section 3 contains the description of the DSGE model. The estimation of the structural parameters is contained in Section 4. In Section 5 we discuss and analyze the results. Finally, Section 6 concludes and summarizes.

2 Estimation

In this section we present the estimation results regarding the impact of tax shocks in the United States. A detailed analysis of the data and robustness analysis is contained in Mertens and Ravn (2009).

2.1 Identification

We identify tax shocks using Romer and Romer's (2007a, 2008) narrative account of federal U.S. tax policy acts. Based on analyses of official government documents, presidential speeches, and Congressional documents, these authors identify 51 legislated federal tax acts in the period 1947-2006 and a total of 110 separate changes in tax liabilities. We focus on the tax liability changes that Romer and Romer (2007a) classify as exogenous either for long run growth reasons or for reasons related to concerns about inherited debt. This corresponds to 70 tax liability changes in total. Mertens and Ravn (2009) establish that there is little statistical evidence to question the assumption that these tax changes can be viewed as exogenous.

We use a timing convention to distinguish between anticipated and unanticipated tax changes. For each tax liability change we define its announcement date as the date at which the tax legislation became law (when it was signed by the President), and its implementation date which is the date at which, according to the legislation, the tax liability changes were to be introduced. We define anticipated tax liability changes as those where the difference between these two dates, the implementation lag, exceeds 90 days. The results are robust to moderate changes in the size of this window because the distribution of the implementation lag is twin peaked, see Mertens and Ravn (2009). This definition implies that 36 of the tax liability changes are anticipated while 34 are defined as surprise tax shocks. The median implementation lag in the data is 6 quarters.

We estimate the impact of the tax shocks from the following regression model, which we later show can be viewed as a finite sample approximation to the representation of the observables in the DSGE model:

$$X_t = A + Bt + C(L) X_{t-1} + D(L) \tau_t^u + F(L) \tau_{t,0}^a + \sum_{i=1}^{K} G_i \tau_{t,i}^a + e_t \tag{1}$$

where X_t is a vector of endogenous variables, A and B control for a constant term and a linear trend, $C(L)$ is P-order lag polynomial, and $D(L)$ and $F(L)$ are $(R+1)$-order lag polynomials.[2]

[2] The results are robust to allowing for a break in the trend in 1973:2, see Ramey and Shapiro (1998) and Burnside,

τ_t^u denotes unanticipated tax shocks which we measure as the dollar change in tax liabilities in percentage of current price GDP at the implementation date. The vector $\left[\tau_{t,i}^a\right]_{i=0}^K$ denotes the anticipated tax shocks that are part of the information set at date t. Specifically, $\tau_{t,i}^a$ are the pre-announced tax changes which are known at date t and which are to be implemented at date $t+i$. This is the sum of tax liability changes announced today or in the past which have the same implementation date.[3] The regression model therefore allow X_t to depend on lags of current and past changes in taxes through the terms $D(L)\,\tau_t^u$ and $F(L)\,\tau_{t,0}^a$, and on currently known, but yet not implemented, changes in taxes through the terms $\sum_{i=1}^K G_i \tau_{t,i}^a$. This latter term therefore corresponds directly to "news" shocks.

We study U.S. quarterly data for the sample period 1947:1 - 2006:4. We consider the following set of endogenous variables:

$$X_t = \begin{bmatrix} y_t, & c_t, & d_t, & i_t, & h_t \end{bmatrix}'$$

where y_t denotes the logarithm of U.S. GDP per adult in constant (chained) prices, c_t is the logarithm of the real private sector consumption expenditure on nondurables and services per capita, d_t is the logarithm of private sector consumption expenditure on durables per capita, i_t is the logarithm of real aggregate gross investment per capita. h_t is the logarithm of average hours worked per adult. Precise definitions and data sources are given in Table A.1 in the appendix.

The VAR above assumes that the tax shocks have persistent but non-permanent effects on the vector of observables (under the condition that the lag-polynomial $C(L)$ does not contain unit roots). We also checked the results when allowing for permanent effects of the tax shocks using a VAR in first differences. The results are very similar to those that we derive with the VAR in equation (1) and are therefore not reported.

2.2 Empirical Results

We assume that $K = 6$, which corresponds to the median implementation lag in the data that we study, that $R = 12$, and that $P = 1$ (the results are robust to assuming longer lag structures). We report the impulse response functions to a one percent decrease in the tax liabilities (relative to GDP) along with 68 percent non-parametric non-centered bootstrapped confidence intervals computed from

Eichenbaum and Fisher (2004).

[3] In order to measure these we assume that pre-announced tax shocks enter agents' information sets at the earliest M quarters before their implementation. We set M equal to 3 years.

10000 replications. The impulse response functions are shown for a forecast horizon of 24 quarters for unanticipated tax liability shocks, and for 6 quarters before its implementation to 24 quarters after the implementation in the case of anticipated shocks.

The left column of Figure 1 shows the impact of an unanticipated tax liability cut. The decrease in taxes sets off an expansion in the economy that is large and persistent the dynamics of the endogenous variables are hump shaped. Investment and consumer durables purchases display by far the largest elasticities to the cut in tax liabilities. Investment increases by around 1 percent point in the first quarter and continues to rise until 10 quarters after the change in tax liabilities where it peaks at 7.6 percent above trend. Consumer durables purchases respond much the same way and peaks at 7.25 percent above trend 9 quarters after the tax cut. Output increases more moderately and reaches a peak increase of 2.17 percent above trend 10 quarters after the tax cut. The impact on hours worked, instead, is estimated to be close to zero until around a year and a half after the change in taxes. After that, hours worked increase gradually to a peak at 1.16 percent above trend 12 quarters after the tax shock. Consumption of nondurables and services adjust much faster to the tax cut than any of the other variables and stabilizes at a new higher level just 6 quarters after the tax cut. The peak response of consumption of nondurables and services corresponds to a 1.07 percent rise above trend.

The right column of Figure 1 illustrates the impact of anticipated tax liability changes. There is strong evidence in favor of anticipation effects: The *announcement* of a future tax liability reduction sets off a downturn in the economy that lasts until the tax cut is eventually implemented. Investment falls 4.9 percent below trend one year before the tax cut is implemented. The peak drop in investment is highly statistically significant. Output drops 1.16 percent three quarters before the tax liability cut is implemented. The decrease in output is statistically significant from zero during almost the entire pre-implementation period. Hours worked also drop significantly below trend throughout the announcement period down to 1.9 percent below trend 4 quarters before the tax cut. We find a 3.5 percent drop in consumer durables purchases 5 quarters before the tax cut is implemented, but the confidence interval is quite wide throughout the announcement period. Consumption of nondurables and services are instead approximately unaffected by the announcement of a future tax cut and is basically at trend when the tax cut is eventually implemented. Thus, the anticipation effects on the consumption variables are very different from the other variables that we investigate.

The actual implementation of the anticipated tax cut is associated with an expansion in the economy similar to the impact of an unanticipated tax cut. Apart from hours worked, the increase in activity occurs slightly faster than in response to unanticipated tax cuts. At forecast horizons beyond two years, anticipated and unanticipated changes in taxes have very similar effects. The maximum increase in output (a 1.5 rise above trend) occurs 9 quarters after the tax cut is implemented, while investment booms at 7.1 percent above trend (also 9 quarters after the cut in the taxes). As in the case of unanticipated tax cuts, the consumption response reaches its new higher level relatively quickly. The response of hours worked is somewhat weaker than the other variables in the post-implementation period (and imprecisely estimated). The sizes of the implementation-to-peak responses of the endogenous variables in response to the anticipated tax cut are very similar to the peak impacts in response to unanticipated tax cuts. Thus, the main differences between the impact of an anticipated and an unanticipated changes in taxes is that the peak response occurs earlier in the latter case.

Our estimation approach gives strong support to the presence of anticipation effects. This is important since it adds concrete empirical evidence to the idea that news shocks may influence the current state of the economy. We find that current good news (about lower future taxes) have a negative impact on output, investment and hours worked until the tax cut is implemented. This contrasts with the view of the technology news literature which has concentrated on scenarios in which current good news provides a stimulus to the economy. This literature, however, has produced little direct evidence on such news driven booms. This said, it is not logically impossible that news on taxes and on technology have different impact on the economy.

Our results regarding the lack of a strong news effect on consumption of nondurables and services. are consistent with the line of papers that have examined how anticipated tax changes affect consumption choices. Poterba (1988) and Heim (2007) fail to derive a significant consumption response to announced future tax cuts while Parker (1999) and Souleles (2002) find that consumption reacts to the *implementation* of pre-announced tax changes. These results are consistent with ours given the lack of response of consumption of nondurables and services during the pre-implementation period and the increase in consumption when the tax cut is implemented.

Mertens and Ravn (2009) demonstrate that the results above are extremely robust. The results do not hinge on particular tax acts. Nor do the results depend crucially on the fact that we do not control for other structural shocks. When we control for either government spending shocks or for monetary policy shocks, we find much the same impact of the tax changes on the vector of observables.

Importantly, Mertens and Ravn (2009) also show that there are little, if any, signs that the unanticipated tax shocks have any impact on the economy before their implementation. In other words, the results do support the timing based distinction that we make between anticipated and unanticipated tax shocks.

The analysis above assumes pre-announced tax changes can have an impact on X_t from a maximum 6 quarters before their implementation. Figure 2 illustrates the impact of an anticipated tax liability cut when we vary K, the maximum anticipation horizon, between 4 and 10 quarters. Regardless of the value of K in this range, the pre-implementation period is characterized by a recession and once the tax cut is implemented, the economy goes into a boom. However, the depth of the pre-implementation downturn and the size of the post-implementation expansion are sensitive to K. In particular, the longer the assumed maximum anticipation horizon (amongst the values that we examine), the deeper is the pre-implementation downturn and the milder is the post-implementation expansion. In Section 4 we will examine whether these results are consistent with economic theory.

3 Theory

We examine whether a dynamic stochastic general equilibrium model can account for the empirical results derived above. We extend earlier DSGE models of distortionary taxation, c.f. Baxter and King (1993), Braun (1994), McGrattan (1994) or House and Shapiro (2006), by introducing features such as habit formation, adjustment costs, consumer durables, and variable capacity utilization. Burnside, Eichenbaum and Fisher (2004) also stress the importance of habit formation and adjustment costs for accounting for the impact of fiscal policy shocks.[4]

3.1 The Benchmark Model

In the benchmark model we assume that there is a large number of identical, infinitely lived households. We will later allow for heterogeneous households when we study the potential impact of liquidity constraints. The representative household's preferences are given by:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{x_t^{1-\sigma} - 1}{1-\sigma} - z_t^{1-\sigma} \frac{\omega}{1+\kappa} n_t^{1+\kappa} \right] \tag{2}$$

[4]See House and Shapiro (2006), Leeper and Yang, 2006, Ramey, 2007, and Yang, 2005, for DSGE analyses of fiscal policy with anticipation effects.

E_t is the mathematical expectations operator conditional on all information available at date t, β is the subjective discount factor, $\sigma > 0$ is a curvature parameter, $\omega > 0$ is a preference weight, $1/\kappa \geq 0$ is the Frisch elasticity of labor supply, and n_t denotes hours worked. z_t denotes the level of labor augmenting technology which we assume grows at a constant rate, γ_z, over time. The term $z_t^{1-\sigma}$ that affects the disutility of work is introduced to allow for a balanced growth path. The variable x_t is defined as:

$$x_t = C_t^{\vartheta} (V_t)^{1-\vartheta} - \mu C_{t-1}^{\vartheta} (V_{t-1})^{1-\vartheta} \tag{3}$$

where $\vartheta \in [0, 1]$ is a share parameter, $\mu \in [0, 1)$ is a habit persistence parameter, C_t denotes consumption of consumer nondurables and V_t denotes the stock of consumer durables.

The representative household maximizes (2) subject to the following set of constraints:

$$V_{t+1} = \left(1 - \Phi_v \left(\frac{D_t}{D_{t-1}}\right)\right) D_t + (1 - \delta_v) V_t \tag{4}$$

$$K_{t+1} = \left(1 - \Phi_k \left(\frac{I_t}{I_{t-1}}\right)\right) I_t + \left(1 - \delta_k - \Psi_k \left(u_t^k\right)\right) K_t \tag{5}$$

$$C_t + D_t + I_t \leq (1 - \tau_t^n) W_t n_t + \left(1 - \tau_t^k\right) r_t u_t^k K_t + \Lambda_t + T_t \tag{6}$$

Equation (4) is the law of motion for the stock of consumer durables. D_t denotes purchases of new consumer durables, $\Phi_v \left(\frac{D_t}{D_{t-1}}\right)$ captures consumer durables adjustment costs, and δ_v is the rate of depreciation of the consumer durables stock. Adjustment costs are assumed to be convex but zero along the balanced growth path implying the restrictions $\Phi_v'' \geq 0$ and $\Phi_v(\gamma_z) = \Phi_v'(\gamma_z) = 0$.

Equation (5) is the law of motion for the stock of "market" capital, K_t. Households rent out this capital stock to firms. We allow for variable capital utilization, u_t^k, and assume that capital services are given by $u_t^k K_t$. $\Phi_k \left(\frac{I_t}{I_{t-1}}\right)$ denotes investment adjustment costs and $\Psi_k \left(u_t^k\right)$ denotes the effect of variations in the capital utilization rate on the effective rate of depreciation of the capital stock. As for durables, we assume that $\Phi_k'', \Psi_k', \Psi_k'' \geq 0$, and we also introduce the restrictions that $\Psi_k(1) = \Phi_k(\gamma_z) = \Phi_k'(\gamma_z) = 0$. δ_k is therefore the normal depreciation rate of the capital stock.

Equation (6) is the flow budget constraint in period t. The left hand side of this equation is the household's spending on the two types of consumption goods and on physical capital. The right hand side is the income flow net of taxes. The term $(1 - \tau_t^n) W_t n_t$ denotes net labor income, the product of hours worked and the real wage (W_t), net of labor income taxes. τ_t^n is a proportional labor income tax rate. $\left(1 - \tau_t^k\right) r_t u_t^k K_t$ is income from renting capital stock net of capital income taxes. r_t denotes the rental rate of capital services and τ_t^k is a proportional capital income tax rate. Λ_t and T_t denote depreciation allowances and lump-sum transfers, respectively. Following Auerbach (1989) and specify depreciation allowances as:

$$\Lambda_t = \tau_t^k \sum_{s=1}^{\infty} \delta_\tau \left(1-\delta_\tau\right)^{s-1} I_{t-s} \tag{7}$$

where δ_τ denotes the rate of depreciation for tax purposes. Note that this allows the depreciation rate for tax purposes δ_τ to differ from δ_k.

The first-order conditions for the household's problem are given as:

$$C_t : \lambda_{c,t} = \left(x_t^{-\sigma} - \mu\beta E_t x_{t+1}^{-\sigma}\right)\gamma\left(\frac{V_t}{C_t}\right)^{1-\gamma} \tag{8}$$

$$n_t : z_t^{1-\sigma}\omega n_t^{\kappa} = \lambda_{c,t}\left(1-\tau_t^n\right)W_t \tag{9}$$

$$K_{t+1} : \lambda_{c,t} q_{k,t} = E_t \beta \lambda_{c,t+1}\left[\left(1-\tau_{t+1}^k\right) r_{t+1} u_{t+1}^k + q_{k,t+1}\left(1-\delta_k-\Psi_k\left(u_{t+1}^k\right)\right)\right] \tag{10}$$

$$V_{t+1} : \lambda_{c,t} q_{v,t} = E_t \beta \lambda_{c,t+1}\left[\frac{1-\gamma}{\gamma}\frac{C_{t+1}}{V_{t+1}} + q_{v,t+1}\left(1-\delta_v\right)\right] \tag{11}$$

$$I_t : 1-\Gamma_t - q_{k,t}\left(1-\Phi_k\left(\frac{I_t}{I_{t-1}}\right)-\Phi_k'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right)$$
$$= \beta E_t \frac{\lambda_{c,t+1}}{\lambda_{c,t}} q_{k,t+1}\Phi_k'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{12}$$

$$D_t : 1 - q_{v,t}\left(1-\Phi_v\left(\frac{D_t}{D_{t-1}}\right)-\Phi_v'\left(\frac{D_t}{D_{t-1}}\right)\frac{D_t}{D_{t-1}}\right)$$
$$= \beta E_t \frac{\lambda_{c,t}}{\lambda_{c,t+1}} q_{v,t+1}\Phi_v'\left(\frac{D_{t+1}}{D_t}\right)\left(\frac{D_{t+1}}{D_t}\right)^2 \tag{13}$$

$$u_t^k : \left(1-\tau_t^k\right) r_t = q_{k,t}\Psi_k'\left(u_t^k\right) \tag{14}$$

where $\lambda_{c,t}$ is the multiplier on (6), $\lambda_{c,t} q_{k,t}$ is the multiplier on (5) and $\lambda_{c,t} q_{v,t}$ is the multiplier on (4).

The variable Γ_t that enters equation (12) is the expected present value of depreciation allowances on new investments. It is determined recursively as:

$$\Gamma_t = \beta\delta_\tau E_t\left[\frac{\lambda_{c,t+1}}{\lambda_{c,t}}\tau_{t+1}^k\right] + \beta\left(1-\delta_\tau\right)E_t\left[\frac{\lambda_{c,t+1}}{\lambda_{c,t}}\Gamma_{t+1}\right] \tag{15}$$

(8) sets $\lambda_{c,t}$ equal to the marginal utility of consumption of nondurables (which depends on both current and future consumption due to habit persistence). (9) equates the marginal rate of substitution between consumption and leisure with the after-tax real wage. (10) implies that the shadow value of new capital expressed in utility units, $q_{k,t}$, equals the expected present value of the stream of future net rental rates net of depreciation. Condition (11) determines the shadow value of new consumer durables, $q_{v,t}$, as the expected present value of the utility stream generated by the durables stock net of depreciation.

The first-order condition for investment in market capital, (12), implies that the change in investment is determined by the expected discounted present value of current and future levels of $q_{k,t}$ and Γ_t. When the shadow value of new capital or the value of depreciation allowances rise above their steady-state values, the growth rate in investment rises. Similarly, equation (13) determines the growth rate of consumer durables as a function of the expected present discounted value of the stream of shadow values of the consumer durables stock. Condition (14) defines implicitly the optimal utilization rate of market capital as a function of its current net return relative to the shadow value of the capital stock.

There is a continuum of identical competitive firms that operate Cobb-Douglas production functions:

$$Y_t = A\left(u_t^k K_t\right)^{\alpha}(z_t n_t)^{1-\alpha} \tag{16}$$

where Y_t denotes output, $A > 0$ is a constant, $\alpha \in (0,1)$ is the elasticity of output to the effective input of capital services and z_t denotes the level of labor augmenting technology. Given competitive behavior on the part of firms, the factor demand functions are defined by the first-order conditions:

$$W_t = (1-\alpha)\, z_t A\left(u_t^k K_t\right)^{\alpha}(z_t n_t)^{-\alpha} \tag{17}$$

$$r_t = \alpha A\left(u_t^k K_t\right)^{\alpha-1}(z_t n_t)^{1-\alpha} \tag{18}$$

The government purchases goods from the private sector, G_t, which it finances with capital and labor income taxes. It is assumed to run a balanced budget and the government budget constraint is given by:

$$G_t + T_t = \tau_t^n W_t n_t + \tau_t^k r_t u_t^k K_t - \Lambda_t \tag{19}$$

The process for government spending, G_t, is given as:

$$G_t = \xi \gamma_z^t G_0 + \pi_G\left[\tau_t^n W_t n_t + \tau_t^k r_t u_t^k K_t - \Lambda_t\right] + \varepsilon_t^g$$

where π_G is a coefficient that determines the feedback from factor income taxation to government spending, and ε_t^g is an iid innovation with mean zero and variance σ_g^2. We assume that lump-sum transfers vary endogenously in response to variations in government tax revenue and in government spending. Therefore, given the representative agent assumption, the results are identical to those that would obtained assuming that deficits are debt financed.[5]

[5] For given sequences of distortionary taxes and government spending, the equilibrium allocations assuming either endogenous variations in lump-sum transfers that keep government debt constant or endogenous variations in government debt that keep lump-sum transfers constrant are identical. This follows from Ricardian equivalence.

Labor income and capital income tax rates are assumed to be stochastic. There are two types of innovations to the tax rate processes, unanticipated shocks, ε_t^n and ε_t^k, and anticipated shocks, $\xi_{t,b}^n$ and $\xi_{t,b}^k$ where the latter are revealed at date t but implemented at date $t+b$. Thus, $b \geq 1$ denotes the anticipation horizon. The capital income and labor income tax rates evolve according to the stochastic processes:

$$\tau_t^n = (1-\rho_1^n-\rho_2^n)\,\tau^n+\rho_1^n\tau_{t-1}^n+\rho_2^n\tau_{t-2}^n+\varepsilon_t^n+\xi_{t,0}^n \tag{20}$$

$$\tau_s^k = \left(1-\rho_1^k-\rho_2^k\right)\tau^k+\rho_1^k\tau_{t-1}^k+\rho_2^k\tau_{t-2}^k+\varepsilon_t^k+\xi_{t,0}^k \tag{21}$$

where $\tau^n, \tau^k \in [0,1)$ are constants that determine the long run unconditional means of the two tax rates. We follow McGrattan (1994) and allow for an AR(2) structure of the tax processes with the restriction that $|\rho_1^n+\rho_2^n| < 1$ and $\left|\rho_1^k+\rho_2^k\right| < 1$. The innovations to the tax rates are assumed to be iid with zero mean, $\varepsilon_t \sim iid\,(0,\Omega_\varepsilon)$ and $\xi_t \sim iid\,(0,\Omega_\xi)$ where $\varepsilon_t = \left[\varepsilon_t^n, \varepsilon_t^k\right]'$ and $\xi_t = \left[\xi_t^n, \xi_t^k\right]'$. The innovations to the tax rates are allowed to be correlated but we assume that ε_t and $\xi_{t,b}$ are orthogonal.

The aggregate resource constraint in the economy is given by:

$$C_t + D_t + I_t + G_t \leq Y_t \tag{22}$$

We make the assumption that the tax liability changes that we analyzed in Section 2 derive from changes in the two distortionary tax rates. Variations in τ_t^n and τ_t^k affect the economy through wealth and substitution effects. There are two sources of wealth effects. First, if π_G is different from zero, changes in distortionary taxes affects government spending and this will impact on the present discounted value of the tax stream that is required to finance the stream of government spending. This will give rise to a change in household wealth. Secondly, changes in distortionary taxes alter households' expected lifetime utility through Harberger triangles, which in classical utility analysis translates into a wealth effect, see e.g. King (1989).

Increases in wealth due to a cut in distortionary taxes is associated with an increase in consumption and a decline in labor supply. The decline in labor supply relative to the increase in consumption is determined by σ/κ, see equations $(8)-(9)$. The higher the Frisch elasticity of labor supply, $1/\kappa$, and the higher is σ, the larger is the decline in labor supply relative to the increase in consumption. Substitution effects occur due to changes in relative prices but these effects depend on how taxes are changed and on the model parameters.

Consider an unanticipated cut in the labor income tax rate. The wealth effect calls for an increase in consumption and a decline in labor supply. The decline in tax rates also raises after-tax wages which stimulates labor supply and consumption. Moreover, changes in the path of after tax wages and in the return on capital affect labor supply through intertemporal substitution. To see this, combine equations (9) and (10):

$$n_t^{\kappa} = E_t \left[\beta \frac{(1-\tau_t^n) W_t}{\left(1-\tau_{t+1}^n\right) W_{t+1}} \gamma_z^{1-\sigma} R_{k,t+1} \right] n_{t+1}^{\kappa} \tag{23}$$

where $R_{k,t+1} = \left[\left(1-\tau_{t+1}^k\right) r_{t+1} u_{t+1}^k + q_{k,t+1} \left(1 - \delta_k - \Psi_k \left(u_{t+1}^k\right)\right) \right] / q_{k,t}$ is the expected net return on market capital. A cut in labor income taxes may increase or decrease current labor supply relative future labor supply depending on its impact on after-tax wages. If $(1-\tau_t^n) W_t$ increases relative to $E_t \left(1-\tau_{t+1}^n\right) W_{t+1}$, current labor supply will rise relative to future labor supply and vice versa.[6] Therefore, the response of labor supply depends on the wealth effect relative to the substitution effects, and the latter depends on the tax process.

The labor supply response impinges on the impact of investment in market capital. A log-linearization of the first-order conditions implies that:

$$\widehat{\imath}_t - \widehat{\imath}_{t-1} = \frac{1}{\Phi_k''(\gamma_z)\gamma_z} E_t \sum_{s=0}^{\infty} \left(\beta \gamma_z^{1-\sigma}\right)^s \left(\widehat{q}_{k,t+s} + \frac{\Gamma}{1-\Gamma} \widehat{\Gamma}_{t+s} \right) \tag{24}$$

where $\widehat{\imath}_t = \ln\left(\frac{I_t/z_t}{I/z}\right)$ denotes the percentage deviation of "detrended" investment from its steady-state value and $\widehat{q}_{k,t}$ and $\widehat{\Gamma}_t$ are defined analogously. When labor supply rises in response to a cut in labor income taxes, the shadow value of capital increases (see equation (10)) which stimulates current investment.

The announcement of a future cut in labor income taxes may have distinctively different effects from the implementation of a cut in labor income taxes. Due to the rise in wealth and the expected future increase in after-tax real wages, labor supply may drop during the pre-implementation period. If this occurs, the drop in hours worked lowers the return on capital goods which depresses investment (see equation (24)) unless adjustment costs are very high. Thus, output will tend to decrease in the anticipation of a future cut in labor income taxes. These predictions all appear consistent with the empirical evidence presented in Section 2. More intriguing is the impact on consumption of nondurables. The wealth effect will tend to increase consumption during the pre-implementation period. This increase

[6] Due to the AR(2) structure of the tax processes, an innovation to taxes may initially lead to an increasing or a decreasing tax profile.

in consumption will occur in a smooth manner if the habit parameter, μ, is sufficiently large. Moreover, the drop in current output increases the intertemporal price of output which has a negative impact on households' purchases of durable consumption goods and, since the two consumption goods are complementary, this further moderates the increase in the consumption of nondurables. Thus, it is possible that the model may be consistent with the lack of a strong consumption response to anticipated future tax changes.

The first-order effect of a surprise cut in capital income taxes is an increase in the return on market capital, which promotes investment. The impact on labor supply is ambiguous since the wealth effect and the intertemporal substitution effects are oppositely signed. The rise in the real interest rate implies that the hours worked profile must be decreasing, which moderates the positive wealth effect on consumption, see Braun (1994). Thus, depending on parameters, labor supply and consumption may increase or decrease in response to a cut in capital income taxes. As discussed by Auerbach (1989), adjustment costs are key for understanding the impact of the announcement of a future cut in capital income tax rates. When adjustment costs are small, investment will tend to fall abruptly when a future capital income tax rate cut is announced until the period immediately before the tax rate cut is implemented. The reason is that the expectation of future low capital income tax rates makes current investment unattractive until the period before the implementation of the tax cut. When adjustment costs are high, it may instead be optimal to increase investment immediately in order to increase the capital stock gradually so that the high returns on capital income can be harvested when the tax rate is eventually adjusted.

In summary, the response of the model to changes in tax rates depends crucially on parameters that determine wealth and substitution effects, on the importance of consumer durables and habit persistence, and on adjustment costs. In order to evaluate its quantitative performance, we formally estimate the structural parameters in the next section.

4 Estimation

We partition the set of parameters into two subsets: $\Theta = [\Theta_1', \Theta_2']'$ where Θ_1 is a vector of parameters that we will calibrate and Θ_2 is a vector of parameters that we estimate formally. Θ_1 contains those parameters for which there are good grounds for selecting their value through a calibration exercise.

We set one model period equal to 3 months. $\beta^* = \beta\gamma_z^{1-\sigma}$, the effective subjective discount factor, is calibrated to match a 3 percent annual real interest rate. ω, the preference weight on the disutility of work, is calibrated so that steady state hours work is equal to 25 percent. We set the share parameter ϑ so that durables consumption expenditure accounts for 11.9 percent of total consumption expenditure which matches the mean expenditure share of consumer durables (relative to total consumption expenditure) in the U.S. during the post World War II sample.

Steady state output (divided by the level of labor augmenting technology) is normalized to 1. We calibrate the constant A in equation (16) to match this normalization. The rate of labor augmenting technological progress, γ_z, is assumed to be equal to 1.005 which implies a long run annual growth rate of output of approximately 2 percent, the average growth rate of real per capita U.S. GDP in the post war period. We assume that $\delta_v = \delta_k = 0.025$ so that the steady-state annual depreciation rates are equal to approximately 10 percent. We set α equal to 36 percent, which produces income shares close to those observed in the U.S. We calibrate $\Psi'_k(1)$ so that it implies a steady state value of capacity utilization in the market sector that equals 1.

In the benchmark estimation we assume that $\pi_G = 0$ so that government spending is not affected by changes in income taxes. We later relax this assumption. In order to isolate the impact of changes in taxes, we look at the limiting case in which $\sigma_G^2 = 0$. We assume that the steady state level of government spending corresponds to 20.1 percent of GDP, a value that matches the post-WWII government spending share in the U.S.

We assume that the announcement horizon is equal to 6 quarters. Next, we set the steady state tax rates, τ^n and τ^k, equal to 26 percent and 42 percent, respectively, which match the average effective U.S. tax rates for labor and capital income estimated by Mendoza, Razin and Tesar (1994). Following Auerbach (1989) we set the depreciation rate for tax purposes, δ_τ, equal to twice the economic rate of depreciation along the balanced growth path. Finally, we assume that tax liability shocks give rise to changes in both the capital income tax rate and in the labor income tax rate and that the two tax innovations are of equal size. Our motivation for this assumption is that most of the tax liability changes listed in Table A.1 affect the taxation of both types of income. Table 1 summarizes the calibration of Θ_1.

The vector of parameters that we estimate formally is given by $\Theta_2 = \left[\sigma, \mu, \kappa, \phi_v, \phi_k, \psi_v, \psi_k, \rho_1^n, \rho_2^n, \rho_1^k, \rho_2^k\right]'$ where $\phi_k = \Phi''_k(\gamma_z)$, $\psi_k = \Psi''_k(\gamma_z)/\Psi'_k(\gamma_z)$, and $\phi_v = \Phi''_v(\gamma_z)$. We estimate Θ_2 by matching the empirical impulse response functions derived in Section 2. We use a simulation estimator rather than matching the "true" model impulse responses with their empirical counterparts directly since the empirical model imposes constraints that may not hold in the model. We show in Appendix 2 that the dynamics of the vector of observables in the theoretical model can be expressed as:

$$
\begin{aligned}
Y_s &= \widetilde{A} + \widetilde{B}s + \widetilde{C}Y_{s-1} + \sum_{i=0}^{\infty} \widetilde{D}_i \eta^u_{s-i} + \sum_{i=0}^{\infty} \widetilde{F}_{i+b} \eta^a_{s-i} + \sum_{i=0}^{b-1} \widetilde{G}_i \eta^a_{s-i} \qquad (25) \\
\eta^{\varepsilon}_{s-i} &= \begin{bmatrix} \frac{\varepsilon^n_s}{\tau^n}, & \frac{\varepsilon^k_s}{\tau^k} \end{bmatrix}', \eta^a_{s-i} = \begin{bmatrix} \frac{\xi^n_{s-i,0}}{\tau^n}, & \frac{\xi^k_{s-i,0}}{\tau^k} \end{bmatrix}', \eta^{\xi}_{s-i} = \begin{bmatrix} \frac{\xi^n_{s-j,b-j}}{\tau^n}, & \frac{\xi^k_{s,b-j}}{\tau^k} \end{bmatrix}'
\end{aligned}
$$

where η^{ε}_{s-i}, η^a_{s-i}, and η^{ξ}_{s-i} denote the surprise tax shocks, the implemented anticipated tax shocks, and the announced, but not yet implemented tax shocks, relative to the steady-state values of the respective tax rates. This representation exists subject to conditions that we lay out in the appendix. (25) differs from (1) since it allows $D(L)$ and $F(L)$ to be infinite order lag polynomials while the empirical model constrains these polynomials to be finite order. Appendix 2 shows that the matrices $\widetilde{D}_i$ and $\widetilde{F}_i$ depend on a dampening matrix Ξ_W and that the roots of this matrix are determined by the persistence of the tax rate processes which we estimate. Therefore, we cannot be sure that constraining $D(L)$ and $F(L)$ to involve a finite number of lags is innocuous. The simulation estimator addresses this problem.[7] We estimate Θ_2 as the vector of variables that solves the following minimization problem:

$$
\widehat{\Theta}_2 = \arg\min_{\Theta_2} \left[\left(\widehat{\Lambda}^d_T - \Lambda^m_T (\Theta_2|\Theta_1) \right)' \Sigma_d^{-1} \left(\widehat{\Lambda}^d_T - \Lambda^m_T (\Theta_2|\Theta_1) \right) \right] \qquad (26)
$$

where $\widehat{\Lambda}^d_T$ denotes the vectorized empirical responses that we aim at matching, $\Lambda^m_T(\Theta_2|\Theta_1)$ are the equivalent estimates from the theoretical model and Σ_d^{-1} is a weighting matrix. We set the weighting matrix to be a diagonal matrix with the estimates of the inverse of the sampling variance of the impulse responses along its diagonal.

We calculate the model equivalent of the empirical impulse responses in the following fashion:

1. Draw 100 sequences of tax innovations from the U.S. data (with replacement) each for a time-horizon of 228 quarters. Simulate the economy in response to each of these sequences of tax innovations. This produces 100 sample paths of the vector X. Denote this collection of vectors by $X^j(\Theta_2|\Theta_1)$ where $j = 1, .., 100$ denotes the j'th replication.

[7] See Cogley and Nason (1995) for an early application of such an approach and Kehoe (2006) and Dupaigne, Fève and Matheron (2007) for recent discussions and evaluations of this approach.

2. Add a small amount of measurement error to $X^j(\Theta_2|\Theta_1)$. Let $\widetilde{X}^j(\Theta_2|\Theta_1)$ denote the resulting artificial samples of X.

3. For each artificial dataset estimate the following model:

$$\widetilde{X}_t^j(\Theta_2|\Theta_1) = \mathfrak{A}^j + \mathfrak{B}^j t + \mathfrak{C}^j(L)\widetilde{X}_{t-1}^j(\Theta_2|\Theta_1) + \mathfrak{D}^j(L)\widetilde{\tau}_t^{u,j} + \mathfrak{F}^j(L)\widetilde{\tau}_{t,0}^{a,j} + \sum_{i=1}^{K}\mathfrak{G}_i^j\widetilde{\tau}_{t,i}^{a,j} + \widetilde{e}_t^j \quad (27)$$

where $\widetilde{\tau}_t^{u,j}$ and $\widetilde{\tau}_{t+1,t}^{a,j}$ are the sequences of tax liability shocks drawn for the j'th replication. Calculate the model equivalent of the empirical impulse response functions in response to a 1 percent cut in tax liabilities and denote them by $\Lambda_T^m(\Theta_2|\Theta_1)^j$. To match the size of the tax shock in the data, the size of the innovations to the tax rates are computed so that they induce a one percent change in tax liabilities relative to GDP at the implementation date. Finally, we average the impulse responses over the 100 replications. This gives us the estimate of $\Lambda_T^m(\Theta_2|\Theta_1)$.

Following Hall et al (2007) , we compute the standard errors of the vector Θ_2 from an estimate of its asymptotic covariance matrix as:

$$\Sigma_{\Theta_2} = \Lambda_{\Theta_2}\frac{\partial\Lambda_T^m(\Theta_2|\Theta_1)'}{\partial\Theta_2}\Sigma_d^{-1}\Sigma_S\Sigma_d^{-1}\frac{\partial\Lambda_T^m(\Theta_2|\Theta_1)}{\partial\Theta_2}\Lambda_{\Theta_2}$$

where:

$$\Lambda_{\Theta_2} = \left[\frac{\partial\Lambda_T^m(\Theta_2|\Theta_1)'}{\partial\Theta_2}\Sigma_d^{-1}\frac{\partial\Lambda_T^m(\Theta_2|\Theta_1)}{\partial\Theta_2}\right]^{-1}$$

$$\Sigma_S = \Sigma + \frac{1}{S^2}\sum_{s=1}^{S}\Sigma_s$$

Σ denotes the covariance matrix of the impulse responses estimated in Section 2, and Σ_s is the covariance matrix of the s'th replication of the model based impulse responses.

5 Results

Table 2 reports the parameter estimates of the benchmark model and the parameter estimates associated with some alternative model specifications. The last column of this table gives the value of the quadratic form in equation (26) evaluated at $\widehat{\Theta}_2$.

The parameters pertaining to preferences are estimated with great precision. The point estimate of $\widehat{\sigma}$, the curvature parameter in the utility function, is 2.572. This estimate is within the range of values usually considered plausible.[8] The point estimate of the habit parameter $\widehat{\mu}$ is 0.822, a value that is similar to e.g. the estimate of Christiano, Eichenbaum and Evans' (2005) (Burnside, Eichenbaum and Fisher (2004) use a very similar calibration in their analysis of fiscal policy).

Our point estimate of the inverse Frisch elasticity is 0.355. This estimate is within the range of values typically assumed in the macroeconomic literature while lower than values typically estimated in the microeconometric literature. House and Shapiro (2006, 2008) assume a somewhat higher value of this parameter in their calibration of a DSGE model applied to the simulation of the impact of tax changes. The higher Frisch elasticity implied by our estimates is important, as we shall see below, for accounting for the impact of tax changes on labor supply. In particular, our estimate implies that labor supply reacts elastically to changes in wages and in real interest rates.

The estimates of the adjustment cost parameters indicate that investment adjustment costs are relevant for both capital stocks but matter more for the market capital stock than for consumer durables. Our point estimate of $\widehat{\phi}_k$ is 6.581, while the point estimate of $\widehat{\phi}_v$ is 4.444. We find that there some role for fluctuations in the utilization rate of the market capital stock. The point estimate of $\widehat{\psi}_k$ is 0.367 which implies that changes in the utilization rate have a moderate impact on the gross depreciation rate of the capital stock.[9]

The estimates for the autoregressive parameters pertaining to the tax processes, $\widehat{\rho}_1^n = 0.999$, $\widehat{\rho}_2^n = 0.0$, $\widehat{\rho}_1^k = 1.629$ and $\widehat{\rho}_2^k = -0.652$, indicate high persistence of the tax processes. These estimates imply that the largest root of Ξ_W, the dampening matrix discussed in the previous section, is very close to one. Therefore, it might potentially be important to take into account that the empirical model imposes a finite moving average structure on the implemented tax shocks.

Figure 3 illustrates the dynamics of the two tax rates following a one percent decrease in tax liabilities. We also show the dynamics of total tax liabilities relative to GDP. In the case of an unanticipated tax liability cut, the resulting initial change in the two tax rates corresponds to a 1.3 percentage points drop in the two distortionary tax rates. The labor income tax rate thereafter remains close to this

[8] Due to habit formation, however, this parameter should not be interpreted as the inverse of the intertemporal elasticity of substitution in consumption.

[9] We also estimated the model allowing for variations in the utilization rate of the consumer durables stock. The estimated elasticity of the depreciation rate of the consumer durables stock, however, is so high that the utilization rate is constant in equilibrium.

level for a long period. The capital income tax rate displays a more volatile pattern reaching a maximum decline of 3.1 percentage points 5 quarters after the tax cut, but then returns relatively quickly to its steady-state level. In the case of an anticipated tax cut, tax liabilities drop slightly during the pre-implementation period, but the implied initial change in tax rates at the implementation date is practically identical to the case of an unanticipated tax cut. The high persistence of the labor income tax rate appears consistent with substantial amounts of tax smoothing.

We now examine the extent to which the model can account for the impact of tax liability changes that we estimated for the U.S. economy in Section 2. Figure 4 illustrates the impact of a one percent tax liability cut in the model economy given the parameter estimates just discussed. In order to facilitate comparison with the empirical estimates of Section 2, we show the theoretical impulse responses along with their empirical counterparts. The left column of Figure 4 shows the response to a one percent surprise tax liability cut (relative to GDP), while the right column shows the impact of a one percent anticipated tax liability cut.

The model can account for all the main features of the empirical estimates. In particular, as in the U.S. data:

- an unanticipated tax liability cut gives rise to a major expansion in output, consumption, investment and hours worked;
- the announcement of a future tax liability cut gives rise to a drop in output, investment and hours worked during the pre-implementation period; and
- the implementation of a pre-announced tax liability cut is associated with expansions of output, consumption, investment and hours worked.

Moreover, the sizes and the shapes of the impulse responses of the model are very similar to their empirical counterparts. In no case do the theoretical responses fall outside the confidence intervals of the empirical estimates for more than a few quarters.[10] Particularly interesting is the fact that the model is fully consistent with the delayed increase in hours worked in response to an unanticipated tax cut and in response to the implementation of an anticipated tax cut. Below we discuss why this is the case.

[10] Notice that we are estimating many fewer parameters (10) than the number of moments (240). Thus, there is aboslutely no guarantee that the model can account for the empirical impulse responses.

The model is also extremely successful in accounting for the dynamics of investment. Due to adjustment costs, cuts in taxes lead to a steady decline in investment during the pre-implementation period in response to a pre-announced tax cut that almost perfectly emulates the pattern observed in the U.S. data. On the other hand, the model underestimates the peak response of investment to implemented tax cuts. Nevertheless, the theoretical responses are within the confidence interval of the empirical estimates.

Recall that consumption of nondurables and services basically does not respond to announcements of future tax changes. The model presented in Section 3 implies a steady, but small, increase in consumption of nondurables and services to an anticipated tax cut during the pre-implementation period. The rise in consumption is sufficiently small that it is inside the confidence interval of the empirical estimates during much of the pre-implementation period. This result appears counterintuitive. For that reason, we examine this aspect of our results in some detail in Section 5.1 below.

Figure 4 shows both the exact model impulse responses (lines with circles) and the model impulse responses estimated by imposing the empirical model on the artificial data (dashed lines). The latter are those that we match with the empirical impulse responses when estimating the structural parameters. The comparison of the two measures of the theoretical impulse responses shows that they are very similar for the forecast horizons that we consider (but not at long forecast horizons). Therefore, although the roots of the tax processes are very persistent, the approximation error due to the finite MA specification of the empirical model appears to be of limited concern for the short to medium term impact of tax liability changes.

In the U.S. data, the size of the pre-implementation contraction in output in response to an anticipated tax cut is smaller the shorter the assumed implementation lag (see Figure 2). We now examine whether the DSGE model is consistent with this finding by computing the impulse response of output varying the parameter b in equations (20) and (21) from 4 to 10 quarters. The result is illustrated in Figure 5. The model reproduces exactly the same result as the empirical VAR: The shorter is the anticipation horizon, the smaller is the pre-implementation contraction of output. This result derives from the presence of adjustment costs. Households are forward looking and wish to increase the capital stock when the returns on it eventually increase. In the presence of adjustment costs, the process of building up the capital stock starts early in order to economize on adjustment costs. This implies a deeper pre-implementation recession the longer the implementation lag (for moderate values of b).[11]

5.1 Accounting For the Consumption Response

As discussed above, the model is quite successful in accounting for the flat consumption response during the pre-implementation period. This result goes against standard intuition and we now wish to bring out the sources of this feature of the model. In order to understand our results better, given the baseline parameter estimates, $\widehat{\Theta}_1$, we provide a Hicksian decomposition of the responses of consumption and hours following a one percent tax liability cut into wealth and substitution effects (see King, 1989).

We compute the wealth effect in the following manner. Let the initial steady-state allocation be denoted by $\left(\overline{C}, \overline{V}, \overline{n}\right)$ with associated after-tax factor prices $\left((1-\overline{\tau}^n)\,\overline{w}, \left(1-\overline{\tau}^k\right)\overline{r}\right)$ and let U_0^{SS} be the discounted lifetime utility associated with this allocation. Let the path of the economy following a one percent tax liability cut be given by the allocation $(C_t, V_t, n_t)_{t=0}^{\infty}$ with associated factor prices $\left((1-\tau_t^n)\,w_t, \left(1-\tau_t^k\right)r_t\right)_{t=0}^{\infty}$ and let U_1 be the present discounted utility associated with this path. The wealth effect is then computed as the constant levels of consumption (of nondurables and of durables) and hours worked such that, at the initial steady-state prices, $U\left(C^1, V^1, n^1\right) = U_1$.

We compute three substitution effects which consist of a real wage effect, a rental rate effect, and a wedge which we compute residually. The latter effect arises due to costs of adjusting the durables stock and the stock of capital.[12] The wage and rental rate effects are computed as the optimal paths of consumption and hours worked when households are faced with the price sequences $\left((1-\tau_t^n)\,w_t, \left(1-\overline{\tau}^k\right)\overline{r}\right)_{t=0}^{\infty}$ and $\left((1-\overline{\tau}^n)\,\overline{w}, \left(1-\tau_t^k\right)r_t\right)_{t=0}^{\infty}$, respectively, under the constraint that present discounted utility associated with these allocations is equal to U_0^{SS}.

Figure 6 illustrates this decomposition for consumption of nondurables and hours worked after a one percent cut in tax liabilities. Since we assume that $\pi_G = 0$, the wealth effects derive from Harberger

[11] These effects are not monotone in the anticipation horizon, b. When b becomes very long, anticipated tax changes have little impact on output until the implementation date gets nearer.

[12] In the absence of adjustment costs, the laws of motion for the capital stock and for the consumer durables stock can be substituted into the household's budget constraint. Iterating this constraint forward (and imposing transversality conditions) gives rise to a single life-time budget constraint for expenditure on the two consumption goods which depends only on initial wealth, on the stream of transfers and depreciation allowances and on the two relative prices. When there are adjustment costs, the two laws of motion cannot be eliminated since adjustment costs introduce a wedge between the (after-tax) real interest rate and the intertemporal marginal rate of substitution.

triangles that arise because lower factor income taxes temporarily reduce the inefficiency induced by distortionary taxes. This wealth effect is very small for both hours worked and consumption. This implies that most of the aggregate response to tax changes must derive from substitution effects.

After an unanticipated tax liability cut, after-tax wages and rental rates initially rise above their steady state values and keep rising for a while until taxes eventually start increasing. The rise in after-tax real wages increases labor supply and consumption due to intratemporal substitution. At the same time, the hump-shaped pattern of the after-tax wage profile implies that the hours worked profile initially is increasing but eventually must revert as after-tax real wages start returning to their steady-state level. Thus, the wage effect is associated with a large and gradual rise in hours worked. The wage effect also gives rise to an increase in consumption but habit formation implies that the increase in consumption occurs very gradually over time. The increase in after-tax rental rates reinforces the rising consumption profile induced by the wage effect but moderates the hours worked response to the tax cut. Intuitively, the persistent rise in rental rates lowers current consumption relative to future consumption while at the same time increasing current labor supply relative to future labor supply. The combination of the wage and rental rate effects accounts for the solid growth in consumption due to the tax cut and for the initially flat response of hours worked.

In response to an anticipated tax cut, after-tax real wages and rental rates remain approximately unaffected during the pre-implementation period but rise rapidly when taxes are eventually cut. The rise in the after-tax rental rate reaches its maximum around a year after the tax cut while the maximum increase in the after tax real wage occurs 2 years after the implementation of the tax cut.

The expectation of higher future after-tax wages depresses hours worked during the pre-implementation period but once the tax cut is implemented, the wage effect is associated with a rise in hours worked. The drop in hours worked during the pre-implementation period associated with the wage effect also reduces spending on consumer durables (and on investment goods) which, due to complementarity between the two consumption goods, implies a negative wage impact on consumption of nondurables.

The rental rate effect implies that the consumption profile must be increasing once taxes are eventually cut. Due to habit persistence, the rental rate effect leads to an increase in consumption already during the pre-implementation period. Thus, the wage and rental rate effects together imply a moderately increasing consumption profile during the pre-implementation period and a more pronounced increase in consumption once taxes are eventually cut. The rental rate effect on labor supply implies that the labor supply profile must be negatively sloped during the pre-implementation period and for a period once taxes are eventually cut. Hence, the wage and rental rate effects give rise to a prolonged drop in hours worked in response to the announcement of future lower taxes that is only reversed once the positive wage effect eventually starts dominating the negative rental rate effect.

This might indicate that habit formation and consumer durables are important for understanding the lack of a solid consumption response to anticipated tax changes. The second row of Table 2 reports the parameter estimates of Θ_2 when we exclude consumer durables from the model.[13] Inspecting the minimized value of the quadratic form, this version of the model fits the empirical impulse responses much worse than the benchmark model. Figure 7 shows the resulting impulse response functions along with those of the alternative empirical VAR. In this case, the announcement of a future tax liability cut is associated with a pronounced increase in consumption of nondurables and services during the pre-implementation period. Recall that in the benchmark model, the drop in consumer durables purchases during the pre-implementation period moderates the increase in nondurables consumption. When durables are eliminated from the model, consumption thus rises immediately in response to the announcement of future lower taxes.

Row (3) reports the parameter estimates when we restrict the habit parameter to be equal to zero, $\mu = 0$. This restriction increases the estimated curvature parameter, $\widehat{\sigma}$. Intuitively, in order to match the smoothness of the consumption response, the model requires a low intertemporal elasticity of substitution. Figure 8 shows the impulse responses of this restricted model. Importantly, when we eliminate consumption habits, the model is actually better suited at accounting for the lack of a strong consumption response to tax news. The reason is that consumers are more willing to accept a sudden rise in consumption when taxes are eventually cut in the model that features time-separable preferences than in the habit model. However, this also implies that consumption rises counterfactually fast in response to surprise tax cuts. The results indicate that, on balance, the habit model fits the data better.

[13] In this case, we estimate the structural parameters by matching the moments of a version of the VAR in equation (**??**) in which the vector of endogenous variables, X_t, does not include the purchases of consumer durables.

6 Extensions

In this section we examine the impact of three extensions of the model. First, we allow for variations in government spending in response to tax changes. Secondly, we examine whether our results depend crucially on the fact that we allow for variations in both labor income tax rates and in capital income tax rates. Third, we examine the consequences of allowing for the presence of liquidity constraints and labor market distortions.

6.1 Fiscal Feedback

The benchmark model assumes that government consumption grows at a constant rate. We now relax this assumption and allow changes in distortionary taxes to affect government consumption. An important consequence of this extension is that it introduces an additional wealth effect because the present value of households' total tax payments change after a change in tax rates. We reestimate the model allowing π_G to differ from zero. Since tax liabilities fall after the decrease in tax rates (see Figure 3), a positive value of π_G indicates a stronger wealth effect while a negative value of π_G instead lowers the wealth effect.

Row (4) of Table 2 reports the parameter estimates for this alternative scenario. The point estimate of π_G is 0.062, which implies that the wealth effects are stronger in this model than in the benchmark model. Quantitatively, however, the impact is small and the implied impulse responses illustrated in Figure 9 are for all means and purposes identical to the benchmark model.[14] We also reestimated the model setting $\xi = 0$ and $\pi_G = 1$. This version of the model also leads to implications that are very similar to the benchmark model.[15] Thus, we conclude that the first-order impact of changes in distortionary tax rates dominates the impact of the financing of government spending.

Alternatively, one might consider the impact of allowing taxes to respond to past, current and possibly future values of output or other endogenous variables. In this case, one might call into question the assumption that exogenous tax liability changes as defined by Romer and Romer (2007) identify movements in taxes that are unrelated to the fiscal authority's current information set. In principle, this

[14] This result squares well with Romer and Romer (2008) who find little impact of tax changes on government spending. According to their results, if anything, tax cuts appear to increase government spending.

[15] Results are available upon request.

might affect the validity of our empirical results. Leeper, Walker and Yang (2008) examine this issue on the basis of a simplified version of our model. In particular, they generate artificial data with a simplified version of the model we presented in section 3 in which they allow tax rates to respond to current and past news about output and the debt-to-GDP ratio. They then estimate a 4-variable version of the empirical model we proposed in Section 2 on the artificial data and examine the discrepancy between the "true" and "estimated" response of consumption and output to changes in labor and capital income taxes. Essentially, the problem that arises when considering this tax rule is that future expected tax liabilities depend on future expected economic conditions due to the endogeneity of tax rates and this invalidates the identifying assumptions imposed on the empirical model. Their results show that our framework works extremely well even under these very unfavorable conditions. In particular, the "true" and "estimated" output responses are very close even when the feedback on taxes is very strong. The consumption response is also precisely estimated if tax liability changes occur mainly due to changes in capital income taxes, but may be biased in favor of a pre-implementation drop in consumption when considering feedback on labor income taxes. However, for this worst case scenario to be of major concern, we would have needed to have estimated a pre-implementation drop in consumption in the U.S. data and as we have discussed, consumption basically remains unaffected by pre-announced tax changes until they are eventually implemented. Thus, Leeper, Walker and Yang's (2008) results underline the reliability of our results.

6.2 Capital Income Taxes vs. Labor Income Taxes

Our analysis allows for changes in both labor income tax rates and in capital income tax rates. It is natural to ask if the implications change radically assuming that tax liability changes are due only one of these two tax rates. To examine this, Table 1 contains the parameter estimates when we allow for changes in the labor income tax rate only (row 5), or in the capital income tax rate only (row 6). Figures 10 and 11 illustrate the resulting impulse response functions.

According to the minimized value of the quadratic form, the ability of the model to account for the response of the observables to changes in tax liabilities falls significantly when only a single tax rate is considered. Moreover, the estimates of the structural parameters are sensitive to these alternative models of taxes. When we allow only for changes in labor income tax rates, the adjustment cost parameter estimates are cut by two thirds while $1/\sigma$ doubles and the Frisch elasticity goes to infinity. Alternatively, when we allow for changes only in the capital income tax rate, the utility function is logarithmic in (habit adjusted) consumption and linear in labor supply, and the elasticity of the depreciation rate to variations in the capital utilization rate doubles.

Qualitatively, however, the model does a good job of accounting for the main features of the data even if we consider changes in only one of the two tax rates. In particular, the model still is able to account for the expansionary impact of an implemented tax cut and for the negative impacts on output, hours and investment of the announcement of a future tax cut. Quantitatively, when we allow for changes in labor income tax rates only, the model underestimates the impact of tax cuts on investment and overestimates the speed of adjustment of hours worked. The reason for the former is that a cut in labor income taxes affect investment mainly through increased hours (which increases the return to capital) but this impact is relatively small. When alternatively setting the labor income tax rate constant, the impact of tax liability changes on hours worked are too volatile at the implementation date relative to the empirical evidence. Nevertheless, the model performs well even when tax liability changes affect only one of the two tax rates.

6.3 Liquidity Constraints

Our empirical estimates on the lack of consumption response to tax news is consistent with earlier microeconometric evidence regarding the impact of pre-announced tax changes on household consumption, see e.g. Johnson, Parker and Souleles (2006), Heim (2007), Parker (1999) and Souleles (1999, 2002). A number of papers have argued that this evidence indicates that a non-trivial proportion of the population face binding liquidity constraints and can best be thought of as rule-of-thumb consumers. Mankiw (2000) makes a strong case for introducing rule-of-thumb consumers as a standard feature of macroeconomic models and estimate the share of these consumers to be close to 50 percent. Subsequently, Galí, Lopéz-Salido and Vallés (2007) show that the presence of such liquidity constrained agents may be important for accounting for the impact of fiscal spending shocks.

Our findings appear to challenge this view since our benchmark model provides a reasonable good fit to the consumption response to tax change despite featuring only intertemporally maximizing households that do not face binding liquidity constraints. Nonetheless, it is still logically possible that introducing rule-of-thumb consumers may help accounting even better for the aggregate responses to tax changes. For that reason, we now extend the model with rule-of-thumb consumers. As in Campbell and Mankiw

(1989), and Galí, Lopéz-Salido and Vallés (2007), we assume that rule-of-thumb consumers can neither borrow nor save and simply consume their income period-by-period. Moreover, rule-of-thumb households are assumed not to consume durables since this introduces a role for savings and we assume that rule-of-thumb consumers have intertemporally separable preferences.[16]

There is a continuum of households. There is a share ψ of intertemporally maximizing consumers described by the preferences in equation (2) – (3) which they maximize subject to the constraints in equations (4) – (6). A share $1-\psi$ of agents are rule-of-thumb consumers. These households face the following maximization problem:

$$\max E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{*1-\sigma} - 1}{1-\sigma} - z_t^{1-\sigma} \frac{\omega^*}{1+\kappa} n_t^{*1+\kappa} \right] \tag{28}$$

$s.t.$

$$C_t^* \leq (1-\tau_t^n) W_t n_t^* + T_t^* \tag{29}$$

where C_t^* denotes consumption of nondurables of rule-of-thumb consumers, n_t^* is their labor supply, and T_t^* are government lump-sum transfers to these households. Note that we allow ω^* to differ from ω. We explain below why we allow this parameter to differ across the two types of households.

Galí, Lopéz-Salido and Vallés (2007) argue that rule-of-thumb behavior by itself does not allow one to account for the impact of fiscal spending shocks (in particular for the positive consumption response to increases in government spending estimated in the VAR literature) but must be combined with imperfectly competitive labor markets. We follow these authors and assume that wages are set by labor unions.[17] The effective labor input hired by, say, firm j is given as:

$$N_{j,t} = \left(\int_0^1 \left(n_{j,t}^i \right)^{1-1/\vartheta} di \right)^{1/(1-1/\vartheta)}$$

where $n_{j,t}^i$ denotes hours worked of household i and $\vartheta > 1$ is the elasticity of substitution between different types of labor. This implies that the demand for labor of type j is given as:

$$N_{j,t} = \left(\frac{W_{j,t}}{W_t} \right)^{-\vartheta} N_t \tag{30}$$

where $W_t = \left(\int_0^1 W_{j,t}^{1-\vartheta} dj \right)^{1/(1-\vartheta)}$.

[16] When we allow for habit forming rule-of-thumb consumers, the habit parameter pertaining to this group of households is estimated to be zero.

[17] Our results regarding the limited importance of rule-of-thumb households are even stronger when we assume competitive labor markets.

The fraction of intertemporally maximizing households and rule-of-thumb households is uniformly distributed over types of workers and we assume that there is one union for each different type. The typical union then sets the wage of its members to maximize (see Galí, Lopéz-Salido and Vallés, 2007, for details):

$$\frac{\psi}{\omega}\left(MU_{c,t}^{j}W_{j,t}n_{j,t}-\omega\frac{z_t^{1-\sigma}n_{j,t}^{1+\kappa}}{1+\kappa}\right)+\frac{1-\psi}{\omega^{*}}\left(MU_{c,t}^{j*}W_{j,t}n_{j,t}^{*}-\omega^{*}\frac{z_t^{1-\sigma}\left(n_{j,t}^{*}\right)^{1+\kappa}}{1+\kappa}\right)$$

where $MU_{c,t}^{j}$ and $MU_{c,t}^{j*}$ denote the marginal utility of consumption for optimizing and rule-of-thumbs consumers, respectively. Following Galí, Lopéz-Salido and Vallés (2007) we calibrate ω^{*} such that the marginal rate of substitution between consumption and hours worked equalize across the two types of agents along the balanced growth path.

The aggregate resource constraint is:

$$\begin{aligned}
Y_t^A &\geq \psi\left(C_t+D_t+I_t\right)+\left(1-\psi\right)C_t^{*}+G_t^A \\
Y_t^A &= A\left(u_t^k\psi K_t\right)^{\alpha}\left(z_t n_t^A\right)^{1-\alpha} \\
n_t^A &= \psi n_t+\left(1-\psi\right)n_t^{*}
\end{aligned}$$

and the government budget constraint reads:

$$G_t^A+\psi T_t+\left(1-\psi\right)T_t^{*}=\tau_t^n W_t n_t^A+\tau_t^k r_t\psi u_t^k K_t-\psi\Lambda_t$$

where we let x_t^A denote the per capita value of x_t. We assume that the government's transfer policy is "neutral" in the sense that the per capita transfers to optimizing and rule-of-thumb households are the same.

Table 1, row 7, reports the estimates of this model where we have extended the list of parameters that are estimated with ψ. According to these estimates, the share of rule-of-thumb consumers $(1-\psi)$ is around 10.5 percent which is much smaller than the standard values used in the literature. Moreover, the standard error of the point estimate of ψ is very small. The remaining parameter estimates are quite similar to those of the benchmark model with the exception of the Frisch elasticity which for the rule-of-thumb model implies that utility is linear in hours worked. We note from the value of the quadratic form that this model appears to fit the data better than the benchmark model (and as well as the extension in which we included feedback on government spending).

Figure 12 illustrates the implied impulse responses of this model. It is clear that the main improvement in the fit of the model is associated with the impact of tax changes on nondurables consumption. The model with rule-of-thumb consumers is better able to account simultaneously for the lack of consumption response to pre-announced tax changes and for the fast response of consumption to implemented tax changes than the benchmark model. This result is consistent with the conclusions drawn by Mankiw (2000) and others regarding the link between consumption responses to pre-announced tax changes and rule-of-thumb behavior.

Nonetheless, we find that the share of rule-of-thumb consumers must be very low. This is explained by two aspects. First, all other things equal, a higher share of rule-of-thumb consumers makes it harder to account for the elastic response of investment to tax changes. Note that even the benchmark model implies a somewhat smaller peak response of investment to tax changes than our empirical estimates. The reason for this is that adjustment costs are needed to account for the response of investment to pre-announced tax changes but, at the same time, also implies a less elastic investment response to implemented tax changes. When we introduce rule-of-thumb consumers, this problem becomes even worse since investment is undertaken by the optimizing households only. This aspect will tend to imply a low share of rule-of-thumb consumers. Secondly, a large share of rule-of-thumb consumers makes it more difficult to account for the hours response to pre-announced tax changes. Recall that we find that hours worked drop persistently in response to the announcement of a future cut in taxes. When the share of rule-of-thumb consumers is large there is little reason for why hours of work should drop during the pre-announcement period regardless of whether the labor market is competitive or not.

Thus, in conclusion, we find that although introducing rule-of-thumb consumers leads to a better fit of the model, the implied share of these agents is small. Our results are consistent with previous claims in the literature that rule-of-thumb consumers are important for accounting for the consumption response to tax changes, but we estimate their share to be low because a large share of these agents makes it difficult to account for the investment and hours worked responses to tax changes.

7 Conclusions

We have investigated the dynamic effects of U.S. tax liability changes and examined its congruency with macroeconomic theory. We have shown that implemented tax changes have a large impact on the economy but also that anticipated tax shocks give rise to a substantial adjustment of main macroeconomic aggregates. In particular, while implemented tax cuts provide a stimulus to the economy giving rise to a major expansion in aggregate output, consumption, investment and hours worked, the announcement of a future tax cut gives rise to a drop in output, investment and hours worked until the tax cut is eventually implemented.

We then showed that a dynamic stochastic general equilibrium model can account for these effects. The important features are adjustment costs, variable capacity utilization, and, to some extent, consumption habits. We also showed that the exact way in which tax cuts are implemented appear not to matter too much. In particular, our results do not hinge too much upon whether the tax changes relate to labor income or capital income tax rates. We showed that substitution effects are key for understanding the dynamic adjustment of the economy to changes in tax while wealth effects are less important. Our analysis also examined the importance of introducing rule-of-thumb consumers. We found that allowing for liquidity constrained households gives rise to a better fit of the consumption response to tax changes but that the implied share of these agents is low and much smaller than previous estimates in the literature.

There are several promising avenues for future research that we plan to pursue. First, it would be interesting to examine more disaggregated tax measures in order to derive finer estimates of the impact of changes in particular taxes. Secondly, it would be important to investigate whether similar results to those reported in the present paper holds true for other countries than the U.S. This feasibility of this venture is severely hampered by the limited availability of narrative accounts for other countries, an issue that would be interesting and important to address in future research. Third, the analysis of the present paper could be extended to examine the impact of debt stabilization, an issue that is bound to be of importance over the coming years as major adjustments need to be adopted following the fiscal expansions that have followed the current recession.

8 References

Auerbach, Alan J., 1989, "Tax Reform and Adjustment Costs: The Impact on Investment and Market Value", *International Economic Review* vol.30(4), 939-962.

Baxter, Marianne, and Robert G. King, 1993, "Fiscal Policy in General Equilibrium", *American Eco-*

nomic Review vol.83(3), 315-334.

Beaudry, Paul, and Franck Portier, 2004, "An Exploration into Pigou's Theory of Cycles", *Journal of Monetary Economics* vol.51(6), 1183-1216.

Beaudry, Paul, and Franck Portier, 2006, "Stock Prices, News, and Economic Fluctuations", *American Economic Review* vol.96(4), 1293-1307.

Beaudry, Paul, and Franck Portier, 2007, "When Can Changes in Expectations Cause Business Cycle Fluctuations in Neo-Classical Settings?", *Journal of Economic Theory* 135(1), 458-77.

Blanchard, Olivier J., 1981, "Output, the Stock Market, and Interest Rates", *American Economic Review* vol.71(1), 132-143.

Blanchard, Olivier J., and Roberto Perotti, 2002, "An Empirical Investigation of the Dynamic Effects of Changes in Government Spending and Taxes on Output", *Quarterly Journal of Economics* vol.117(4), 1329-1368.

Braun, R. Anton, 1994, "Tax Disturbances and Real Economic Activity in the Postwar United States", *Journal of Monetary Economics* 33(3), 441-462.

Burnside, Craig, Martin Eichenbaum and Jonas D. M. Fisher, 2004, "Fiscal Shocks and Their Consequences", *Journal of Economic Theory* 115, 89-117.

Campbell, John Y., and N. Gregory Mankiw, 1989, "Consumption, Income, and Interest Rates: Reinterpreting the Time Series", *NBER Macroeconomics Annual 1989*, edited by O.J. Blanchard and S. Fischer, MIT Press, 185-216.

Christiano, Lawrence, Martin Eichenbaum, and Charles Evans, 2005, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy", *Journal of Political Economy* 113, 1-49.

Cochrane, John, 1994, "Shocks", *Carnegie-Rochester Series on Public Policy* 41, 295-364.

Cogley, Tim, and James M. Nason, 1995, "Output Dynamics in Real-Business-Cycle Models", *American Economic Review*.79(4), 492-511.

Danthine, Jean Pierre, John B. Donaldson and Thore Johnsen, 1998, "Productivity Growth, Consumer Confidence and the Business Cycle", *European Economic Review* 42, 1113-1140.

Den Haan, Wouter J., and Georg Kaltenbrunner, 2006, "Anticipated Growth and Business Cycles in Matching Models", manuscript, University of Amsterdam.

Dupaigne, Martial, Patrick Fève, and Julien Matheron, 2007, "Avoiding Pitfalls in Using Structural VARs to Estimate Economic Models", *Review of Economic Dynamics* 10, 238-255.

Francis, Neville, and Valerie Ramey, 2005, "Is the Technology Driven Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revisited", *Journal of Monetary Economics* vol.52(8), 1379-1399.

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

Hall, Alastair, Atsushi Inoue, James M. Nason, and Barbara Rossi, 2007, "Information Criteria for Impulse Response Function Matching Estimation of DSGE Models", manuscript, Duke University.

Heim, Bradley T., 2007, "The Effect of Tax Rebates on Consumption Expenditures: Evidence from State Tax Rebates", *National Tax Journal*, 685-710.

House, Christopher L., and Matthew D. Shapiro, 2006, "Phased-In Tax Cuts and Economic Activity", *American Economic Review* 96(4), 1835-1849.

House, Christopher L., and Matthew D. Shapiro, 2008, "Temporary Investment Tax Credits: Theory with Evidence from Bonus Depreciation", *American Economic Review* 98(3), 737-68.

Jaimovich, Nir, and Sergio T. Rebelo, 2006, "Can News About the Future Drive the Business Cycle?", manuscript, Northwestern University.

Johnson, David S., Jonathan A. Parker, and Nicholas Souleles, 2006, "Household Expenditure and the Income Tax Rebates of 2001", *American Economic Review* 96(5), 1589-1610.

Kehoe, Patrick J., "How to Advance Theory with Structural VARs: Use the Sims-Cogley-Nason Approach", Research Department Staff Report 379, Federal Reserve Bank of Minneapolis.

King, Robert G., 1989, "Value and Capital - In the Equilibrium Business Cycle Program", RCER working paper no. 207, University of Rochester.

Leeper, Eric M., and Shu-Chun Susan Yang, 2006, "Dynamic Scoring: Alternative Financing Schemes", manuscript, Indiana University.

Leeper, Eric M., Todd B. Walker and Shu-Chun Susan Yang, 2008, "Fiscal Foresight: Analytics and Econometrics", manuscript, Indiana University.

Mankiw, N. Gregory, 2000, "The Savers-Spenders Theory of Fiscal Policy", *American Economic Review* 90, 120-125.

McGrattan, Ellen R., 1994, "The Macroeconomic Effects of Distortionary Taxation", *Journal of Monetary Economics* 33(3), 573-601.

Mendoza, Enrique G., Assaf Razin and Linda L. Tesar, 1994, "Effective Tax Rates in Macroeconomics: Cross-Country Estimates of Tax-Rates of Factor Incomes and Consumption", *Journal of Monetary Economics* 34(3), 297-323.

Mertens, Karel, and Morten O. Ravn, 2009, "Empirical Evidence on the Aggregate Effects of Anticipated and Unanticipated U.S. Tax Policy Shocks", CEPR Discussion Paper no. 7370.

Mountford, Andrew, and Harald Uhlig, 2005, "What are the Effects of Fiscal Policy Shocks?", SFB Discussion Paper no. 2005-039, Humboldt University.

Parker, Jonathan A., 1999, "The Reaction of Household Consumption to Predictable Changes in Social Security Taxes", *American Economic Review* vol.89(4), 959-973.

Perotti, Roberto, 2007, "Estimating the Effects of Fiscal Policy in OECD Countries", forthcoming, **NBER Macroeconomics Annual**.

Poterba, James M., 1988, "Are Consumers Forward Looking? Evidence from Fiscal Experiments", *American Economic Review* vol.78(2), 413-418.

Ramey, Valerie A., 2007, "Identifying Government Spending Shocks: It's All in the Timing", manuscript, University of California, San Diego.

Ramey, Valerie A., and Matthew D. Shapiro, 1998, "Costly Capital Reallocation and the Effects of Government Spending", *Carnegie-Rochester Series on Public Policy* vol.48, 145-194.

Mertens, Karel, and Morten O. Ravn, 2009, "Empirical Evidence on the Aggregate Effects of Anticipated and Unanticipated U.S. Tax Policy Shocks", CEPR Discussion Paper no. 7370.

Romer, Christina D., and David H. Romer, 2007a, "A Narrative Analysis of Postwar Tax Changes", manuscript, University of California, Berkeley.

Romer, Christina D., and David H. Romer, 2007b, "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks", manuscript, University of California, Berkeley.

Romer, Christina D., and David H. Romer, 2008, "Do Tax Cuts Starve the Beast? The Effect of Tax Changes on Government spending", manuscript, University of California, Berkeley.

Souleles, Nicholas S., 1999, "The Response of Household Consumption to Income Tax Refunds", *American Economic Review* vol.89(4), 947-958.

Souleles, Nicholas S., 2002, "Consumer Response to the Reagan Tax Cut", *Journal of Public Economics* vol.85, 99-120.

Taylor, John B., **Macroeconomic Policy in a World Economy**, W.W. Norton: New York.

Yang, Shu-Chun Susan, 2005, "Quantifying Tax Effects Under Policy Foresight", *Journal of Monetary Economics* 52(8), 1557-1168.

9 Appendix 1: Data: Definitions and Sources

Table A.1: Definitions of Variables

Variable	Definition	Source
Output	Nominal GDP divided by its implicit deflator and by population	Bureau of Economic Analysis
Consumption	Consumers nominal expenditure on nondurables divided by its deflator and expenditure on services divided by its deflator and by population	Bureau of Economic Analysis
Durables Purchases	Consumers nominal expenditure on durables divided by its deflator and by population	Bureau of Economic Analysis
Investment	Sum of private sector gross investment divided by its deflator and government investment divided by its deflator. The sum is divided by population.	Bureau of Economic Analysis
Hours worked	Product of hours per worker and civilian non-farm employment divided by population combined with Francis and Ramey (2002) hours worked series.	Bureau of Economic Analysis and Francis and Ramey (2002)
Population	Population above 16 years of age	Bureau of Labor Statistics

10 Appendix 2: Deriving Equation (25)

We solve the model by log-linearizing the first-order conditions around the deterministic steady-state. Due to growth in technology, we first transform the growing variables into variables that are stationary along the balanced growth path. We implement a standard procedure to solve the resulting set of linear stochastic difference equations. The solution of our model can be expressed by the following system of equations:

$$Z_s = \Lambda_Z Z_{s-1} + \Xi_Z W_s \tag{31}$$

$$W_s = \Xi_W W_{s-1} + \Gamma_W \eta_s \tag{32}$$

$$U_s = \Lambda_U Z_{s-1} + \Xi_U W_s \tag{33}$$

where Z_s is the vector of endogenous states, W_s is the vector of exogenous states, η_s is the vector of innovations, and U_s is the vector of controls. The vectors Z_s, W_s, η_s and U_s are given as:

$$\begin{aligned} Z_s &= \left[\widehat{c}_s, \widehat{d}_s, \widehat{v}_s, \widehat{i}_s, \widehat{k}_s\right]', \; W_s = \left[\widehat{\tau}^n_s, \widehat{\tau}^k_s, \widehat{\tau}^n_{s-1}, \widehat{\tau}^k_{s-1}, \widetilde{\xi}^n_{s,1}, \widetilde{\xi}^k_{s,1}, .., \widetilde{\xi}^n_{s,b}, \widetilde{\xi}^k_{s,b}\right]' \\ U_s &= \left[\widehat{n}_s, \widehat{w}_s, \widehat{r}_s, \widehat{u}^v_s, \widehat{u}^k_s, \widehat{y}_s, \widehat{t}_s\right]', \; \eta_s = \left[\begin{array}{cccc} \widetilde{\varepsilon}^n_s & \widetilde{\varepsilon}^k_s & \widetilde{\xi}^n_{s,b} & \widetilde{\xi}^k_{s,b} \end{array}\right]' \end{aligned}$$

where:

$$\begin{aligned} \widehat{x}_s &= \ln\left(\frac{x_s}{x^*}\right), \; x_s = X_s/z_s \text{ for growing variables} \\ \widehat{x}_s &= \ln\left(\frac{X_s}{X^*}\right) \text{ for non-growing variables} \end{aligned}$$

where a '$*$' denotes the steady-state value. Therefore, we derive the solution for the $\widehat{x}_s$ variables; constant terms and trend can be added later. Finally, variables with '$\tilde{}$' are defined in terms of ratios of steady-state values of the relevant tax-variables. The solution for the observables, Y_s can be expressed as:

$$Y_s = \Lambda_Y Z_{s-1} + \Xi_Y W_s \tag{34}$$

where Y_s is a subset of the control and state variables. It follows from equation (31) that:

$$Z_s = (I - \Lambda_Z L)^{-1} \Xi_Z W_s \tag{35}$$

which converges under the condition that the roots of Λ_Z are strictly less than one in modulus. Under the condition that Λ_Y is invertible, equations $(34) - (35)$ imply that

$$Y_s = \Lambda_Y \Lambda_Z \Lambda_Y^{-1} Y_{s-1} + (\Phi_Y + \Lambda_Y \Xi_Z) W_s + \Lambda_Z \Xi_Y W_{s-1} \tag{36}$$

Note that in our application, $\dim(Y) = \dim(Z)$ making invertibility straightforward to check. From equation (32) we have that:

$$W_s = \Gamma_W \eta_s + \Xi_W \Gamma_W \eta_{s-1} + \Xi_W^2 \Gamma_W \eta_{s-2} + ..$$

which converges given that Ξ_W has roots inside the unit circle. Inserting this into equation (36) we find that:

$$\begin{aligned} Y_s &= AY_{s-1} + \sum_{i=0}^{\infty} B_i \eta_{s-i} \quad (37) \\ A &= \Lambda_Y \Lambda_Z \Lambda_Y^{-1},\ B_0 = (\Xi_Y + \Lambda_Y \Xi_Z)\Gamma_W \\ B_i &= [(\Xi_Y + \Lambda_Y \Xi_Z)\Xi_W + \Lambda_Z \Xi_Y] \Xi_W^{i-1} \Gamma_W \text{ for } i \geq 1 \end{aligned}$$

Ξ_W is a dampening matrix given as:

$$\Phi_W = \begin{bmatrix} R_1 & R_s & I_2 & 0_{2,2(b-1)} \\ I_2 & 0_{2,2} & 0_{2,2} & 0_{2,2(b-1)} \\ 0_{2(b-1),2} & 0_{2(b-1),2} & 0_{2(b-1),2} & I_{2(b-1)} \\ 0_{2,2} & 0_{2,2} & 0_{2,2} & 0_{2,2(b-1)} \end{bmatrix},\ R_1 = \begin{bmatrix} \rho_1^n & 0 \\ 0 & \rho_1^k \end{bmatrix},\ R_2 = \begin{bmatrix} \rho_2^n & 0 \\ 0 & \rho_2^k \end{bmatrix}$$

Therefore, the roots of Φ_W are less than or equal to one under the conditions that $|\rho_1^n + \rho_2^n| < 1$ and $|\rho_1^k + \rho_2^k| < 1$. Finally, in order to derive equation (25) note that, $\eta_{s-j} = \begin{bmatrix} \tilde{\varepsilon}_{s-j}^n & \tilde{\varepsilon}_{s-j}^k & \tilde{\xi}_{s-j,b-j}^n & \tilde{\xi}_{s,b-j}^k \end{bmatrix}'$ for $j < b$ while $\eta_{s-j} = \begin{bmatrix} \tilde{\varepsilon}_{s-j}^n & \tilde{\varepsilon}_{s-j}^k & \tilde{\xi}_{s+b-j,0}^n & \tilde{\xi}_{s+b-j,0}^k \end{bmatrix}'$. Thus, the process for the observables can be expressed as:

$$Y_s = AY_{s-1} + \sum_{i=0}^{\infty} B_i^{\varepsilon} \eta_{s-i}^u + \sum_{i=0}^{\infty} B_{i+b}^{\xi} \eta_{s-i}^a + \sum_{i=0}^{b-1} B_i^{\xi} \eta_{s-i}^{\xi} \quad (38)$$

where:

$$\begin{aligned} \eta_{s-i}^{\varepsilon} &= \begin{bmatrix} \tilde{\varepsilon}_s^n & \tilde{\varepsilon}_s^k \end{bmatrix}',\ \eta_{s-i}^a = \begin{bmatrix} \tilde{\xi}_{s-i,0}^n & \tilde{\xi}_{s-i,0}^k \end{bmatrix}',\ \eta_{s-i}^{\xi} = \begin{bmatrix} \tilde{\xi}_{s-j,b-j}^n & \tilde{\xi}_{s,b-j}^k \end{bmatrix}' \\ B_i^{\varepsilon} &= B_i H_{\varepsilon},\ B_i^{\eta} = B_i H_{\eta},\ H_{\varepsilon} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix},\ H_{\xi} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \end{aligned}$$

Table 1: Baseline Calibration

Calibrated parameters			
Parameter	**Value**	Interpretation	Target
$1-\alpha$	0.64	The elasticity of output to hours worked	64% labor share of income
γ_z	1.005	Growth rate of technology	2% annual growth rate of real GDP per capita
$\beta\gamma_z^{1-\sigma}$	$1.03^{-0.25}$	Subjective discount factor	4% annual real interest rate
δ_k	0.025	Steady state depreciation rate of capital	-
δ_v	0.025	Steady state depreciation rate of durables	-
$\Psi_k'(1)$	0.0324	Parameter of capital accumulation	Steady state level of capacity utilization equal to 1
ϑ	0.873	Preference parameter	steady state consumption spending share of durables of 11.9%
ω	249.9	Preference parameter	Steady state hours worked equal to 25%
s_g	0.201	Steady state output share of government spending	-
δ_τ	0.05	Depreciation rate for tax purposes	-
τ^k	0.42	Steady state capital income tax rate	Estimate of average effective capital income tax rate by Medoza, Razin and Tesar (1994)
τ^n	0.26	Steady state labor income tax rate	Estimate of average effective labor income tax rate by Medoza, Razin and Tesar (1994)

Table 2: Estimation Results

	Parameter												
Model	σ	μ	κ	ϕ_k	ψ_k	ϕ_v	ρ_1^n	ρ_2^n	ρ_1^k	ρ_2^k	π_g	ψ	Q
(1) Benchmark	2.572	0.822	0.355	6.581	0.367	4.444	0.999*	0*	1.629	-0.652	-	-	80.41
	(0.102)	(0.017)	(0.040)	(0.219)	(0.035)	(0.185)	-	-	(0.012)	(0.012)			
(2) No durables	2.517	0.767	0.000*	5.302	0.526	-	1.049	-0.050	1.586	-0.629	-	-	107.44
	(0.233)	(0.021)	-	(0.242)	(0.054)		(0.055)	(0.055)	(0.017)	(0.017)			
(3) No habits	3.191	-	0.296	8.449	0.513	4.109	1.037	-0.039	1.704	-0.726	-	-	91.07
	(0.086)		(0.045)	(0.287)	(0.038)	(0.179)	(0.037)	(0.037)	(0.010)	(0.010)			
(4) Fiscal	2.314	0.913	0.437	8.148	0.364	6.510	1.253	-0.254	1.654	-0.684	0.062	-	71.01
feedback rule	(0.074)	(0.006)	(0.062)	(0.299)	(0.037)	(0.341)	(0.052)	(0.052)	(0.012)	(0.012)	(0.003)		
(5) Fixed	1.535	0.870	0.241	2.827	0.017	1.513	0.999*	0*	-	-	-	-	155.14
capital tax	(0.066)	(0.014)	(0.016)	0.139)	(0.002)	(0.088)	-	-					
(6) Fixed	0.376	0.828	0.000*	1.522	4.292	2.639	-	-	1.288	-0.306	-	-	137.27
labor tax	(0.018)	(0.009)	-	(0.037)	(0.072)	(0.135)			(0.013)	(0.013)	-		
(7) Rule-of-	2.863	0.819	0.000*	6.281	0.270	5.863	0.999*	0*	1.626	-0.645	-	0.895	67.13
thumb consumers	(0.088)	(0.013)	-	(0.198)	(0.026)	(0.296)	-	-	(0.010)	(0.010)		(0.005)	

Standard errors are given in the parentheses.

$*$: The parameter was up against the boundary of the permissable parameter set.

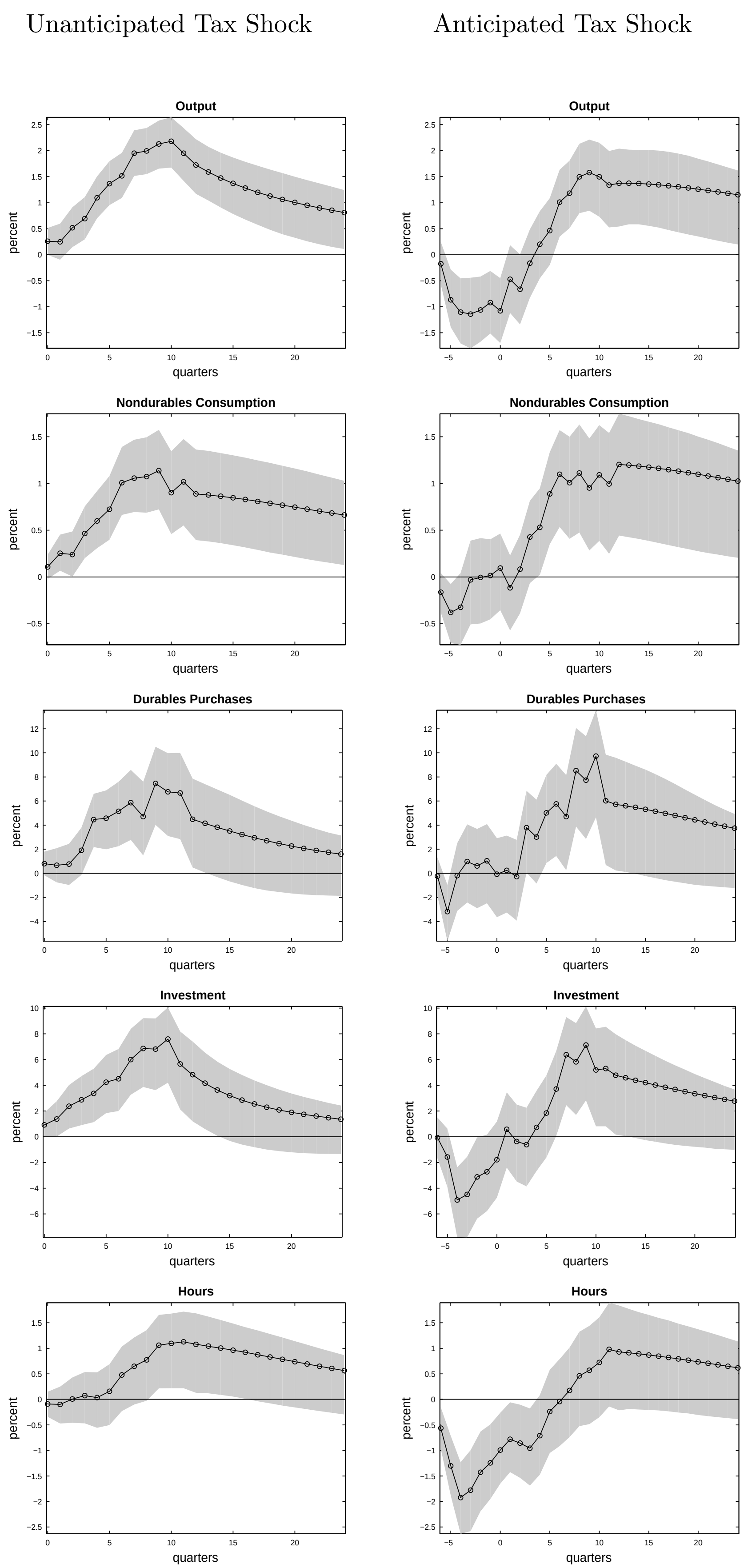

Figure 1: The Responses to Tax Shocks in the U.S.

(anticipated tax shocks are announced at date -6 and implemented at date 0)

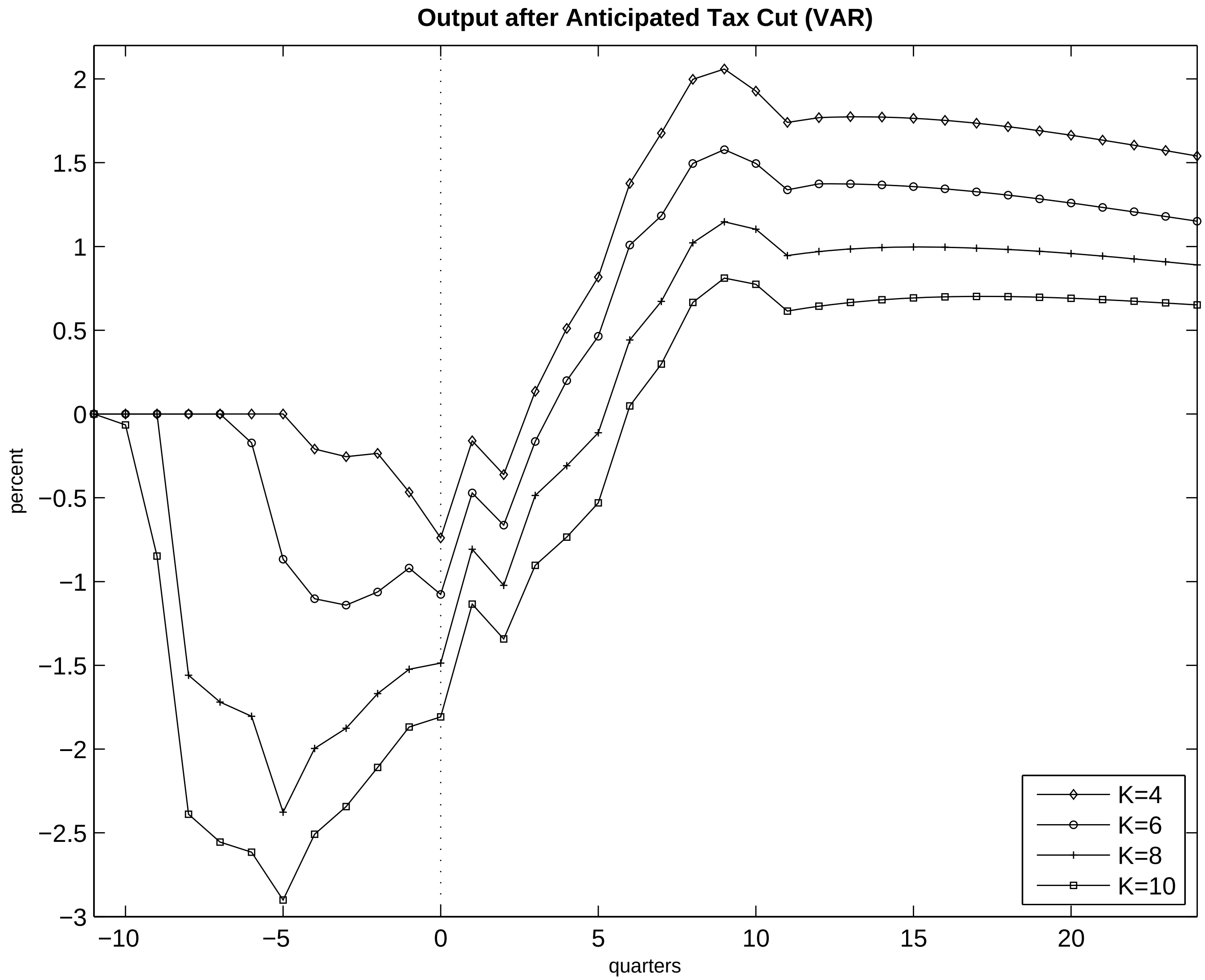

Figure 2: The Effects of Anticipated Tax Cuts for Alternative Anticipation Horizons.

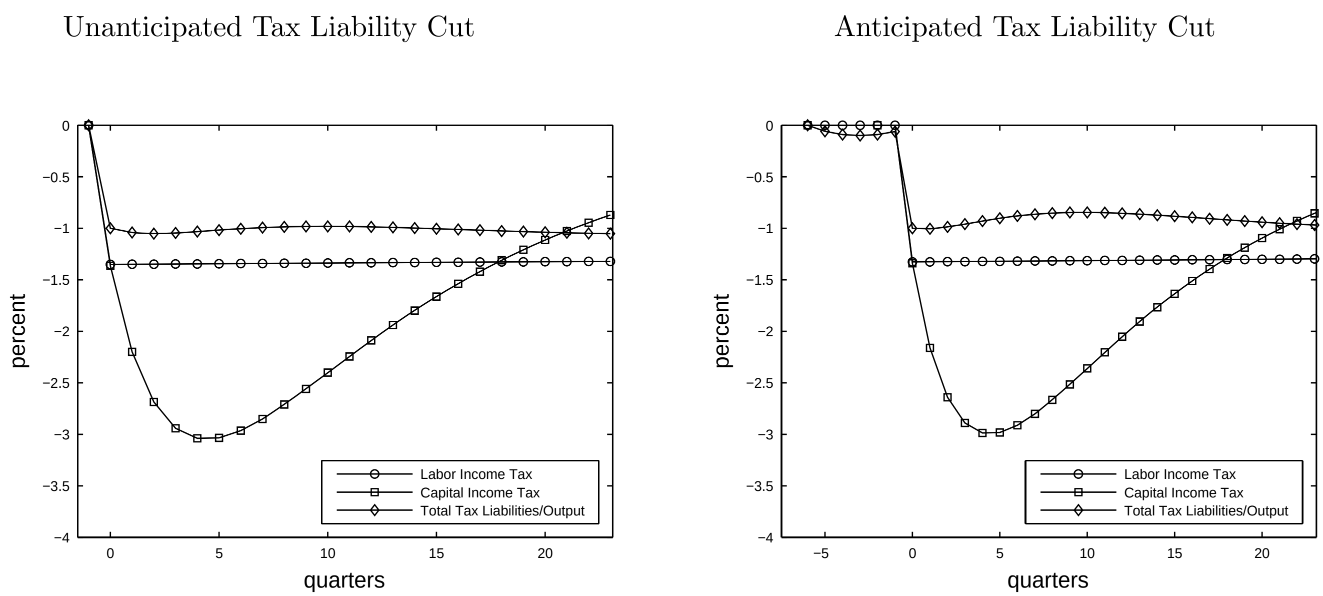

Figure 3: The Dynamics of Taxes in the Model Economy

Unanticipated Tax Shock Anticipated Tax Shock

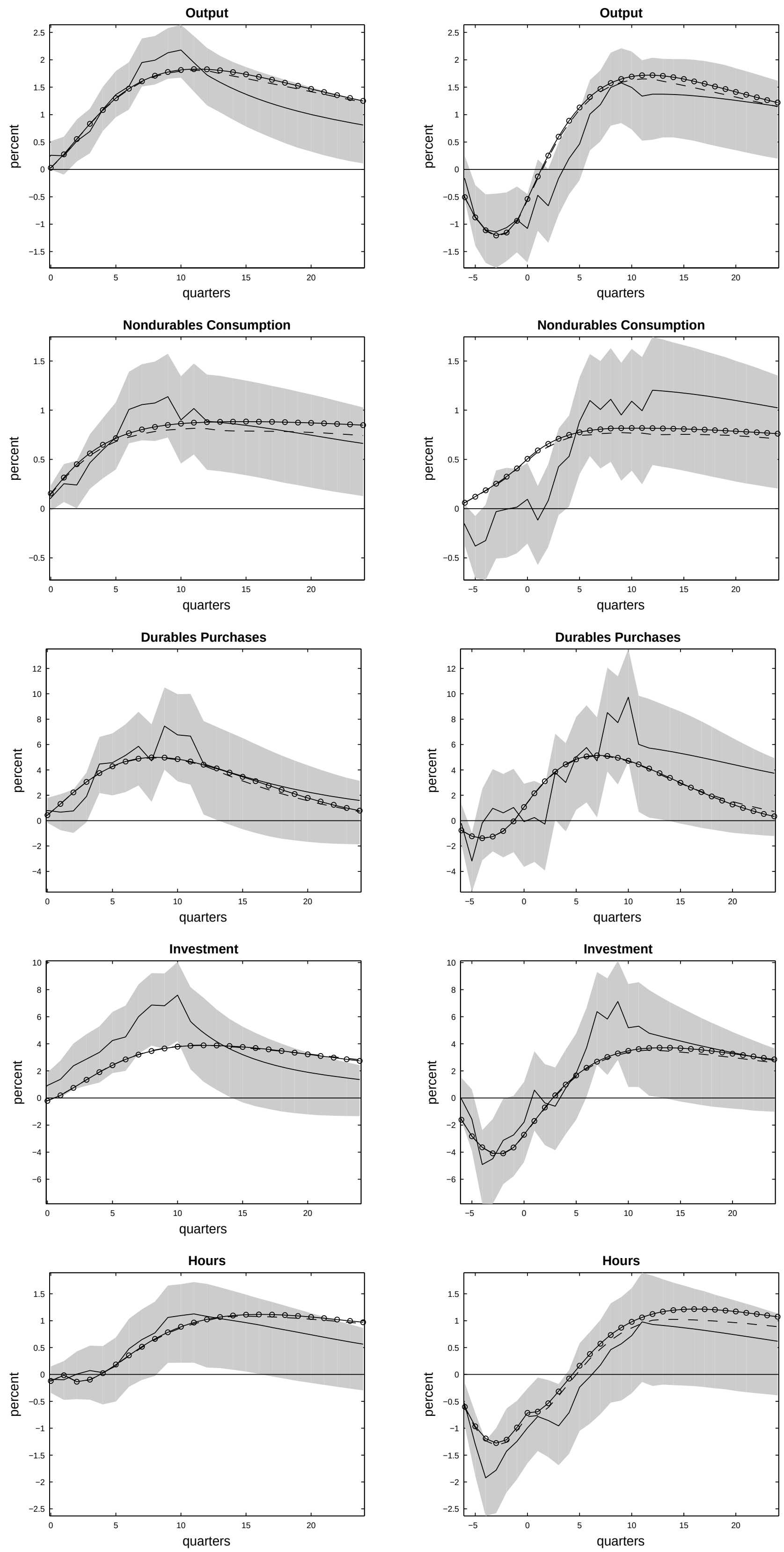

Figure 4: The Impulse Responses of the Benchmark Model (full drawn lines: empirical IRs, dotted lines: the model IRs imposing a VAR, lines with circles: the exact model IRs)

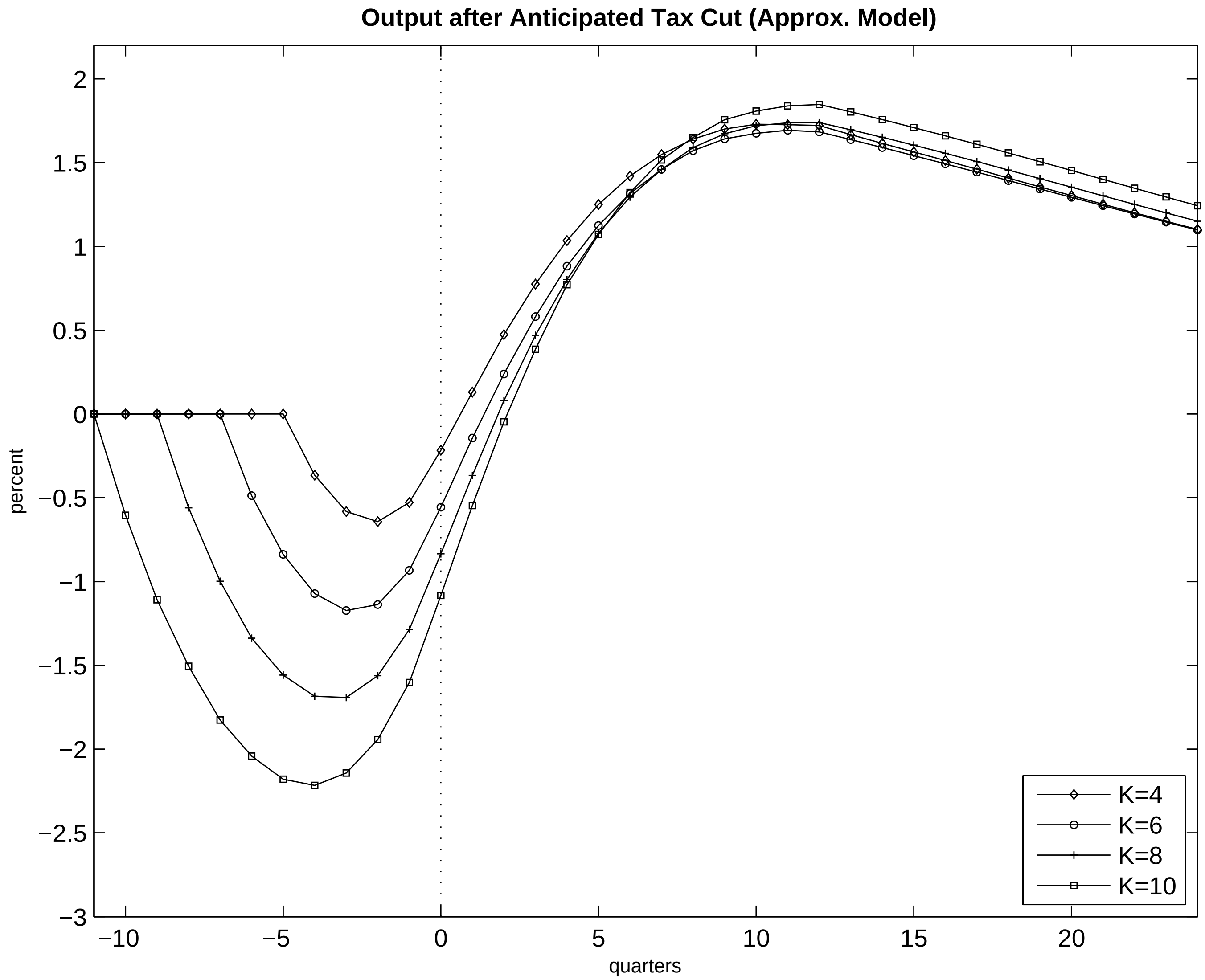

Figure 5: The Dependence of the Dynamics of Output on the Anticipation Horizon in the Model

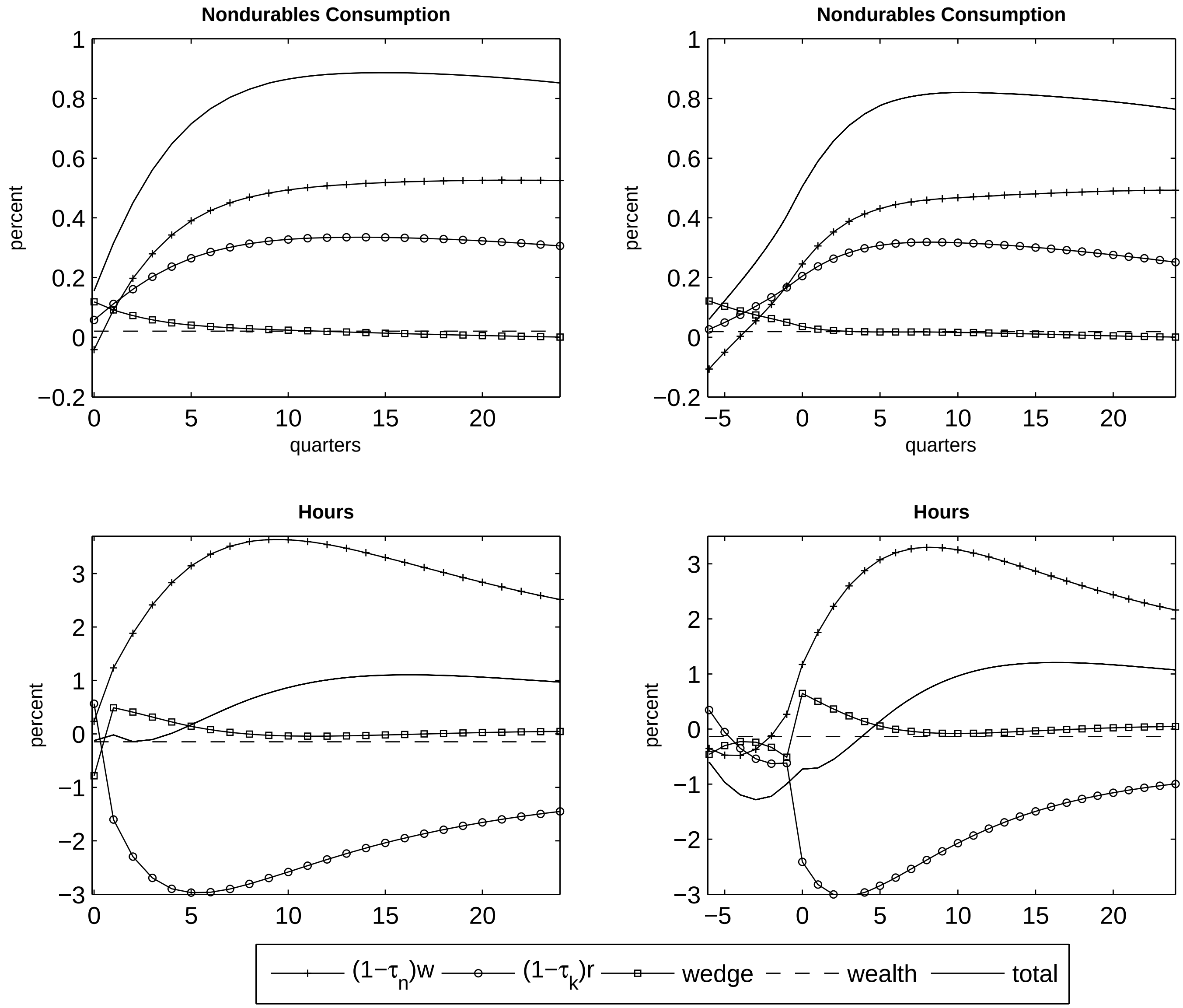

Figure 6. The Decomposition of the Consumption and Hours Response

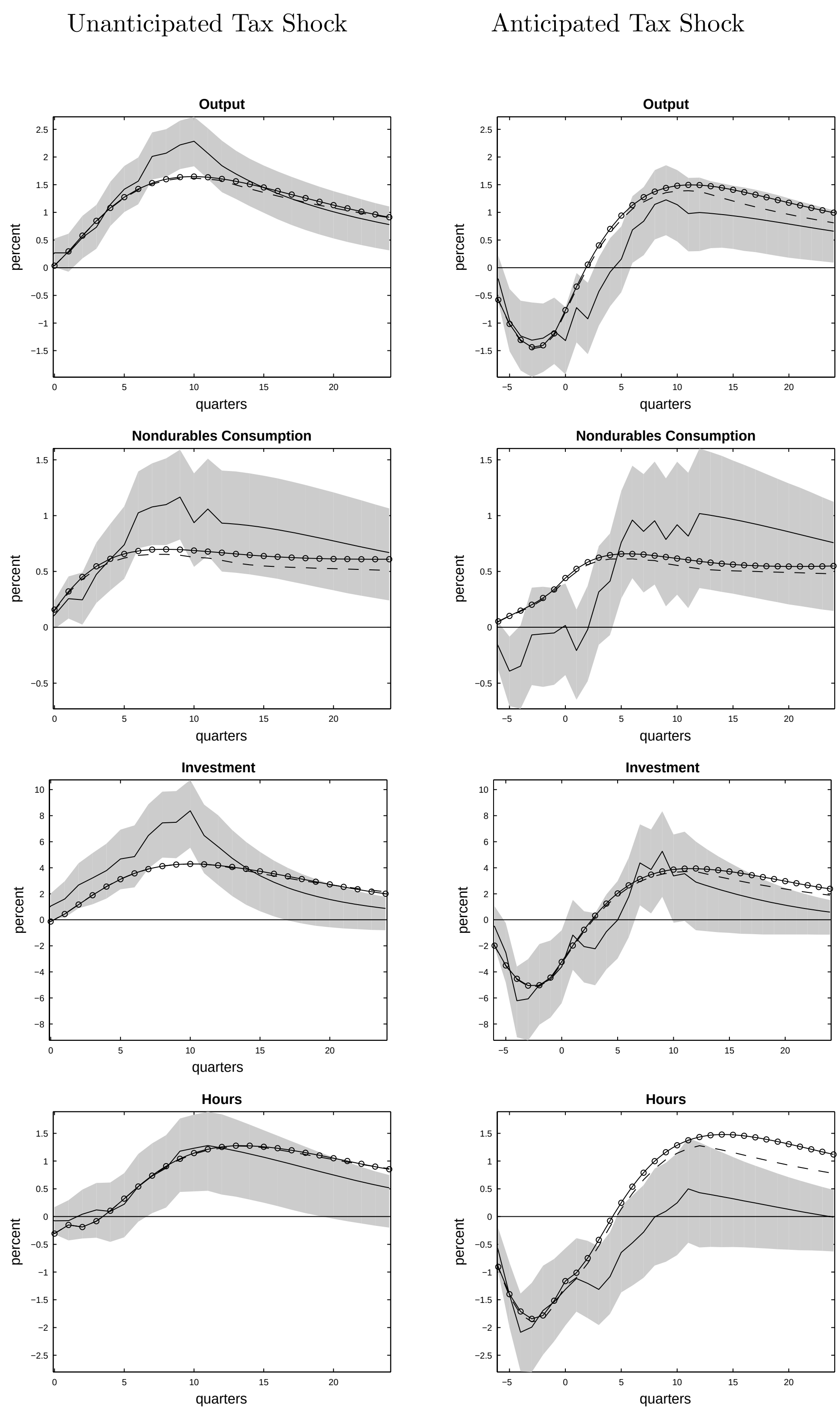

Figure 7: The Model with no Durable Consumption Goods

Unanticipated Tax Shock Anticipated Tax Shock

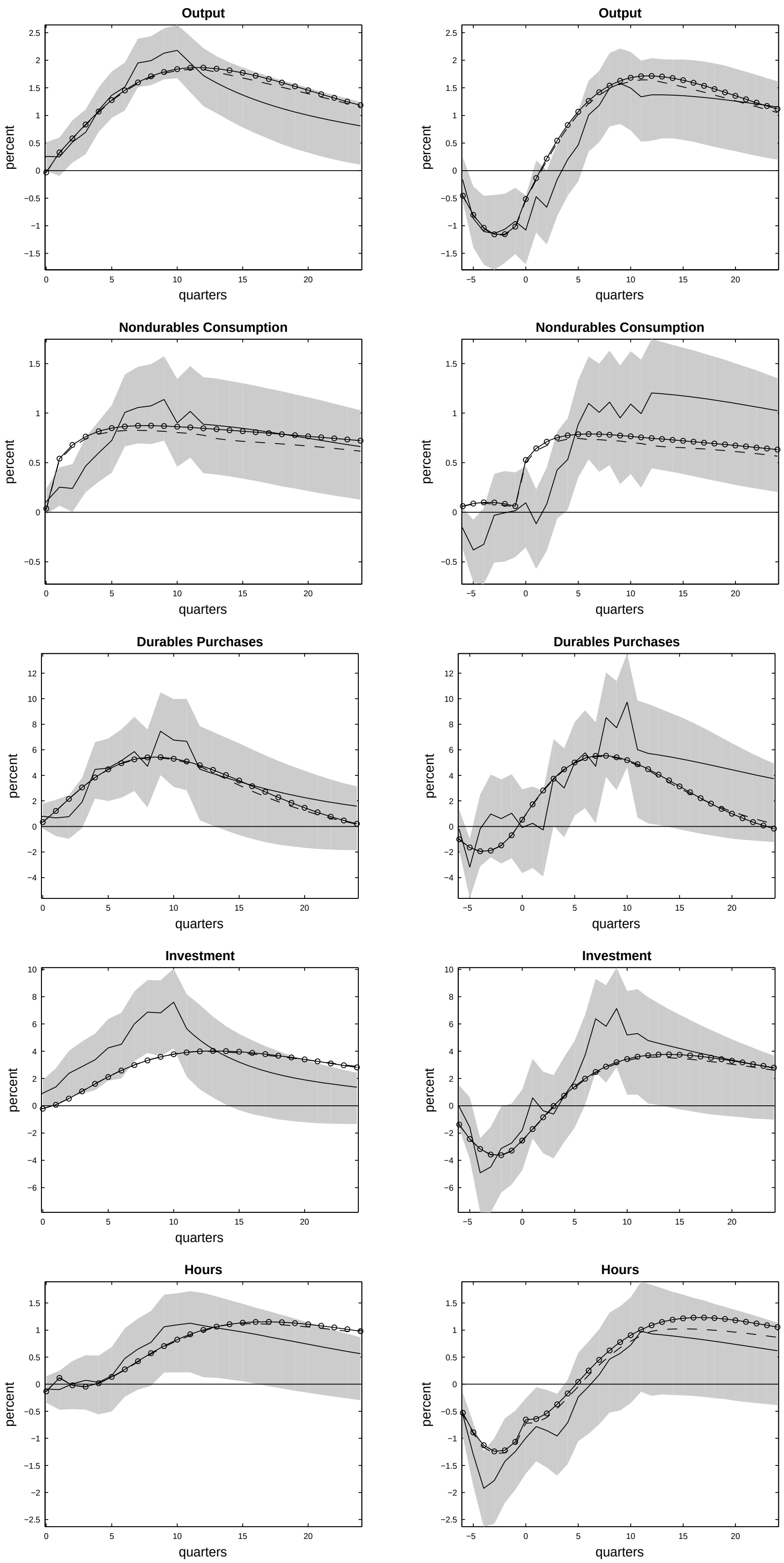

Figure 8: The Model with no Habit Formation

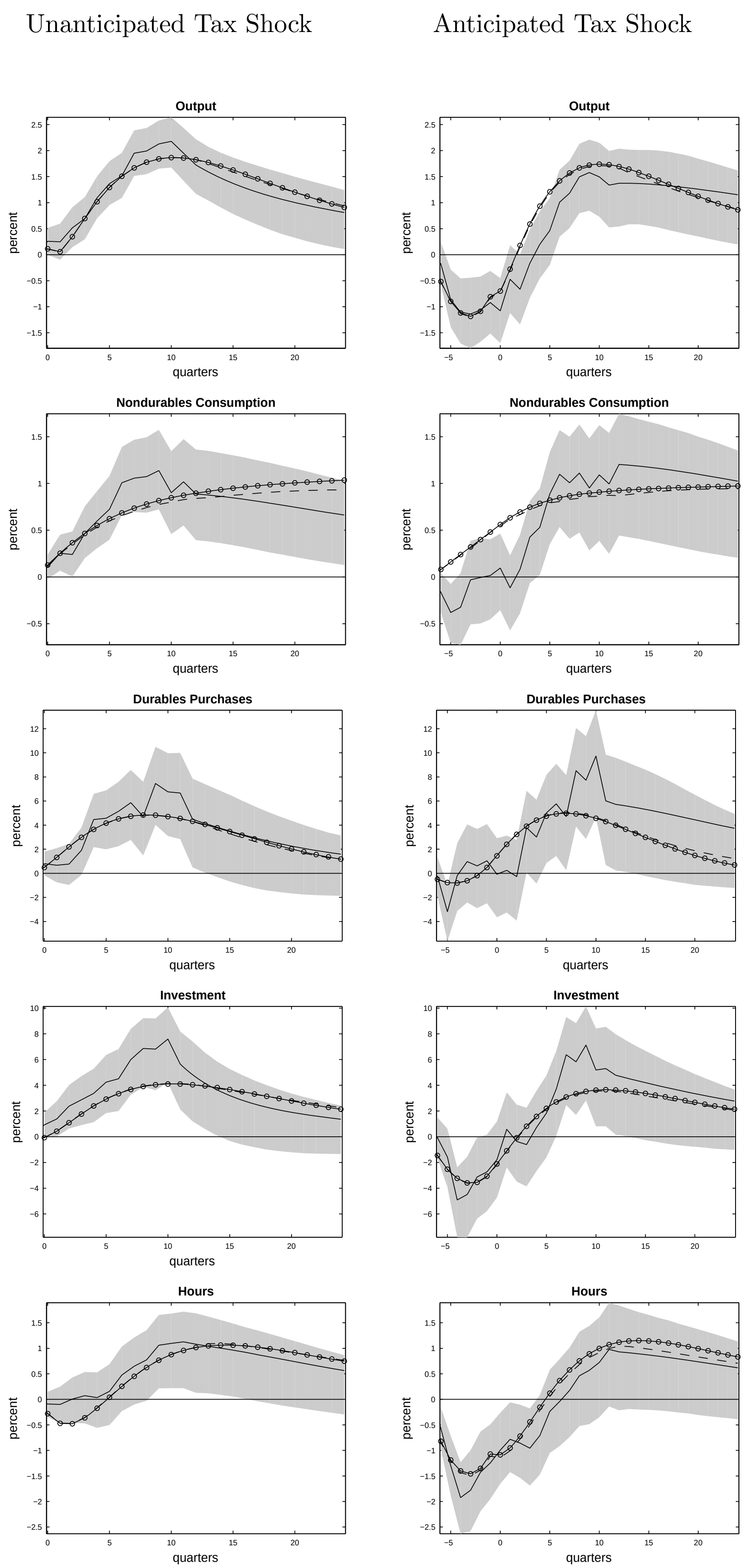

Figure 9: The Model with Endogenous Government Spending

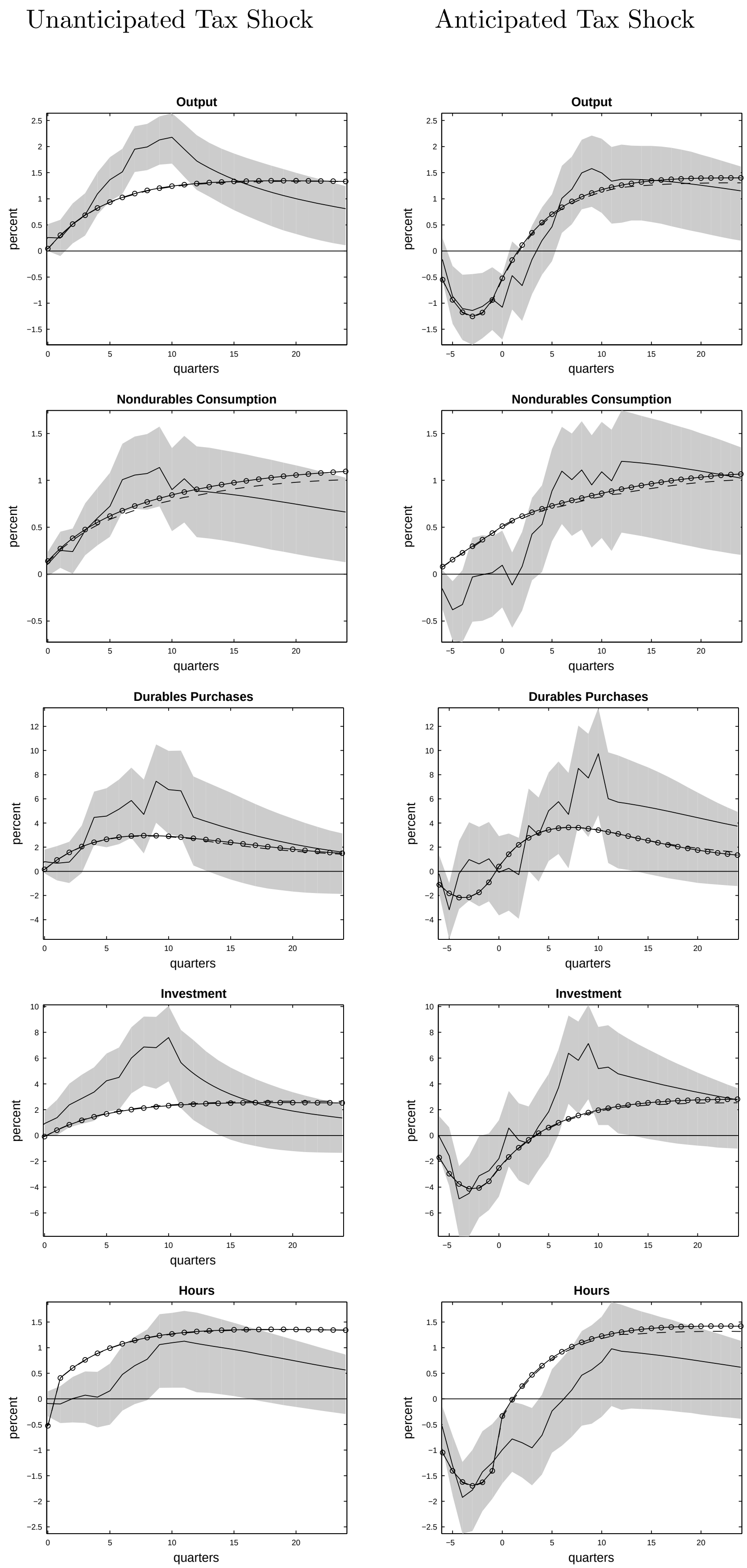

Figure 10: The Model with Constant Capital Income Taxes

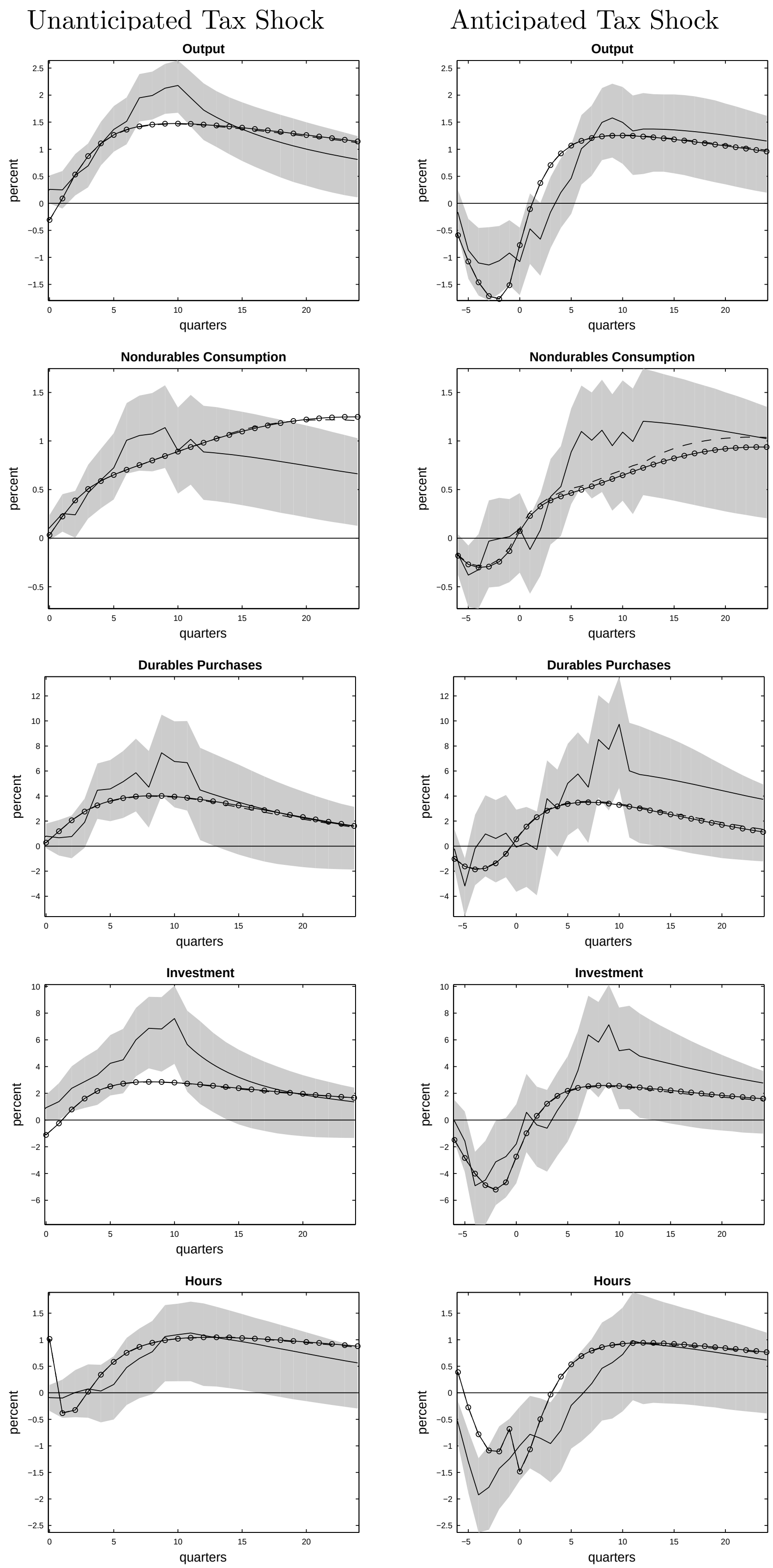

Figure 11: The Model with Constant Labor Income Taxes

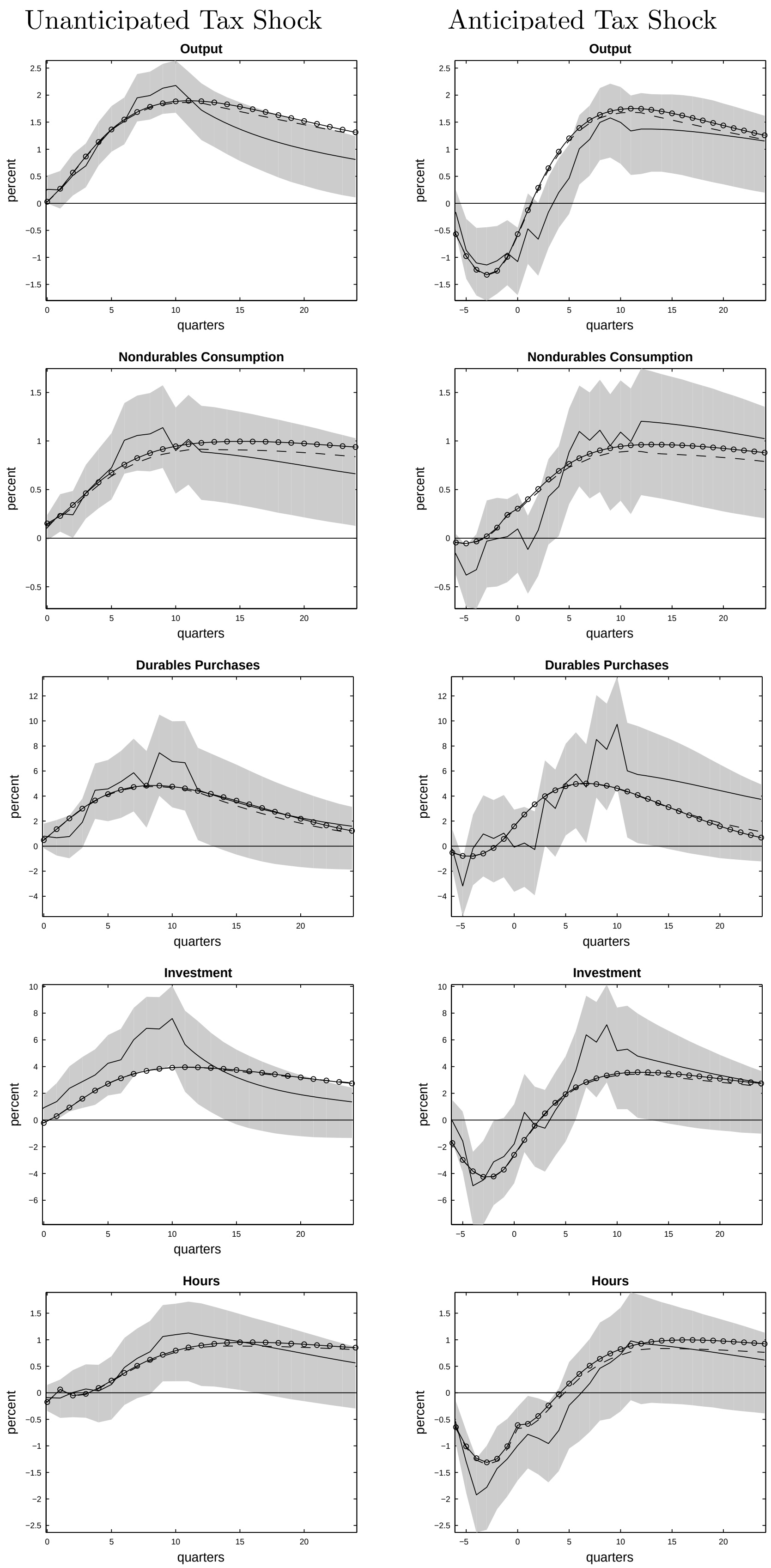

Figure 12: The Model with Rule-of-Thumb Consumers