

Understanding the Aggregate Effects of Anticipated and Unanticipated Tax Policy Shocks*

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Abstract

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. Mertens and Ravn (2009) show that surprise tax cuts have expansionary and persistent effects on output, consumption, investment and hours worked. Prior to their implementation, anticipated tax liability cuts give rise to contractions in output, investment and hours worked. After their implementation, anticipated tax liability cuts lead 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 but we do not rely on preferences with low short run wealth effects on labor supply that have been highlighted in the technology news literature. We also derive Hicksian decompositions of the consumption and labor supply responses and show that substitution effects are key for understanding the impact of tax shocks.

Key words: Fiscal policy, tax liabilities, anticipation effects, structural estimation.

JEL: E20, E32, E62, H30

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1 Introduction

In this paper we ask how changes in taxes affect the economy in a dynamic stochastic general equilibrium model. We contrast a DSGE model with U.S. postwar time-series evidence on the impact of unanticipated and anticipated changes in taxes. The distinction between anticipated and unanticipated tax changes is based upon the use of timing assumptions that we apply to Romer and Romer's (2007, 2008) narrative account of federal U.S. tax liability changes. We show that implemented exogenous tax cuts give rise to a prolonged expansion of the economy while announced but yet not implemented tax cuts are associated with a decline in aggregate activity, investment and hours worked. This evidence on anticipation effects is particularly helpful in evaluating economic theory because it allows us to evaluate the impact of tax "news" shocks.

We follow Mertens and Ravn (2009) and measure tax shocks using Romer and Romer's (2007a) narrative account of legislated federal tax liability changes in the U.S. Based upon official government reports, presidential speeches and Congressional documents, these authors provide a detailed account of all significant federal tax bills during the post-war period. We study the impact of those tax changes that according to Romer and Romer (2007a) can be assumed to be exogenous. We make a simple yet informative classification of tax changes into anticipated and unanticipated tax shocks by using information on the timing differences between the dates of the announcement of tax changes and the implementation of these tax changes. Specifically, tax liability that were to take place within (later than) 90 days of the law being signed by the president are classified as unanticipated (anticipated).

These tax shocks are embedded in a vector autoregressive analysis in order to derive estimates of the dynamic effects of tax policy shocks assuming that the tax liability changes are exogenous. We study the impact of the tax shocks on aggregate output, consumption of nondurables and services, purchases of durable consumption goods, investment, and hours worked. We find that unanticipated tax cuts give rise to significant increases in output, consumption, and investment which peak around 2.5 years after the introduction of the tax cut. There is also a rise in hours worked but it occurs more gradually. 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 and investment 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. There is also a significant pre-implementation drop in hours worked.

In order to evaluate the extent to which the empirical estimates of the impact of changes in federal tax liabilities are consistent with economic theory, we construct a dynamic stochastic general equilibrium model in which variations in distortionary tax rates give rise to changes in tax liabilities. We allow for variations both in labor income tax rates and in capital income tax rates and for unanticipated as well as anticipated tax shocks. Key parameters are estimated by matching the theoretical impulse response functions of the observables with those estimated in the U.S. data.

We show that the DSGE model accounts very well for the shapes and sizes of the response of the observables to implemented changes in tax liabilities and for the announcement effects that we estimate in the U.S. data. Interestingly, we find that the anticipation effects can be accounted for using a model with standard preferences and without liquidity constraints. These results are interesting 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 taxes lead to a pre-implementation decline in aggregate activity and that this effect can be accounted for by standard preference models. On the other hand, consistently with the technology news literature, we find that adjustment costs and variable capacity utilization are pertinent to account for the impact of tax shocks. The importance of adjustment costs shows the relevance of Auerbach’s (1989) analysis of the impact of anticipated tax changes on aggregate investment.

Another important insight relates to the anticipation effects on consumption of nondurables and services. Our empirical results complement earlier studies of the consumption impact of 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 Heim (2007) studies data from the Consumer Expenditure Survey (CEX) and tests for announcement effects of state tax

¹Poterba (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.

rebates. He finds no significant household consumption response to rebate announcements. Parker (1999) and Souleles (1999, 2002) also study CEX data and test whether household consumption responds to actual changes in taxes when these were known in advance of their implementation.² They find significant impacts of tax changes at the implementation dates. These results are often interpreted as evidence of lack of forward looking behavior, the presence of binding liquidity constraints or other aspects that prevent consumers from adjusting consumption plans to predictable changes in income. Our empirical results are consistent with this earlier literature, but we show that the lack of a strong response of consumption to announcements about future taxes, and a significant consumption response to actual changes in taxes when these were pre-announced, are not necessarily inconsistent with a rational expectations DSGE model that abstracts from liquidity constraints.

We also extend the literature in terms of understanding the impact of tax changes. First, we show that, in contrast to e.g. Yang (2005), that the impact of anticipated changes in capital and labor income taxes are not fundamentally different. Assuming an anticipation horizon of 4 quarters, Yang (2005) 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 show that these results do not hold through in an economy with a more rigorous modeling of production and preference structures and with reasonable degrees of adjustment costs. In the face of such aspects, the anticipation effects of capital income and labor income tax changes are quite similar.

Secondly, in order to understand how the economy responds to changes in taxes, 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”. The latter arises because of adjustment costs. The responses of hours worked and consumption to changes in taxes are dominated by the substitution effects while the wealth effects are very small. We show that the key to understanding why hours worked respond sluggishly to surprise changes in taxes are 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

²Parker (1999) examines the impact of Social Security changes during the 1980’s while Souleles (2002) investigates the Reagan tax cut of the early 1980’s.

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). It is this empirical evidence that we shall later examine whether the DSGE model can account for.

2.1 Identification

We identify tax shocks using Romer and Romer's (2007a, 2008) narrative account of federal U.S. tax policy acts. A key advantage of the narrative approach is that it allows one to make a distinction between anticipated and unanticipated tax shocks based on timing assumptions. Romer and Romer's (2007a) base their account on analyses of official government documents, presidential speeches, and Congressional documents. They identify 49 significant legislated federal tax acts in the period 1947-2006 and a total of 104 separate changes in tax liabilities. Some of these tax liability changes were introduced to address concerns about the state of the economy or motivated by the need to finance of government spending plans while other changes in tax liabilities were exogenous in nature. We focus on the tax liability changes that Romer and Romer (2007a) classify as exogenous. This corresponds to 70 tax liability changes in total.

The tax data allows us to introduce a natural timing based distinction between unanticipated and anticipated tax shocks. For each tax liability change we define an announcement date which corresponds to the date at which the tax legislation became law, i.e. when it was signed by the President, and an implementation date which is the date at which, according to the legislation, the tax liability changes were to be introduced. We define a tax liability change as anticipated if the difference between these two dates exceeds 90 days. We use a 90 days window because it strikes a balance between robustness of the results to the date within a quarter that a tax change became law, and the ability to measure anticipation effects.

Based on our use of a 90 day window, 38 of the tax liability changes are anticipated and 32 are defined

as surprise tax shocks.³ The median implementation lag in the data is 6 quarters. This relatively long median anticipation lag implies that identification schemes of tax policy shocks based on the existence of decision lags are not easily implemented, see Blanchard and Perotti (2002).

The impact of tax shocks are estimated from the following regression model:

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

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.⁴ τ_t^u and $\tau_{t,i}^a$ are the tax shocks. The former of these corresponds to the unanticipated tax shocks which are measured as the implied dollar change in tax liabilities in percentages 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, $\tau_{t,i}^a$ measures 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.⁵ The regression model then implies that the current realization of X_t depends 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 terms 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:

$$X_t = \left[y_t, \quad c_t, \quad d_t, \quad i_t, \quad h_t \right]'$$

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

³Alternatively, Lustig, Sleet and Yeltekin (2007) use information on “abnormal” return to measure expected government defense spending changes.

⁴The results are robust to allowing for a break in the trend in 1973:2, see Ramey and Shapiro (1998) and Burnside, Eichenbaum and Fisher (2004). The results are also robust to first differencing the X_t vector.

⁵In order to measure these we assume that pre-announced tax shocks enters agents’ information sets at the earliest M quarters before their implementation. We set this maximum lag equal to 3 years.

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 (??) 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 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 thereafter in the case of anticipated shocks.

The left column of Figure 1 reports the impact of an unanticipated tax liability cut. The decrease in taxes sets off a major expansion in the economy and the effects on the endogenous variables are very persistent and follow hump shaped dynamics. Investment and consumer durables purchases display by far the largest elasticity to the cut in tax liabilities. Upon impact, investment increases by around 1 percent point 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 gradually 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 and peak at 1.16 percent above trend 12 quarters after the tax shock. The impact on consumption of nondurables and services is qualitatively different from the other variables. In particular, the increase in private consumption stabilizes at a new higher level already 6 quarters after the tax cut. The peak response of consumption of nondurables and services corresponds to a 1.07 percent rise above trend.

Our estimates of the impact of unanticipated tax liability changes are similar to the results of Romer and Romer (2007b) who find large and protracted responses to changes in tax liabilities. The shape of the responses are similar to the impact of a “basic government revenue shock” estimated by Mountford and Uhlig (2005). Relative to the estimates of Blanchard and Perotti (2002), the response of output to tax liability shocks occurs more gradually than the output response to the tax shock that these authors identify with a structural VAR approach. However, our results are similar to theirs in terms of the persistence of the output response.

The right column of Figure 1 shows 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. The most dramatic result pertains to investment which 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 by up to 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 peaking at 1.9 percent below trend 4 quarters before the tax cut. The response of consumers’ purchases of durable goods to the announcement of a future tax cut is not very precisely estimated. 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. Romer and Romer (2007b) examine whether the expected present value of future not yet implemented tax changes affect the current level of key macroeconomic aggregates. They find that the pre-implementation response is oppositely signed of the post-implementation response. They conclude that there is mild evidence in favor of expectational effects. The advantage of our approach is that we analyze the full path of the adjustment of the economy from when the tax liability changes are announced until several quarters after its implementation. Mountford and Uhlig (2005) identify the impact of a pre-announced government revenue shock using an “ex-post” identification approach based on sign restrictions. In particular, they examine the impact of an government tax revenue shock which takes place one year out in the future with the restriction that the shock is orthogonal to “business cycle” shocks and monetary policy shocks. In contrast to us, they find that a pre-announced revenue increase is associated with a pre-implementation increase in output while their estimates of the impact on investment agree with our results. Their identification strategy is fundamentally different from ours since they do not include currently available information about future tax liability changes. For that reason, it is perhaps not surprising that they find a different impact of pre-announced fiscal policy shocks.⁶

Our results 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

⁶Moreover, as discussed by Leeper, Walker and Yang (2008), their identification is applied to government tax revenue rather than to tax liabilities relative to GDP. Thus, to the extent that tax revenue is derived from income taxation, the pre-implementation increase in output that they estimate in response to a future tax revenue increase implies that tax rates must adjust during the pre-implementation period.

not hinge on particular tax acts. In particular, the anticipation effects and the effects of implemented tax changes are roughly the same when we remove the Kennedy tax act, the Reagan tax acts or the Bush 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 (2009a) 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 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 , 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, 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. The sensitivity of the anticipation effects to the assumed length of the maximum anticipation horizon reconciles our findings with those of Blanchard and Perotti (2002) who find little evidence of anticipation effects but allow only for a one quarter anticipation horizon. Our results indicate that for longer, and empirically relevant, anticipation horizons, there are significant pre-implementation effects of pre-announced tax liability changes.

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, see e.g. 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.⁷

3.1 The Model

There is a large number of identical, infinitely lived households. The representative household's preferences are given by:

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

where E_t denotes 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, and n_t denotes hours worked. The parameter $\kappa \geq 0$ is the inverse of the Frisch elasticity of labor supply. 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 enters on the disutility of work is introduced to allow for a balanced growth path. The variable x_t is defined as:

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

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 consumer durables stock.

The representative household maximizes the expected present value of its utility stream subject to the following set of constraints:

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

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

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

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. We assume that $\Phi_v'' \geq 0$ and that $\Phi_v(\gamma_z) = \Phi_v'(\gamma_z) = 0$. This implies that adjustment costs are zero along the balanced growth path.

Equation (5) is the law of motion for the stock of "market" capital, K_t . Households rent out this capital stock to the production sector of the economy. We allow for variable capital utilization, u_t^k , and

⁷See House and Shapiro (2006), Leeper and Yang, 2006, Ramey, 2007, and Yang, 2005, for DSGE analyses of fiscal policy with anticipation effects.

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 $\Psi_k (u_t^k)$ denotes the effect of variations in the capital utilization rate on the effective rate of depreciation of the capital stock. We assume that $\Phi_k'', \Psi_k', \Psi_k'' \geq 0$, and 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. Note that equations (4) – (5) assume that adjustment costs arise when the growth rate of investment deviates from its steady-state level, see Christiano, Eichenbaum and Evans (2005).

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. $(1 - \tau_t^k) r_t u_t^k K_t$ 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. We assume that depreciation allowances are given as:

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

where δ_τ denotes the rate of depreciation for tax purposes. As Auerbach (1989) we allow for the possibility that δ_τ may differ from δ_k .

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

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

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

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

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

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

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

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

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:

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

(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), $q_{k,t}$, is given as the expected present value of the stream of future net rental rates corrected for the depreciation of capital over time. 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 corrected for 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. When the current net-return exceeds its shadow value, the utilization rate rises above its trend value.

There is a continuum of identical competitive firms. The production function is given by the following Cobb-Douglas specification:

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

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:

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

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

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:

$$G_t + T_t = \tau_t^n W_t n_t + \tau_t^k r_t u_t^k K_t - \Lambda_t \quad (19)$$

We assume that G_t is given by the following process:

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

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 government spending. Allowing for endogenous variations in government debt would deliver exactly the same results.⁸

The two 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 are assumed to evolve according to the stochastic processes:

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

$$\tau_t^k = (1 - \rho_1^k - \rho_2^k) \tau^k + \rho_1^k \tau_{t-1}^k + \rho_2^k \tau_{t-2}^k + \varepsilon_t^k + \xi_{t,0}^k \quad (21)$$

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 $|\rho_1^k + \rho_2^k| < 1$. We assume that the innovations to the tax rates are iid with zero mean, $\varepsilon_t \sim iid(0, \Omega_\varepsilon)$ and $\xi_t \sim iid(0, \Omega_\xi)$ where $\varepsilon_t = [\varepsilon_t^n, \varepsilon_t^k]'$ and $\xi_t = [\xi_t^n, \xi_t^k]'$. 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:

$$C_t + D_t + I_t + G_t \leq Y_t \quad (22)$$

Changes in the tax rates, τ_t^n and τ_t^k , affect the economy through wealth and substitution effects. There are two sources of wealth effects. First, if the change in distortionary taxes affect government spending, the corresponding change in the present value of the tax stream gives rise to a wealth effect.

⁸For 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 constant are identical. This follows from Ricardian equivalence.

Secondly, changes in distortionary taxes alter households' expected lifetime utility 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 . The higher is 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, see equations (8) – (9). 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 raises after-tax wages which increases labor supply and consumption. Moreover, intertemporal substitution gives rise to an increasing path of labor supply. To see this, combine equations (9) and (10):

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

where $R_{k,t+1} = [(1 - \tau_{t+1}^k) r_{t+1} u_{t+1}^k + q_{k,t+1} (1 - \delta_k - \Psi_k(u_{t+1}^k))] / q_{k,t}$ is the expected net return on market capital. Thus, a cut in taxes calls for an increase in current labor supply relative to future labor supply if τ_t^n falls relatively to τ_{t+1}^n while a decrease in τ_{t+1}^n relative to τ_t^n calls for a decrease in current labor supply relative to future labor supply.⁹ 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:

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

where $\hat{i}_t = \ln \left(\frac{I_t/z_t}{I/z} \right)$ denotes the percentage deviation of “detrended” investment from its steady-state value and $\hat{q}_{k,t}$ and $\hat{\Gamma}_t$ 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

⁹Due to the AR(2) structure of the tax processes, an innovation to taxes may initially lead to an increasing or a decreasing tax profile.

increase in after-tax real wages, labor supply drops during the pre-implementation period. 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 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 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. Thus, in order to evaluate its quantitative performance, we formally estimate the structural parameters in the next section. This is a necessary step since the model introduces a number of variables that are not easily calibrated on the basis of pre-existing evidence/

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. The vector of parameters that we calibrate 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 are 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 baseline scenario 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 output 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 Θ_1 .

The vector of parameters that we estimate formally is given by $\Theta_2 = [\sigma, \mu, \kappa, \phi_v, \phi_k, \psi_v, \psi_k, \rho_1^n, \rho_2^n, \rho_1^k, \rho_2^k]'$ 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 this vector 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:

$$\begin{aligned}
Y_s &= \tilde{A} + \tilde{B}s + \tilde{C}Y_{s-1} + \sum_{i=0}^{\infty} \tilde{D}_i \eta_{s-i}^u + \sum_{i=0}^{\infty} \tilde{F}_{i+b} \eta_{s-i}^a + \sum_{i=0}^{b-1} \tilde{G}_i \eta_{s-i}^a \\
\eta_{s-i}^\varepsilon &= \left[\frac{\varepsilon_s^n}{\tau^n}, \frac{\varepsilon_s^k}{\tau^k} \right]', \eta_{s-i}^a = \left[\frac{\xi_{s-i,0}^n}{\tau^n}, \frac{\xi_{s-i,0}^k}{\tau^k} \right]', \eta_{s-i}^\xi = \left[\frac{\xi_{s-j,b-j}^n}{\tau^n}, \frac{\xi_{s,b-j}^k}{\tau^k} \right]'
\end{aligned} \tag{25}$$

where η_{s-i}^ε , η_{s-i}^a , and η_{s-i}^ξ 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) constrains $C(L)$ to be a first-order lag polynomial, but allows $D(L)$ and $F(L)$ to be infinite order lag polynomials. In Section 2.3 we adopted the first of these restrictions but obviously not the latter. Appendix 2 shows that the matrices \tilde{D}_i and \tilde{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.¹⁰ We estimate Θ_2 as the vector of variables that solves the following minimization problem:

$$\hat{\Theta}_2 = \arg \min_{\Theta_2} \left[\left(\hat{\Lambda}_T^d - \Lambda_T^m(\Theta_2|\Theta_1) \right)' \Sigma_d^{-1} \left(\hat{\Lambda}_T^d - \Lambda_T^m(\Theta_2|\Theta_1) \right) \right] \tag{26}$$

where $\hat{\Lambda}_T^d$ denotes the vectorized empirical responses that we aim at matching, $\Lambda_T^m(\Theta_2|\Theta_1)$ 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:

¹⁰See 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.

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 $j = 1, \dots, 100$ denotes the j 'th replication.
2. Add a small amount of measurement error to $X^j (\Theta_2|\Theta_1)$. Let $\tilde{X}^j (\Theta_2|\Theta_1)$ denote the resulting artificial samples of X .
3. For each artificial dataset estimate the following model:

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

where $\tilde{\tau}_t^{u,j}$ and $\tilde{\tau}_{t+1,t}^{a,j}$ 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, of 2.572. This estimate is within the range of values usually considered plausible.¹¹ 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 microeconomic 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 implies by our estimates are 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 and that the wealth effect of changes in tax rates is born mostly by labor supply.

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 also find that there is a significant 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 significant impact on the gross depreciation rate of the capital stock.¹²

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. This implies that the largest root of the dampening matrix Ξ_W 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

¹¹Due to habit formation, however, this parameter should not be interpreted as the inverse of the intertemporal elasticity of substitution in consumption.

¹²We 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.

two tax rates. We also show the dynamics of total tax liabilities relative to GDP in response to changes in tax rates. The initial change in the two tax rates is such that the implied change in tax liabilities at the implementation date corresponds to a one percent drop. In the case of an unanticipated tax liability cut, the resulting initial change in the two tax rates corresponds to a 1.3 percentage point drop in the two distortionary tax rates. The labor income tax rate thereafter remains close to this 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.

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 7 shows the response to a one percent surprise tax liability (relative to GDP) cut while the right column shows the impact of a one percent anticipated tax liability cut.

The model can account 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 few quarters.¹³ 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.

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 nondurable and services basically do not respond to announcements of future tax changes. The model presented in Section 3 implies a steady but small increase in consumption of nondurable 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 4.1 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 irrelevant 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 is 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

¹³Notice that we are estimating many fewer parameters (10) than the number of moments (240). Thus, there is absolutely no guarantee that the model can account for the empirical impulse responses.

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 is the implementation lag (for moderate values of b).¹⁴

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, $\hat{\Theta}_1$, 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 $(\bar{C}, \bar{V}, \bar{n})$ with associated after-tax factor prices $((1 - \bar{\tau}^n) \bar{w}, (1 - \bar{\tau}^k) \bar{r})$ 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 $((1 - \tau_t^n) w_t, (1 - \tau_t^k) r_t)_{t=0}^{\infty}$ 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, $U(C^1, V^1, n^1) = U_1$. We compute three substitution effects which consist of a relative 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.¹⁵ 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 $((1 - \tau_t^n) w_t, (1 - \bar{\tau}^k) \bar{r})_{t=0}^{\infty}$ and

¹⁴These 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.

¹⁵In 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.

$((1 - \bar{\tau}^n) \bar{w}, (1 - \tau_t^k) r_t)_{t=0}^\infty$, respectively, under the constraint that present discounted utility associated with these allocations are 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 $\pi_G = 0$, wealth effects arise solely because lower factor income taxes temporarily reduce the inefficiency induced by distortionary taxes. Quantitatively, the wealth effects are very small (but positive for consumption and negative for hours worked) regardless of whether the change in tax liabilities is anticipated or unanticipated.

In the case of 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.¹⁶ 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 initial limited labor supply response. In the case of the unanticipated tax cut, the wedge effect (which is small) initially stimulates consumption due to the rise in adjustment costs induced by the desire to increase the capital stock (and the consumer durables stock) in response to the tax cut.

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 depress labor supply 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

¹⁶Real wages keep on rising for a while also because the capital stock is increasing gradually.

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 some importance of habit formation and of consumer durables for the lack of a solid consumption response to anticipated changes in tax liabilities. We examine this in some more detail by eliminating these two aspects from the model. The second row of Table 2 reports the parameter estimates of Θ_2 when we exclude consumer durables from the model.¹⁷ 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 baseline 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, $\hat{\sigma}$. 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. Consumption now rises counterfactually fast in response to the implementation of tax cuts. On the other hand, when

¹⁷In 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.

we eliminate habits, the model is consistent with the complete absence of a consumption response to announcements of future tax cuts. Effectively, while habit forming households spread the consumption response to changes over taxes over the pre-implementation period, households with time-separable preferences are willing to sacrifice relative low consumption in the pre-implementation period for high consumption thereafter.

5.2 Fiscal Feedback

The benchmark model assumes that government consumption grows at a constant rate. Allowing instead changes in distortionary taxes to affect government consumption introduces an additional wealth effect because the present value of households' total tax payments change. Given the importance of wealth effects, we therefore 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 gives rise to 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 larger in this model than in the benchmark model. Quantitatively, however, the impact is small and the implied impulse responses (see Figure 9) are almost identical to the benchmark model.¹⁸ 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.¹⁹ Thus, the first-order impact of changes in distortionary tax rates dominate 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) identifies movements in taxes that are unrelated to the fiscal authority's current information set. In principle, this 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 4-variable version of the

¹⁸This 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.

¹⁹Results are available upon request.

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.

5.3 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 at 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 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. Importantly, the model does not rely upon the absence of wealth effects on labor supply that earlier contributions to the news literature have stressed. Instead, 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.

7 References

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8 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 non-durables divided by its deflator and expenditure on services divided by its deflator and by population	Bureau of Economic Analysis
Durables	Consumers nominal expenditure on durables	Bureau of Economic Analysis
Purchases	divided by its deflator and by population	
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

9 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:

$$Z_s = \Lambda_Z Z_{s-1} + \Xi_Z W_s \quad (28)$$

$$W_s = \Xi_W W_{s-1} + \Gamma_W \eta_s \quad (29)$$

$$U_s = \Lambda_U Z_{s-1} + \Xi_U W_s \quad (30)$$

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:

$$\begin{aligned} Z_s &= [\hat{c}_s, \hat{d}_s, \hat{v}_s, \hat{i}_s, \hat{k}_s]' , \quad W_s = [\hat{\tau}_s^n, \hat{\tau}_s^k, \hat{\tau}_{s-1}^n, \hat{\tau}_{s-1}^k, \tilde{\xi}_{s,1}^n, \tilde{\xi}_{s,1}^k, \dots, \tilde{\xi}_{s,b}^n, \tilde{\xi}_{s,b}^k]' \\ U_s &= [\hat{n}_s, \hat{w}_s, \hat{r}_s, \hat{u}_s^v, \hat{u}_s^k, \hat{y}_s, \hat{t}_s]' , \quad \eta_s = \begin{bmatrix} \tilde{\varepsilon}_s^n & \tilde{\varepsilon}_s^k & \tilde{\xi}_{s,b}^n & \tilde{\xi}_{s,b}^k \end{bmatrix}' \end{aligned}$$

where:

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

where a ‘*’ denotes the steady-state value. Therefore, we derive the solution for the \hat{x}_s variables; constant terms and trend can be added later. Finally, variables with ‘ $\tilde{\cdot}$ ’ 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:

$$Y_s = \Lambda_Y Z_{s-1} + \Xi_Y W_s \quad (31)$$

where Y_s is a subset of the control and state variables. It follows from equation (28) that:

$$Z_s = (I - \Lambda_Z L)^{-1} \Xi_Z W_s \quad (32)$$

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 (31) – (32) imply that

$$Y_s = \Lambda_Y \Lambda_Z \Lambda_Y^{-1} Y_{s-1} + (\Phi_Y + \Lambda_Y \Xi_Z) W_s + \Lambda_Z \Xi_Y W_{s-1} \quad (33)$$

Note that in our application, $\dim(Y) = \dim(Z)$ making invertibility straightforward to check. From equation (29) we have that:

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

which converges given that Ξ_W has roots inside the unit circle. Inserting this into equation (33) we find that:

$$\begin{aligned} Y_s &= AY_{s-1} + \sum_{i=0}^{\infty} B_i \eta_{s-i} \\ A &= \Lambda_Y \Lambda_Z \Lambda_Y^{-1}, \quad B_0 = (\Xi_Y + \Lambda_Y \Xi_Z) \Gamma_W \\ B_i &= [(\Xi_Y + \Lambda_Y \Xi_Z) \Xi_W + \Lambda_Z \Xi_Y] \Xi_W^{i-1} \Gamma_W \text{ for } i \geq 1 \end{aligned} \quad (34)$$

Ξ_W is a dampening matrix given as:

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

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:

$$Y_s = AY_{s-1} + \sum_{i=0}^{\infty} B_i^\varepsilon \eta_{s-i}^\varepsilon + \sum_{i=0}^{\infty} B_{i+b}^\xi \eta_{s-i}^a + \sum_{i=0}^{b-1} B_i^\xi \eta_{s-i}^\xi \quad (35)$$

where:

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

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

Model	Parameter											
	σ	μ	κ	ϕ_k	ψ_k	ϕ_v	ρ_1^n	ρ_2^n	ρ_1^k	ρ_2^k	π_g	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 feedback rule	2.314	0.913	0.437	8.148	0.364	6.510	1.253	-0.254	1.654	-0.684	0.062	71.008
	(0.074)	(0.006)	(0.062)	(0.299)	(0.037)	(0.341)	(0.052)	(0.052)	(0.012)	(0.012)	(0.003)	
(5) Fixed capital tax	1.535	0.870	0.241	2.827	0.017	1.513	0.999*	0*	-	-	-	155.14
	(0.066)	(0.014)	(0.016)	0.139)	(0.002)	(0.088)	-	-				
(6) Fixed labor tax	0.376	0.828	0.000*	1.522	4.292	2.639	-	-	1.288	-0.306	-	137.27
	(0.018)	(0.009)	-	(0.037)	(0.072)	(0.135)			(0.013)	(0.013)		

Standard errors are given in the parentheses.

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

Unanticipated Tax Shock

Anticipated Tax Shock

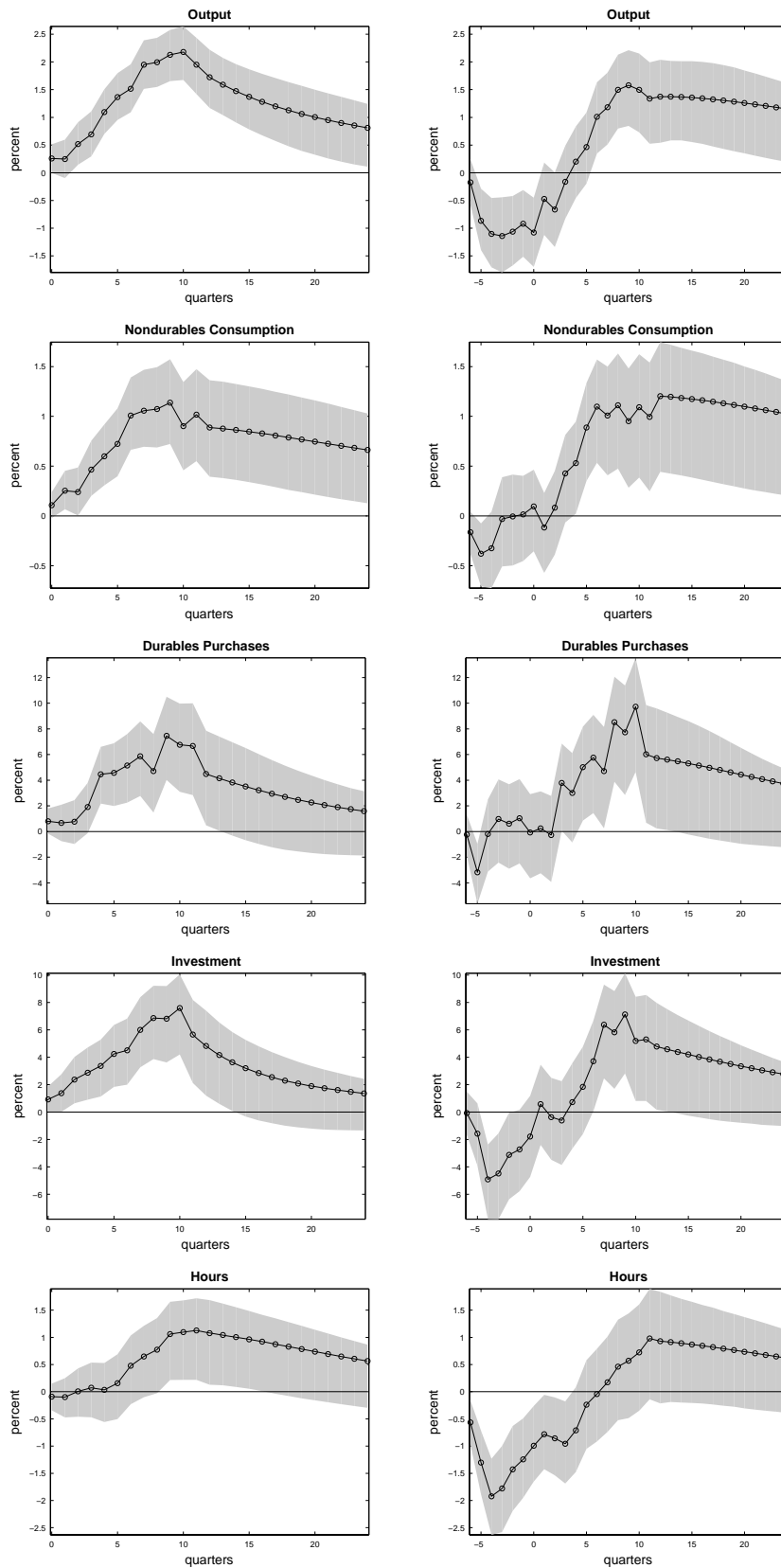


Figure 1: The Responses to Tax Shocks in the U.S.

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

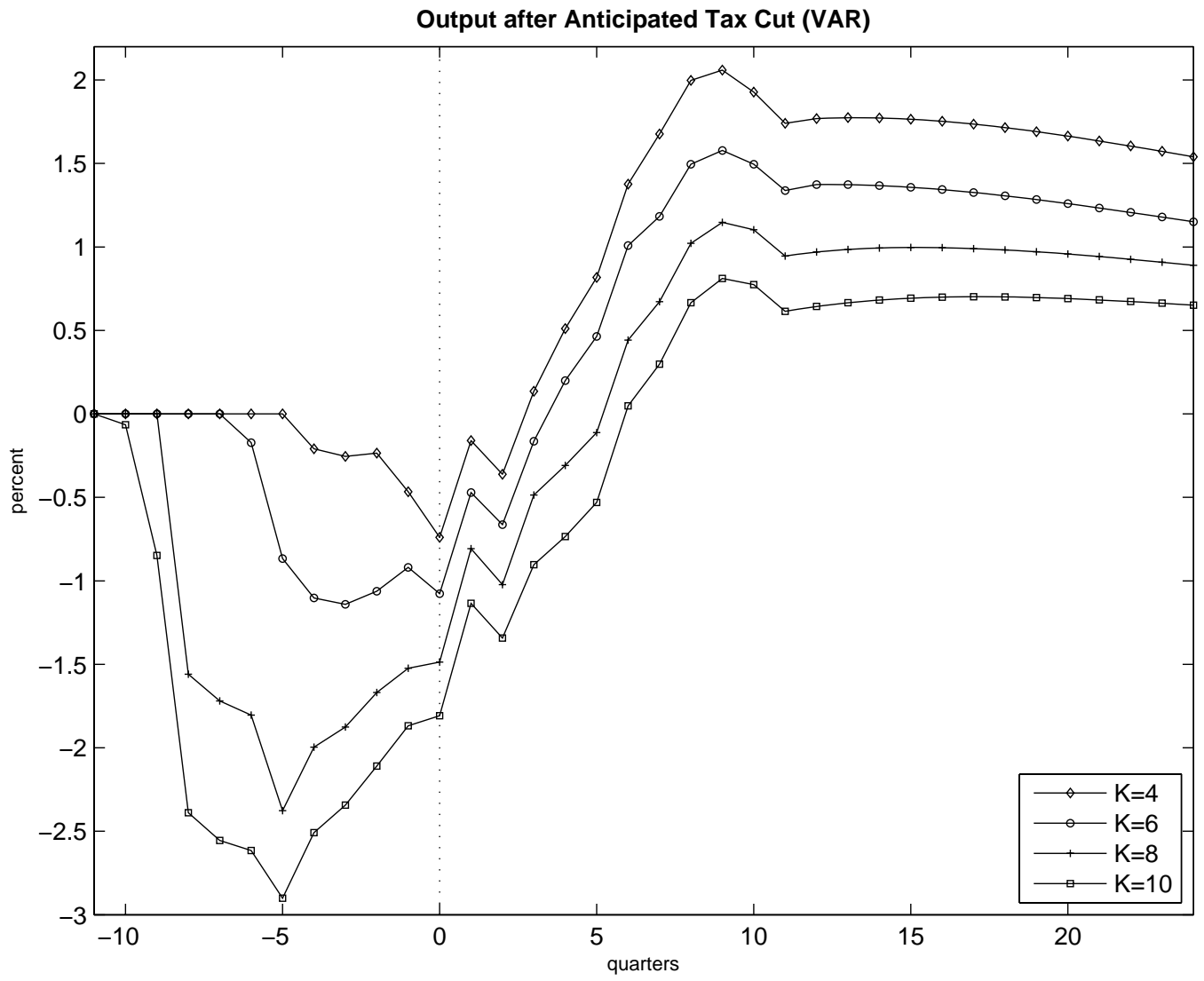
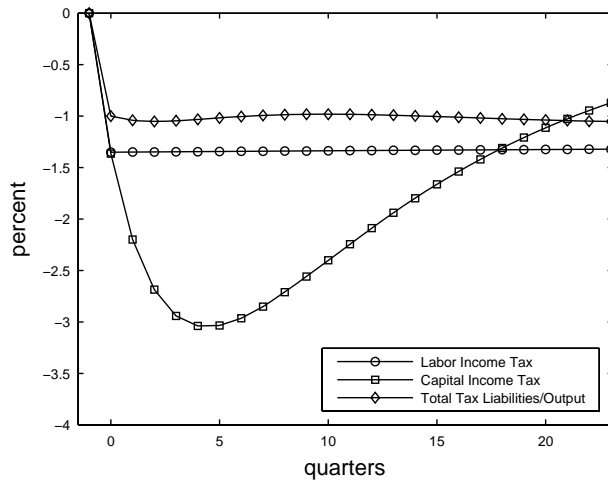


Figure 2: The Effects of Anticipated Tax Cuts for Alternative Anticipation Horizons.

Unanticipated Tax Liability Cut



Anticipated Tax Liability Cut

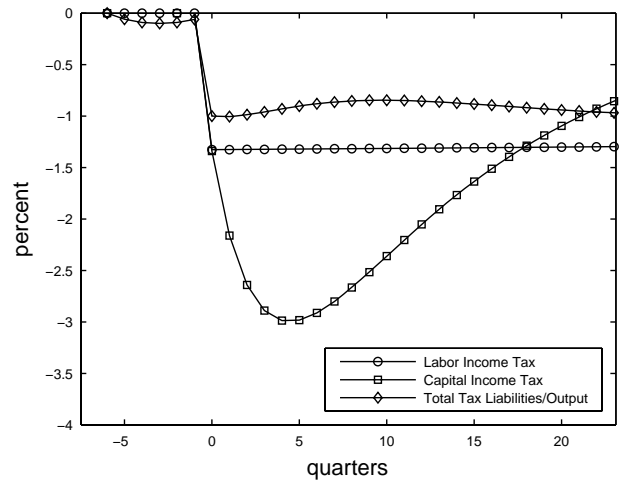


Figure 3: The Dynamics of Taxes in the Model Economy

Unanticipated Tax Shock

Anticipated Tax Shock

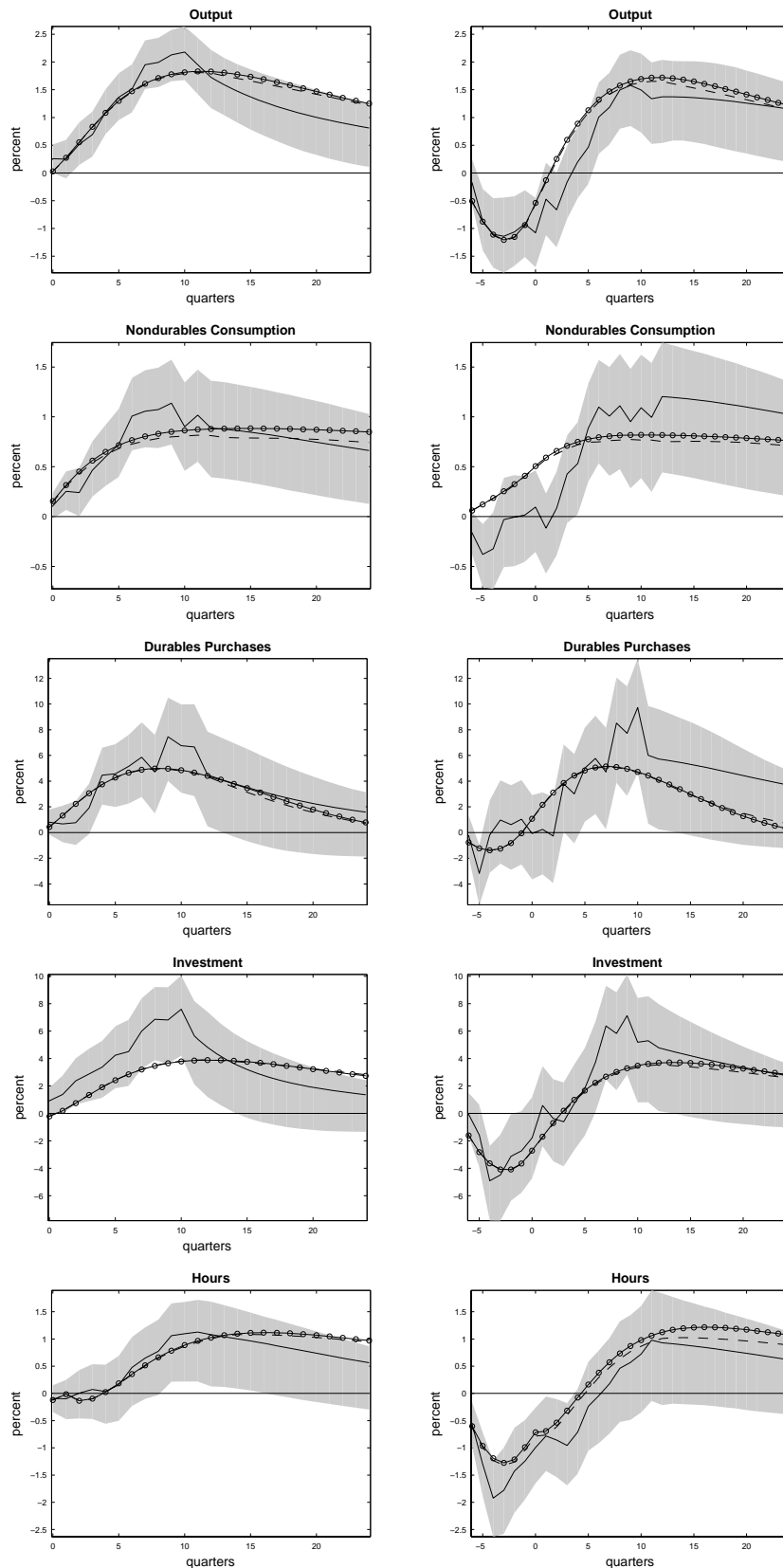


Figure 4: The Impulse Responses of the Benchmark Model (full drawn lines: empirical IRs, dotted lines: the model IRs imposing a VAR, lines with circles: the exact model IRs)

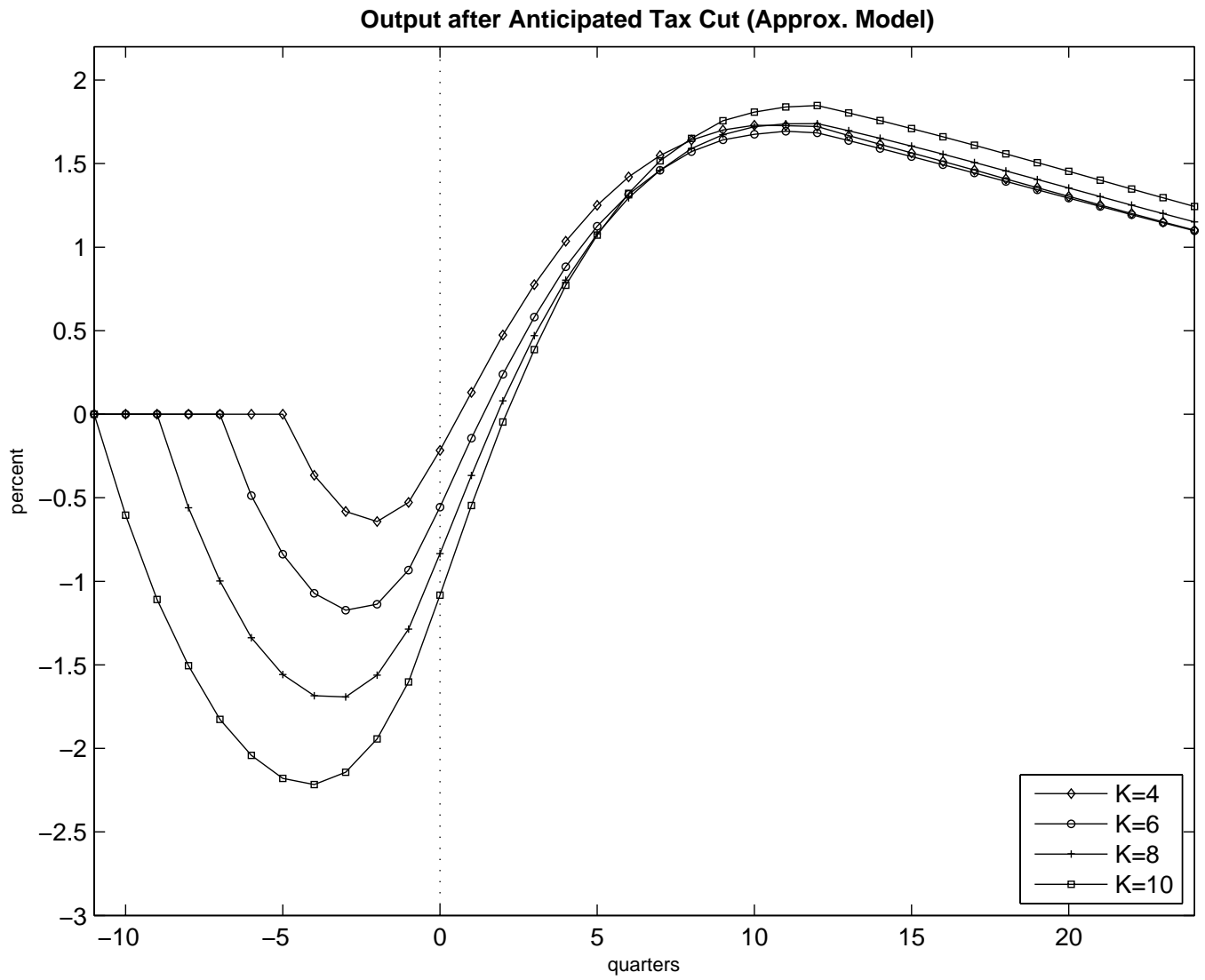


Figure 5: The Dependence of the Dynamics of Output on the Anticipation Horizon in the Model

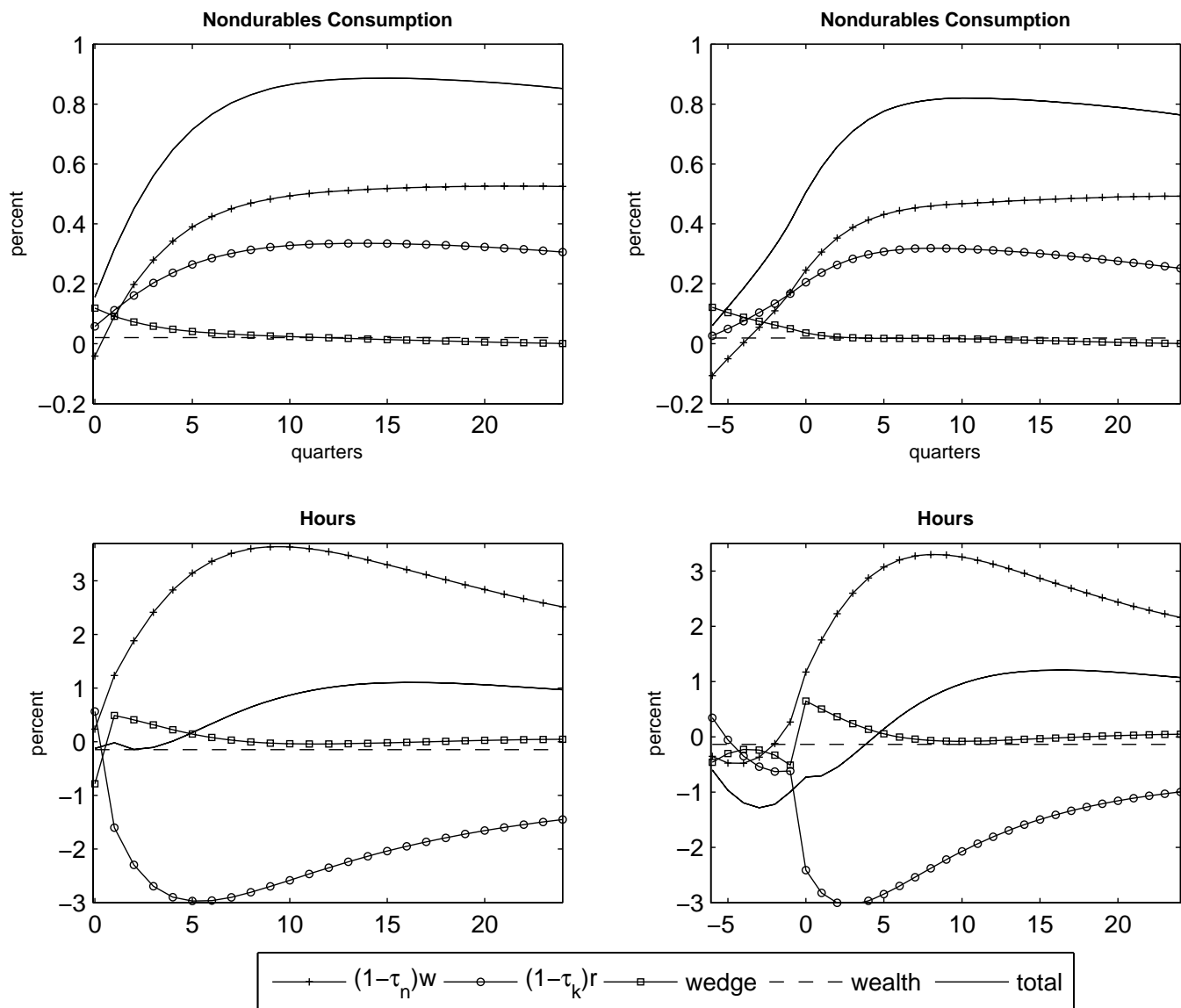


Figure 6. The Decomposition of the Consumption and Hours Response

Unanticipated Tax Shock

Anticipated Tax Shock

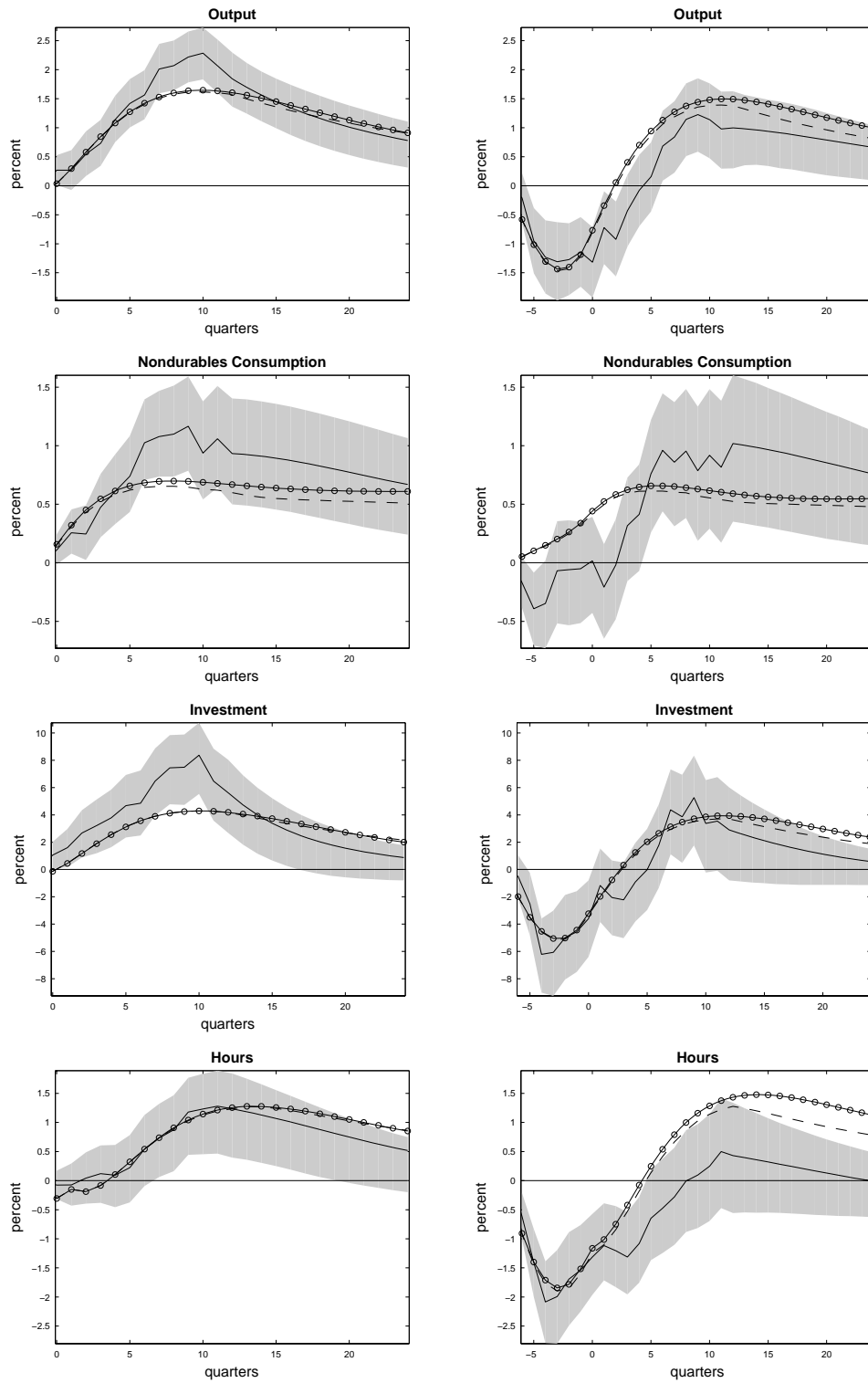
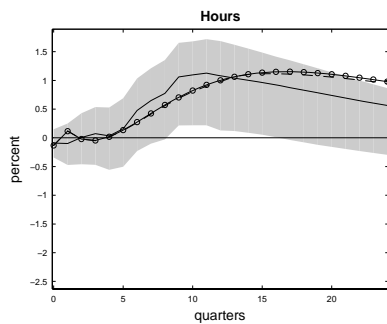
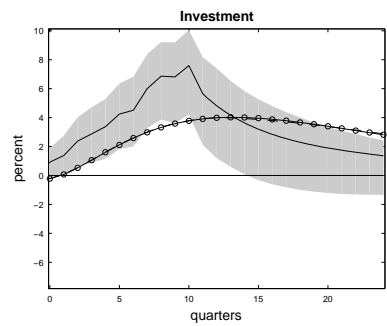
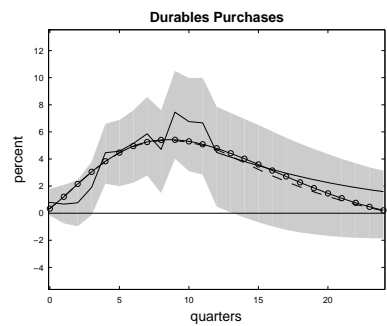
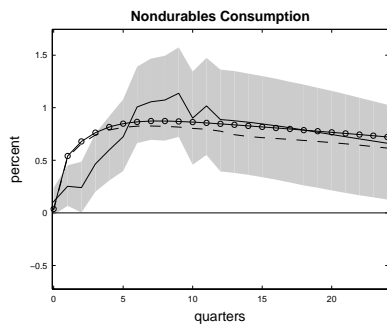
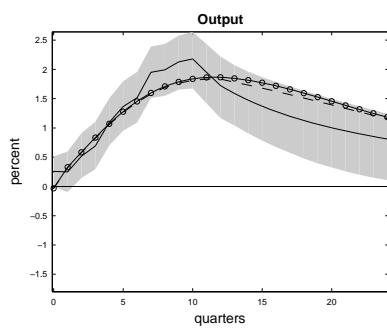


Figure 7: The Model with no Durable Consumption Goods

Unanticipated Tax Shock



Anticipated Tax Shock

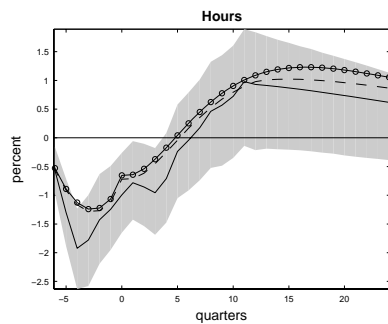
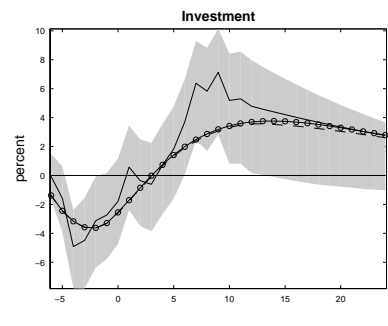
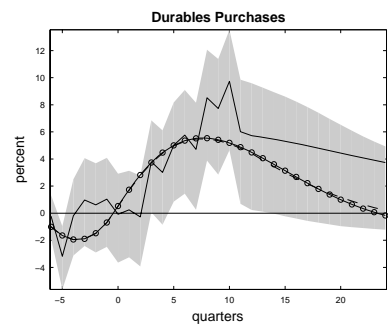
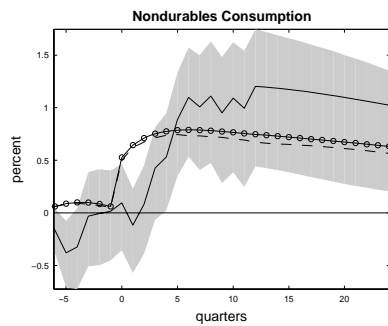
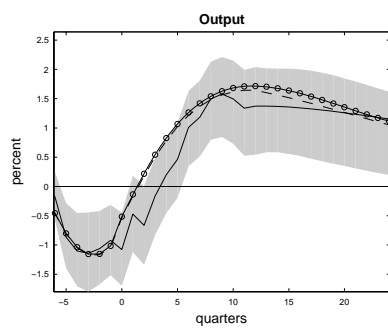


Figure 8: The Model with no Habit Formation

Unanticipated Tax Shock

Anticipated Tax Shock

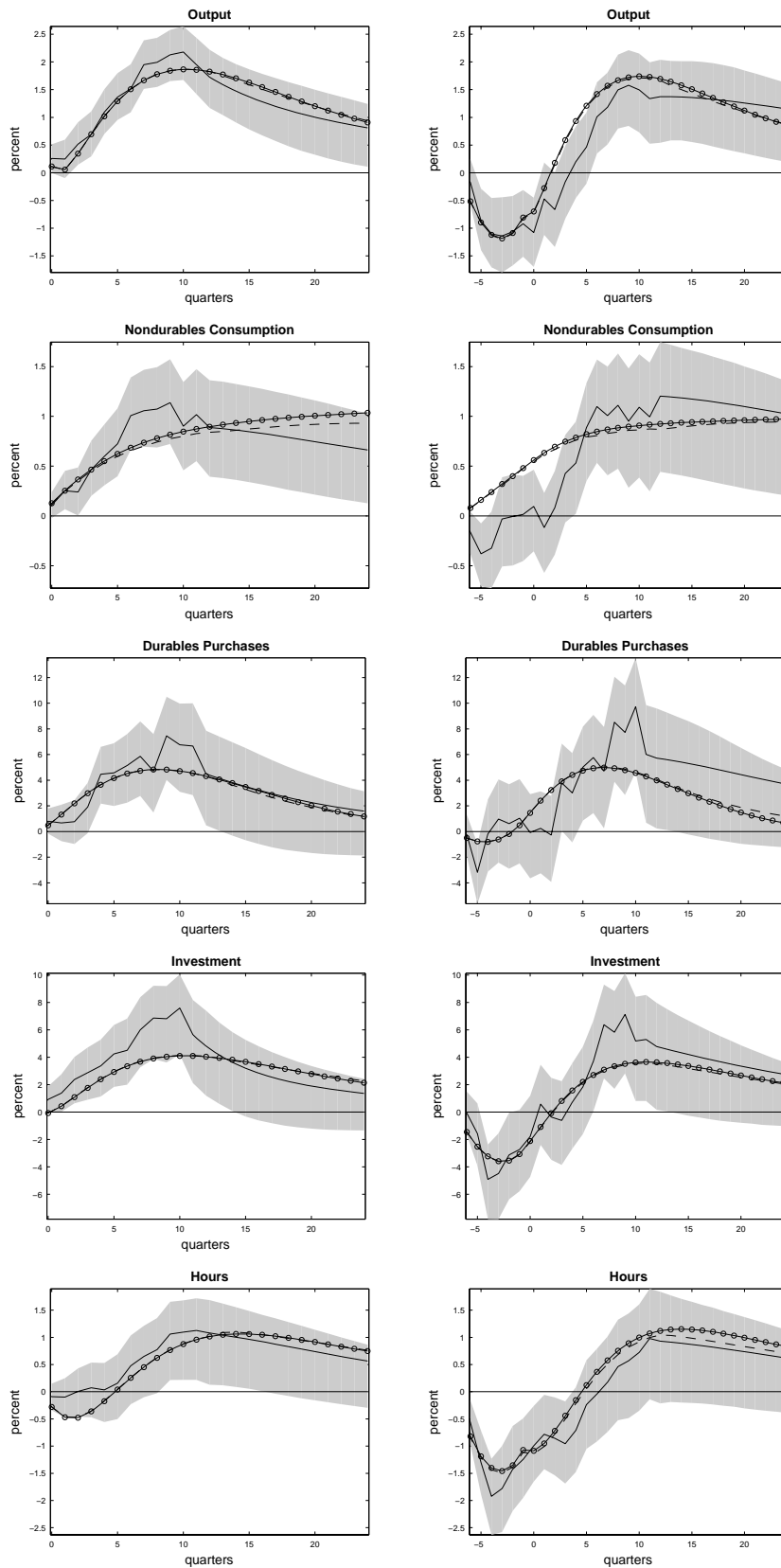


Figure 9: The Model with Endogenous Government Spending

Unanticipated Tax Shock

Anticipated Tax Shock

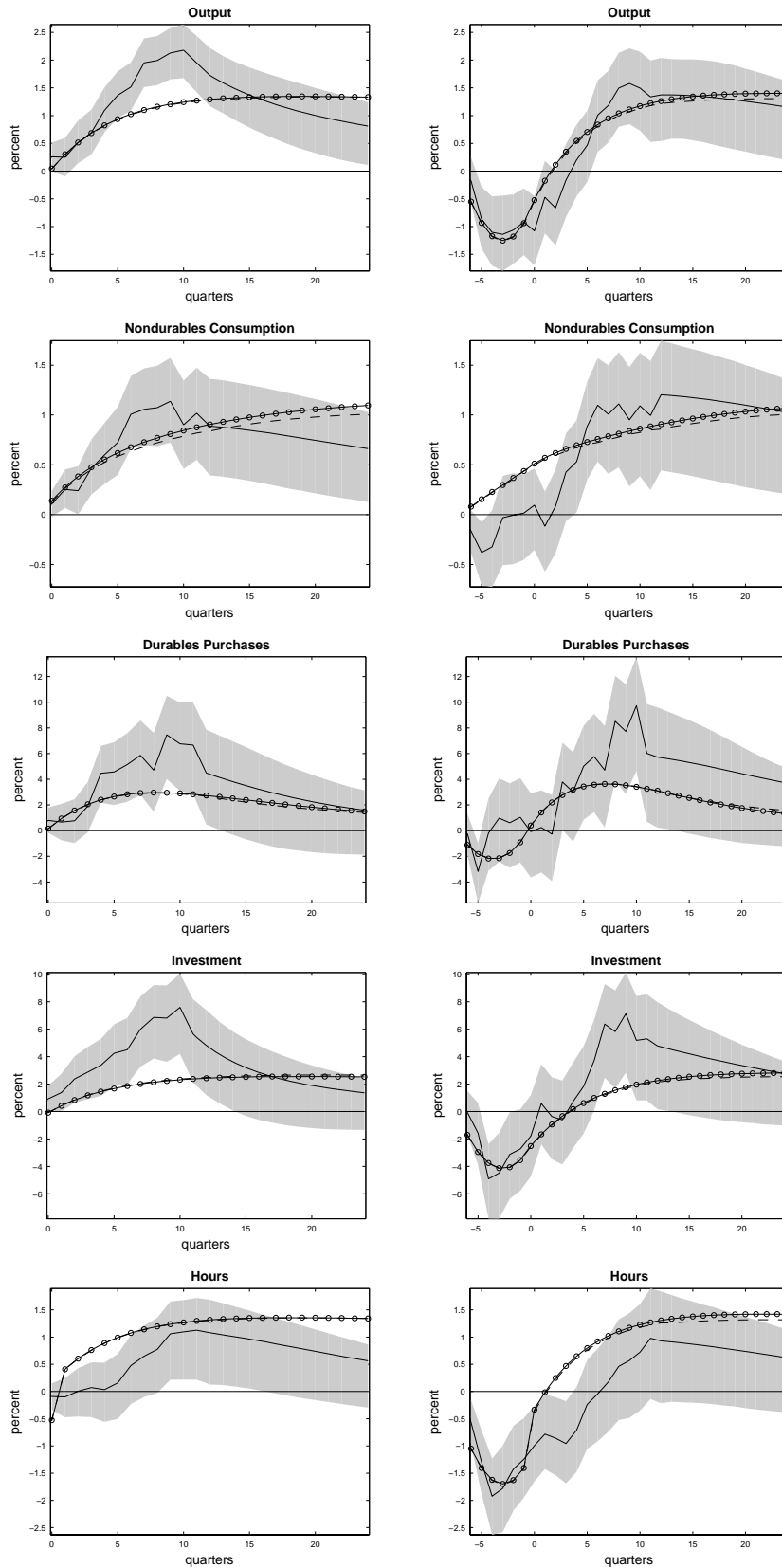
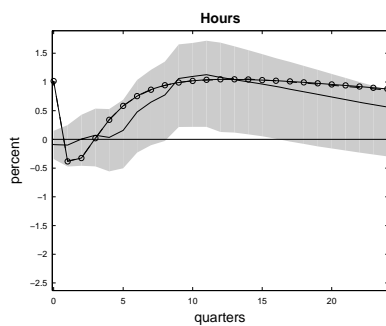
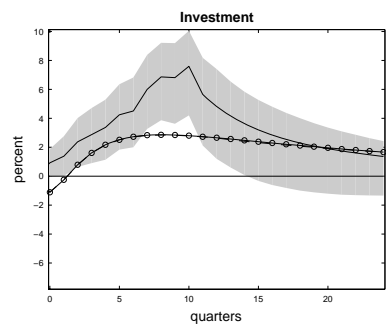
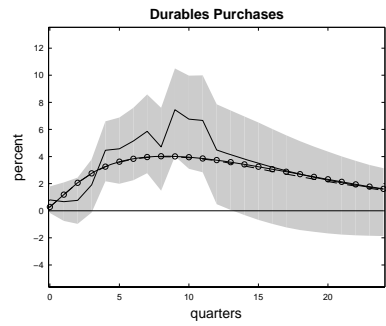
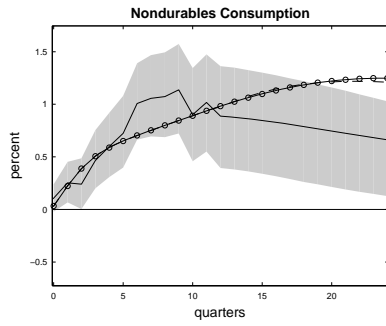
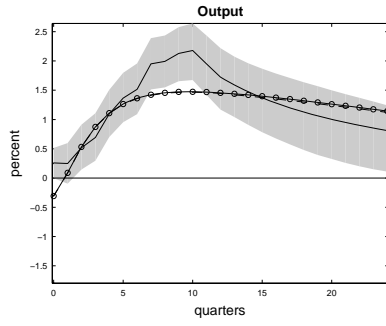


Figure 10: The Model with Constant Capital Income Taxes

Unanticipated Tax Shock



Anticipated Tax Shock

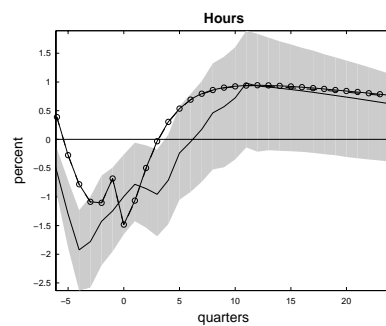
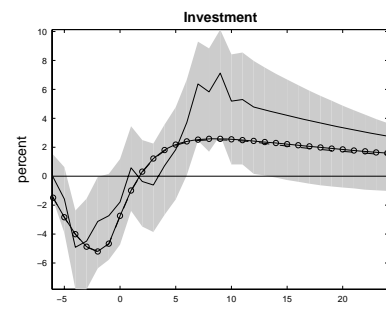
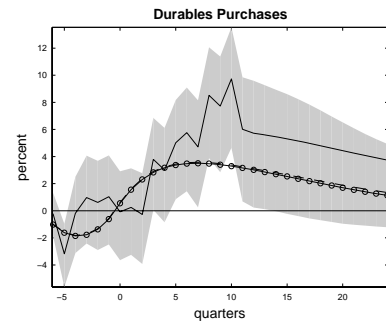
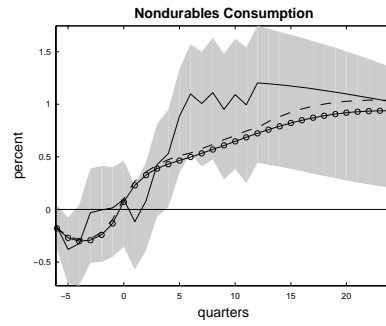
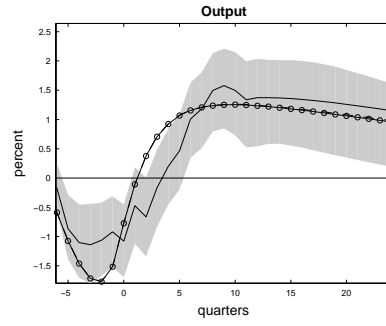


Figure 11: The Model with Constant Labor Income Taxes