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The Aggregate Effects of Anticipated and Unanticipated Tax Policy Shocks: Theory and Empirical Evidence

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The Aggregate Effects of Anticipated and Unanticipated U.S. Tax Policy Shocks: Theory and Empirical Evidence*

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Abstract

We provide empirical evidence on the effects of tax liability changes in the United States. We distinguish between "surprise" and "anticipated" tax shocks. We find that surprise tax cuts have expansionary and persistent effects on output, consumption, investment and hours worked. Prior to their implementation, anticipated tax liability tax cuts give rise to contractions in output, investment and hours worked. After their implementation, anticipated tax liability cuts lead to an economic expansion. We build a DSGE model with changes in tax rates that may be anticipated or not, estimate key parameters and show that it can account for the main features of the data. We argue that tax shocks are empirically important for U.S. business cycles and that the Reagan tax cut, which was largely anticipated, was a main factor behind the early 1980's recession.

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

JEL: E20, E32, E62, H30

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1 Introduction

This paper estimates the dynamic macroeconomic impact of changes in federal tax liabilities in the U.S. during the post World War II period. We distinguish between anticipated and unanticipated tax liability changes. This distinction is empirically relevant since tax laws often introduce changes in tax liabilities that become effective well out in the future. We find that the *implementation* of a tax liability cut gives rise to a major macroeconomic expansion of the U.S. economy while the *announcement* of a future tax cut is associated with a decline in aggregate activity, hours worked and investment during the pre-implementation period. We demonstrate that a dynamic stochastic general equilibrium model with changes in distortionary tax rates can account for the impact of anticipated and unanticipated tax liability shocks that we estimate in the U.S. data.

Our empirical analysis makes use of Romer and Romer's (2007a) narrative account of U.S. federal tax liability changes. We focus on the tax liability changes that Romer and Romer (2007a) deem exogenous. These data suggest a natural approach to distinguishing between anticipated and unanticipated tax liability changes. In particular, tax legislations are distinguished by the date at which they were signed by the President (thus became law) and the date at which the tax liability changes were due according to the law. We categorize a tax liability change as "anticipated" when it was implemented more than 90 days after the legislation was signed by the President. Tax liability changes with implementation lags below 90 days are categorized as "unanticipated". On the basis of this definition, around half of the tax liability changes in the U.S. during the post World War II sample are anticipated and the median implementation lag of these legislations is 6 quarters.

We find that the implementation of a tax liability changes has substantial macroeconomic impact. In response to a one percent decrease in tax liabilities, output per capita rises by up to 2.2 percent, consumption of nondurables and services increase by 1.1 percent, investment in capital goods rise by more than 7 percent and hours worked rise by 1.1 percent. The responses of each of these macroeconomic aggregates are highly persistent reaching their maximum impact around two and half years after the change in tax liabilities.

The *implementation* of a pre-announced tax liability change gives rise to a response of the economy that is similar in shape and size to an unanticipated tax liability change. However, during the pre-implementation period an anticipated future tax liability cut has contractionary effects. The impact is especially sharp for investment that falls by almost 5 percent in response to a 1 percent anticipated tax liability cut announced 6 quarters in advance but the pre-implementation downturn is significant also for output and for hours worked. In contrast, consumption of nondurables and services reacts little to announcements of future lower taxes. Blanchard and Perotti (2002) instead find little evidence of anticipation effects of tax policy changes but focus on very short anticipation horizons. Consistently with their results, we show that the pre-implementation impact is small for short implementation lags. However, tax announcements with the median implementation lag (6 quarters) are associated with a significant pre-implementation response of the economy.

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. The 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.

The potential relevance of implementation lags for understanding fiscal policy has previously been highlighted by a number of authors. Blanchard (1981), Taylor (1993) and Ramey (2007) analyze how anticipated changes in government purchases of goods and services affect the economy. More closely related to our analysis are Auerbach (1989), Yang (2005), and House and Shapiro (2006). Auerbach (1989) studies the impact of the Tax Reform Act of 1986 on business investment in a partial equilibrium investment model and shows that the investment response to anticipated tax changes depends crucially on adjustment costs, a theme that we also stress in our general equilibrium set-up. House and Shapiro (2006) and Yang (2005) consider the impact of tax changes in DSGE settings akin to ours. Yang (2005) argues that empirical estimates of the impact of tax changes may be problematic when agents have policy foresight. House and Shapiro (2006) use a DSGE model as a tool for analyzing the impact of the 2001 Economic Growth and Tax Relief Reconciliation Act and the 2003 Jobs and Growth Tax Relief Reconciliation Act taking into account the phase-ins and sunsets built into these tax laws. They argue that anticipation effects may have been partially responsible for the slow recovery from the 2001 recession in the U.S. None of these contributions, however, have provided empirical evidence on the relevance of such anticipation effects and, for that reason, have not assessed whether the quantitative effects of anticipated fiscal policy shocks can be accounted for by economic theory. We address both these concerns and we also provide detailed analysis of how fiscal policy shocks affect the economy through wealth and substitution effects which is useful for understanding the channels through which the economy adjusts to changes in taxes.

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 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 examine the importance of tax shocks as impulses to the U.S. business cycle by examining counterfactual experiments with the empirical model. We find that both unanticipated and anticipated tax liability shocks have contributed importantly to the U.S. business cycle. Particularly interesting is the finding that the anticipation effects associated with the Social Security Amendments of 1977 and the Economic Recovery Tax Act of 1981 appear to explain a large fraction of the 1981-82 recession and the mid-1980's boom in the U.S.

[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.

[2] Parker (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.

2 Empirical Evidence

In order to identify tax shocks, we make use of Romer and Romer's (2007a) narrative account of U.S. federal tax liability changes. Romer and Romer (2007a) identify 49 significant legislated federal tax acts in the period 1947-2006 and a total of 104 separate changes in tax liabilities. We focus on the tax liability changes that Romer and Romer (2007a) classify as either "exogenous due to long-term growth objectives" or exogenous due to "deficit concerns". The former of these are tax changes that were introduced with no explicit concerns about the current state of the economy while the latter are tax changes introduced to address *inherited* budget deficits. Therefore, we assume that these tax liability changes are exogenous in the sense that they are orthogonal to the current realizations of other structural shocks. This selection leaves us with 67 tax liability changes deriving from 34 different federal tax policy acts listed in Table A.1.

We distinguish between anticipated and unanticipated tax liability tax changes on the basis of the difference in timing between dates at which the tax legislations were signed by the President and the dates at which the tax liability changes were to be implemented. We define a tax liability change as *anticipated* if the implementation lag exceeds 90 days. Based on this taxonomy, 36 of the tax liability changes are deemed anticipated and 31 are defined as surprise tax shocks.[3] The great advantage of the combination of the use of the narrative approach and the timing assumption that we introduce to identify the anticipated tax shocks is that it allows us to circumvent the non-invertibility problem of traditional VAR approaches to estimating the impact of fiscal policy in the face of policy foresight, see Yang (2006) and Leeper, Walker and Yang (2008).

The resulting tax shocks are illustrated in Figure 1 (in percentages of GDP). The top panel shows the unanticipated shocks, the middle panel shows the anticipated shocks dated by the quarter of implementation, and the bottom panel reports the anticipation horizon of the anticipated tax shocks (truncated at 4 years). The Reagan tax initiative, in particular, was associated with major anticipated tax changes. The Economic Recovery Act of 1981, signed by Reagan in August 1981, consisted of five separate changes in tax liabilities due in 1981:3, 1981:4, 1982:1, 1983:1, and 1984:1. The first two tax changes are defined as surprise changes according to our taxonomy while the last three initiatives are

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

defined as anticipated policy changes. This sequence of tax cuts as a whole constitutes by far the largest anticipated tax changes in the sample that we study.

The median implementation lag in the data is 6 quarters. The longest implementation lag is associated with the Social Security Amendments of 1983 signed by the President in April 1983 which had tax liability changes taking place as far out in the future as 1990. We assume that the date at which the public becomes informed about the changes in tax liabilities coincides with the date at which the legislations were signed by the President. It is possible that in some instances the public might have expected the tax changes prior to the date at which the President signed the tax law. Our approach therefore, if anything, underestimates the extent to which tax policy changes were anticipated.

2.1 The Measurement of Tax Shocks

We measure surprise tax liability changes, denoted by τ_t^u, in terms of the implied dollar change in tax liabilities in percentages of current price GDP at the implementation date. Anticipated tax changes are distinguished by their size, the date at which they were signed by the President, and by their anticipation horizon. Let $s_t^{a,i}$ denote tax liability changes that were signed by the President at date t and which had an anticipation horizon of i quarters measured as a percentage of GDP at the implementation date. Ideally, we would like to allow for differential effects of tax liabilities that had different anticipation horizons. Directly adopting this approach implies that the information set at date t needs to include the vector of anticipated tax shocks $\left[s_t^{a,i=1,..M}, s_{t-1}^{a,i=2,..,M}, s_{t-M}^{a,M}\right]$ where M denotes the largest implementation lag in the data.[4] The large dimension of this vector makes estimation difficult due to the implied loss of degrees of freedom. Therefore, we choose instead to distinguish between anticipated tax shocks on the basis of their *remaining* anticipation horizon. We define the following anticipated tax shocks:

$$\tau_{t,i}^a = \sum_{j=0}^{M-i} s_{t-j}^{a,i+j} \tag{1}$$

Thus, $\tau_{t,i}^a$ measures the sum of all anticipated tax liability changes that are known at date t and are to be implemented at date $t+i$. Using definition (1) of the anticipated tax shocks implies that the number of anticipated tax variables that enter the information set at date t is at most equal to M,

[4] Even for moderate values of M, this implies that a large amount of parameters need to be estimated. The largest anticipation horizon in the data is 20 quarters which would imply that we would need to estimate 210 parameters for each of the variables in question relating to the effects of anticipated tax shocks.

making estimation feasible.

2.2 Estimating the Impact of Tax Liability Changes

We estimate the impact of tax liability changes from the following regression model:

$$X_t = A + Bt + C(L) X_{t-1} + D(L) \tau_t^u + F(L) \tau_{t,0}^a + \sum_{i=1}^{K} G_i \tau_{t,i}^a + e_t \quad (2)$$

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.[5] We allow the maximum anticipation horizon in equation (2), K, potentially to differ from the maximum implementation lag observed in the data, M.

This regression model can be viewed as a vector autoregression for X_t treating the tax variables as exogenous. Since we do not include actual tax rates in the vector X_t, in order to allow for persistence in the tax liability changes, the VAR includes moving average terms of *implemented* tax liability changes, τ_t^u and $\tau_{t,0}^a$ (the $D(L)$ and $F(L)$ lag polynomials).[6] We evaluate the impact of tax liability changes on the basis of the implied impulse response functions to changes in τ_t^u and in $\tau_{t,K}^a$. The anticipation effects of pre-announced tax liability changes are introduced through the terms $G_1 - G_K$ (the coefficient vectors on the pre-announced but not yet implemented tax liability changes).

Our treatment of the tax shocks contrasts with the standard "dummy variable" measurement of the policy interventions usually adopted in the narrative approach, see e.g. Ramey and Shapiro (1998).[7] Our approach imposes a linearity constraint on the measurement of the tax shock (by measuring them in terms of percentage of GDP) but allows us to aggregate the evidence on the effects of tax shocks across different episodes. Romer and Romer (2007b) adopt the same strategy to the measurement of the tax policy shocks.

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

[5] The results are robust to allowing for a break in 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.

[6] Alternatively, one might include estimates of actual tax rates in the VAR, see e.g. Burnside, Eichenbaum and Fisher (2004), but in our application this would require one to introduce a mapping between estimates of average marginal tax rates and tax liability changes.

[7] See Perotti (2007) for an insightful survey of the literature has adopted the narrative approach to fiscal policy.

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.2 in the appendix.

2.3 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 2 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. Relative to 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 2 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. Output drops by up to 1.16 percent with the largest drop taking place 3 quarters before the tax liability cut is implemented. The decrease in output is statistically significant from zero during much of the pre-implementation period. Hours worked also drop 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 that is 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 is very flat and reaches its new higher level 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 response of the endogenous variables to 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.

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.

2.3.1 Sensitivity to the Anticipation Horizon

The analysis above assumes pre-announced tax changes can impact on X_t from a maximum 6 quarters before their implementation. Figure 3 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.

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.

2.3.2 Stability

One may ask if the results are sensitive to the presence of particular tax interventions in the sample. We examine this issue by considering the robustness of the results across alternative sample periods. We first consider the sample period 1965:2 - 2006:4 which excludes the Kennedy tax initiative. Secondly, we exclude the Bush tax initiatives (the Economic Growth and Tax Relief Reconciliation Act of 2001 and the Jobs and Growth Relief Reconciliation Act of 2003) by eliminating the last five years of the sample. Third, we exclude the Reagan tax cut (the Economic Recovery Tax Act of 1981). This tax initiative occurs in the middle of the sample and is therefore a bit less straightforward to deal with. We consider the sample period 1947:4-1981:2 which therefore excludes the last 25 years of the sample.

Figure 4 shows the response of output to anticipated and unanticipated tax liability changes for the full sample period and the three alternative sample periods. The impact of anticipated tax changes estimated for the full sample is basically identical to the estimates when eliminating either the Kennedy tax act or the Bush tax acts. The results are more sensitive to eliminating the last 25 years of the data. Using this sample period, we find much larger effects of anticipated tax cuts and that the expansion in aggregate output following the implementation of an anticipated tax cut takes place faster. Nevertheless, the presence of a pre-implementation contraction in the economy is very robust.

2.3.3 Anticipation Effects of Surprise Tax Changes

Our distinction between anticipated and unanticipated tax shocks is based on the difference in the timing between tax laws being signed by the President and the implementation of the tax liability changes according to these laws. It is possible that surprise tax liabilities to some extent were anticipated by the private sector which would invalidate this distinction. In order to examine this issue, we check whether there is evidence of systematic responses to surprise tax shocks before their implementation. We estimate the following model:

$$X_t = A + Bt + C(L) X_{t-1} + D(L) \tau_t^u + \sum_{i=1}^{K} H_i \tau_{t+i}^u + e_t \tag{3}$$

which allows for the possibility that there are anticipation effects of surprise tax shocks. We estimate this relationship assuming, as above, that $K = 6$.

Figure 5 illustrates the impact of a one percentage point decrease in τ^u_{t+6} on output and on investment. For comparison, this figure also shows the estimates of the impact of anticipated tax changes that were reported above. Leads of unanticipated tax shocks have little effect upon output and on investment and the dynamics of these two variables differ markedly form their responses to anticipated tax shocks during the pre-implementation period. The difference is particularly stark for investment. Thus, it seems safe to conclude that there is a systematic difference between the impact of anticipated tax shocks and surprise tax shocks as measured by our timing convention.

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 (11993), Braun (1994), McGrattan (1994) or House and Shapiro (2006), by introducing features such as habit formation, adjustment costs, consumer durables, and variable capacity utilization.[8]

3.1 The Model

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

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{x_t^{1-\sigma} - 1}{1-\sigma} - z_t^{1-\sigma} \frac{\omega}{1+\kappa} n_t^{1+\kappa} \right] \quad (4)$$

where E_t denotes the mathematical expectations operator conditional on all information available at date t. β denotes 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:

$$x_t = C_t^{\vartheta} (V_t)^{1-\vartheta} - \mu C_{t-1}^{\vartheta} (V_{t-1})^{1-\vartheta} \quad (5)$$

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.

[8] House and Shapiro, 2006, also allow for capital adjustment costs in an analysis of anticipation effects.. See also Leeper and Yang, 2006, Ramey, 2007, and Yang, 2005, for analyses of fiscal policy with anticipation effects.

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

$$\begin{aligned} V_{t+1} &= \left(1-\Phi_v\left(\frac{D_t}{D_{t-1}}\right)\right)D_t+(1-\delta_v)\,V_t && (6)\\ K_{t+1} &= \left(1-\Phi_k\left(\frac{I_t}{I_{t-1}}\right)\right)I_t+\left(1-\delta_k-\Psi_k\left(u_t^k\right)\right)K_t && (7)\\ C_t+D_t+I_t &\leq (1-\tau_t^n)\,W_t n_t+\left(1-\tau_t^k\right)r_t u_t^k K_t+\Lambda_t+T_t && (8)\end{aligned}$$

Equation (6) is the law of motion for the household's stock of consumer durables. D_t denotes the household's 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 (7) is the law of motion for the household's stock of "market" capital, K_t. This capital stock is rented out by the household's to the production sector of the economy. 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. 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 the adjustment cost formulations in equations $(6)-(7)$ assume that adjustment costs arise when the growth rate of investment deviates from its steady-state level, see Christiano, Eichenbaum and Evans (2005).

Equation (8) is the household's 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 household's income flow net of taxes. The term $(1-\tau_t^n)\,W_t n_t$ is the household's 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. The term $\left(1-\tau_t^k\right)r_t u_t^k K_t$ is the household's income from renting out its 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:

$$\Lambda_t = \tau_t^k \sum_{s=1}^{\infty} \delta_\tau\,(1-\delta_\tau)^{s-1}\, I_{t-s} \qquad (9)$$

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:

$$C_t : \lambda_{c,t} = \left(x_t^{-\sigma} - \mu\beta E_t x_{t+1}^{-\sigma}\right)\gamma\left(\frac{V_t}{C_t}\right)^{1-\gamma} \tag{10}$$

$$n_t : z_t^{1-\sigma}\omega n_t^{\kappa} = \lambda_{c,t}\left(1-\tau_t^n\right)W_t \tag{11}$$

$$K_{t+1} : \lambda_{c,t}q_{k,t} = E_t\beta\lambda_{c,t+1}\left[\left(1-\tau_{t+1}^k\right)r_{t+1}u_{t+1}^k + q_{k,t+1}\left(1-\delta_k-\Psi_k\left(u_{t+1}^k\right)\right)\right] \tag{12}$$

$$V_{t+1} : \lambda_{c,t}q_{v,t} = E_t\beta\lambda_{c,t+1}\left[\frac{1-\gamma}{\gamma}\frac{C_{t+1}}{V_{t+1}} + q_{v,t+1}\left(1-\delta_v\right)\right] \tag{13}$$

$$\begin{aligned} I_t : 1-\Gamma_t - q_{k,t}&\left(1-\Phi_k\left(\frac{I_t}{I_{t-1}}\right) - \Phi_k'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right) \\ &= \beta E_t\frac{\lambda_{c,t+1}}{\lambda_{c,t}}q_{k,t+1}\Phi_k'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \end{aligned} \tag{14}$$

$$\begin{aligned} D_t : 1 - q_{v,t}&\left(1-\Phi_v\left(\frac{D_t}{D_{t-1}}\right) - \Phi_v'\left(\frac{D_t}{D_{t-1}}\right)\frac{D_t}{D_{t-1}}\right) \\ &= \beta E_t\frac{\lambda_{c,t}}{\lambda_{c,t+1}}q_{v,t+1}\Phi_v'\left(\frac{D_{t+1}}{D_t}\right)\left(\frac{D_{t+1}}{D_t}\right)^2 \end{aligned} \tag{15}$$

$$u_t^k : \left(1-\tau_t^k\right)r_t = q_{k,t}\Psi_k'\left(u_t^k\right) \tag{16}$$

where $\lambda_{c,t}$ is the multiplier on (8), $\lambda_{c,t}q_{k,t}$ is the multiplier on (7) and $\lambda_{c,t}q_{v,t}$ is the multiplier on (6). The variable Γ_t that enters equation (14) is the expected present value of depreciation allowances on new investments. It is determined recursively as:

$$\Gamma_t = \beta\delta_\tau E_t\left[\frac{\lambda_{c,t+1}}{\lambda_{c,t}}\tau_{t+1}^k\right] + \beta\left(1-\delta_\tau\right)E_t\left[\frac{\lambda_{c,t+1}}{\lambda_{c,t}}\Gamma_{t+1}\right] \tag{17}$$

(10) 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). (11) equates the marginal rate of substitution between consumption and leisure with the after-tax real wage. (12) 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 (13) 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, (14), 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 (15) 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 (16) 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:

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

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:

$$W_t = (1-\alpha) z_t A\left(u_t^k K_t\right)^{\alpha}(z_t n_t)^{-\alpha} \tag{19}$$

$$r_t = \alpha A\left(u_t^k K_t\right)^{\alpha-1}(z_t n_t)^{1-\alpha} \tag{20}$$

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:

$$G_t + T_t = \tau_t^n W_t n_t + \tau_t^k r_t u_t^k K_t - \Lambda_t \tag{21}$$

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.[9]

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

[9] 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.

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:

$$\tau_t^n = (1-\rho_1^n-\rho_2^n)\,\tau^n + \rho_1^n\tau_{t-1}^n + \rho_2^n\tau_{t-2}^n + \varepsilon_t^n + \xi_{t,0}^n \tag{22}$$

$$\tau_s^k = \left(1-\rho_1^k-\rho_2^k\right)\tau^k + \rho_1^k\tau_{t-1}^k + \rho_2^k\tau_{t-2}^k + \varepsilon_t^k + \xi_{t,0}^k \tag{23}$$

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 $\left|\rho_1^k+\rho_2^k\right| < 1$. 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 $\varepsilon_t = \left[\varepsilon_t^n, \varepsilon_t^k\right]'$ 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:

$$C_t + D_t + I_t + G_t \leq Y_t \tag{24}$$

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. 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 $(10)-(11)$. 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 (11) and (12):

$$n_t^\kappa = E_t\left[\beta\frac{(1-\tau_t^n)\,W_t}{\left(1-\tau_{t+1}^n\right)W_{t+1}}\gamma_z^{1-\sigma}R_{k,t+1}\right]n_{t+1}^\kappa \tag{25}$$

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. 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.[10] 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:

$$\widehat{i}_t - \widehat{i}_{t-1} = \frac{1}{\Phi_k''(\gamma_z)\gamma_z} E_t \sum_{s=0}^{\infty} \left(\beta\gamma_z^{1-\sigma}\right)^s \left(\widehat{q}_{k,t+s} + \frac{\Gamma}{1-\Gamma}\widehat{\Gamma}_{t+s}\right) \tag{26}$$

where $\widehat{i}_t = \ln\left(\frac{I_t/z_t}{I/z}\right)$ denotes the percentage deviation of "detrended" investment from its steady-state value and $\widehat{q}_{k,t}$ 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 (12)) 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 drops during the pre-implementation period. The drop in hours worked lowers the return on capital goods which depresses investment (see equation (26)) 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

[10] 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.

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.

3.2 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 (18) 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 $\Theta_2 = \left[\sigma, \mu, \kappa, \phi_v, \phi_k, \psi_v, \psi_k, \rho_1^n, \rho_2^n, \rho_1^k, \rho_2^k\right]'$ 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 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:

$$\begin{aligned} Y_s &= \widetilde{A} + \widetilde{B}s + \widetilde{C}Y_{s-1} + \sum_{i=0}^{\infty} \widetilde{D}_i \eta_{s-i}^u + \sum_{i=0}^{\infty} \widetilde{F}_{i+b} \eta_{s-i}^a + \sum_{i=0}^{b-1} \widetilde{G}_i \eta_{s-i}^a \qquad (27) \\ \eta_{s-i}^{\varepsilon} &= \left[\begin{array}{cc} \frac{\varepsilon_s^n}{\tau^n}, & \frac{\varepsilon_s^k}{\tau^k} \end{array}\right]', \eta_{s-i}^a = \left[\begin{array}{cc} \frac{\xi_{s-i,0}^n}{\tau^n}, & \frac{\xi_{s-i,0}^k}{\tau^k} \end{array}\right]', \eta_{s-i}^{\xi} = \left[\begin{array}{cc} \frac{\xi_{s-j,b-j}^n}{\tau^n}, & \frac{\xi_{s,b-j}^k}{\tau^k} \end{array}\right]' \end{aligned}$$

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. (27) 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 $\widetilde{D}_i$ 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.[11] We estimate Θ_2 as the vector of variables that solves the following minimization problem:

$$\widehat{\Theta}_2 = \arg\min_{\Theta_2} \left[\left(\widehat{\Lambda}_T^d - \Lambda_T^m (\Theta_2|\Theta_1) \right)' \Sigma_d^{-1} \left(\widehat{\Lambda}_T^d - \Lambda_T^m (\Theta_2|\Theta_1) \right) \right] \tag{28}$$

where $\widehat{\Lambda}_T^d$ 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:

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.

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:

$$\widetilde{X}_t^j (\Theta_2|\Theta_1) = \mathfrak{A}^j + \mathfrak{B}^j t + \mathfrak{C}^j (L) \widetilde{X}_{t-1}^j (\Theta_2|\Theta_1) + \mathfrak{D}^j (L) \widetilde{\tau}_t^{u,j} + \mathfrak{F}^j (L) \widetilde{\tau}_{t,0}^{a,j} + \sum_{i=1}^{K} \mathfrak{G}_i^j \widetilde{\tau}_{t,i}^{a,j} + \widetilde{e}_t^j \tag{29}$$

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 $\Lambda_T^m (\Theta_2|\Theta_1)$.

[11] 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.

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.

4 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 (28) 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.[12] 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, an estimate that is very similar to the calibration of House and Shapiro (2006). This value 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 (rather than consumption).

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

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

significant role for fluctuations in the utilization rate of the market capital stock. The point estimate of $\widehat{\psi}_k$ is 0.355 which implies that changes in the utilization rate have a significant impact on the gross depreciation rate of the capital stock.[13]

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 6 illustrates the dynamics of the 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 7 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 anticipated 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:

[13] 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.

- 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. 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 in Section 4.1 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 7 shows both the exact model impulse responses (the lines with circles) and the model impulse responses estimated by imposing the empirical model on the artificial data (dotted 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 appear 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 3). 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 (22) and (23) from 4 to 10 quarters. The result is illustrated in Figure 8. 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 is the implementation lag (for moderate values of b).

4.1 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 $\left(\left(1-\overline{\tau}^n\right)\overline{w}, \left(1-\overline{\tau}^k\right)\overline{r}\right)$ 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 $\left(C_t, V_t, n_t\right)_{t=0}^{\infty}$ with associated factor prices $\left(\left(1-\tau_t^n\right)w_t, \left(1-\tau_t^k\right)r_t\right)_{t=0}^{\infty}$ 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 relative wage effect, an "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.[14] 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 are equal to U_0^{SS}.

Figure 10 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.[15] 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.

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[14] 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 forwards (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 introduces a wedge between the (after-tax) real interest rate and the intertemporal marginal rate of substitution.

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

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 higher future after-tax wages depresses 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 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.[16] 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 10 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 this

[16] In this case, we estimate the structural parameters by matching the moments of a version of the VAR in equation (2) in which the vector of endogenous variables, X_t, does not include the purchases of consumer durables.

effect is eliminated, there is little reason for nondurables consumption not to rise 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 11 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 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.

4.2 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 6), 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 12) are almost identical to the benchmark model.[17] 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.[18] 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

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

[18] Results are available upon request.

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 the simplified version of the model 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 our empirical model presented in Section 2 on this 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.

4.3 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 labor income tax rate only (row 5), or in the capital income tax rate only (row 6). Figures 13 and 14 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 $1/\sigma$ double 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.

5 Tax Shocks and the Business Cycle

An interesting question is the whether tax liability changes have been important impulses to the U.S. business cycle. We investigate this issue using a counterfactual approach by computing the paths of the observables predicted by the empirical model (2) when shutting down all shocks but the tax liability changes. We first set $e_t = \tau^a_{t+i,t} = 0$. In this case, all variations in X_t (around its trend) are due unanticipated tax shocks. Next, we simulate (2) setting $e_t = \tau^u_t = 0$ in which case the fluctuations in X_t are due to anticipated tax shocks only. Finally, we simulate the VAR considering both types of tax shocks. We Hodrick-Prescott filter the resulting time series for the observables and compare them with the corresponding actual (Hodrick-Prescott filtered) U.S. time series. The results are presented in Figure 15. Panel A shows the results for unanticipated tax shocks, Panel B reports the case of anticipated tax shocks, and Panel C shows the results when we allow for both types of tax shocks.

The two tax shocks have both contributed importantly to U.S. business cycle fluctuations. Surprise tax changes were important impulses to the business cycle during three episodes. First, during the early to mid 1960's, the tax liability increase associated with the Revenue Act of 1962 led to a slow uptake in activity after the 1960-61 recession while the 2.55 percent tax liability cut contained in the Revenue Act of 1964 provided a major stimulus to the economy which accounts for a large fraction of the boom in the U.S. economy during the mid 1960's. Secondly, the 1.23 percent tax cut contained in the Revenue Act of 1971 contributed to the pre-OPEC I boom of the U.S. economy in the early 1970's. Finally, the 2.86 percent tax liability cut associated with the Jobs and Growth Tax Relief Reconciliation Act of 2003 provided a major boost to the economy in the mid 2000's.

Anticipated tax liability changes were particularly relevant impulses to the business cycle during the early 1980's recession, the expansion that followed thereafter, and during the early 2000's. Particularly interesting is the 1980's episode where the Economic Recovery Tax Act of 1981 and the Social Security Amendments of 1977 together had a large impact on the U.S. economy. The Social Security Amendments of 1977 (signed by Carter in December 1977) included a 0.56 percent tax increase implemented in 1981. This tax liability change had an expansionary effect on the economy prior to its implementation but provided a negative stimulus once implemented in 1981. The Economic Recovery Tax Act of 1981, signed by Reagan in August 1981, was associated with major tax cuts implemented gradually from 1982 to 1984. These anticipated tax cuts had a negative impact on the U.S. economy from late 1981 up till the end of 1983 at the same time as the negative effects of the Social Security Amendments of 1977 were setting in. When the Reagan tax cuts were eventually implemented through 1982 to 1984 it provided a major stimulus to the economy during the mid 1980's. Together, these anticipated tax cuts therefore stimulated the economy prior to 1981, gave rise to a contractionary effects from 1981 to late 1983, and helped the economy recover thereafter. Quantitatively, our results indicate that the early 1980's recession was to a large extent caused by fiscal policy rather than induced by tight monetary policy during the Volcker monetary regime. Anticipation effects are also relevant in the case of the Economic Growth and Tax Relief Reconciliation Act of 2001 and the Jobs and Growth Tax Relief Reconciliation Act of 2003 signed by Bush in June 2001 and in May 2003, respectively. The former introduced a 0.80 percent cut in tax liabilities in the first quarter of 2002 while the latter introduced anticipated tax increases in the third quarter of 2004 (a 1.70 percent increase) and in the first quarter of 2005 (a 0.56 increase). In agreement with House and Shapiro (2006) we find that the anticipation effect of the first of these tax acts contributed to the slow recovery from the 2001 U.S. recession while the implementation of the tax cut helped stimulate the economy from 2002 onwards. Ironically, the anticipation effects associated with the latter of these tax increases further stimulated the economy during the pre-implementation period (2003q2 - 2004q3) until its implementation eventually starts having a negative impact from the end of 2004 onwards.

As is clear from panel C, the combination of the two tax liability shocks are non-trivial as impulses to the business cycle. Over the sample period, the standard deviation of (Hodrick-Prescott filtered) output is 1.62 percent. The two tax shocks account for 19 percent of the in-sample variance of output and the cross-correlation between the counterfactual time-series for output and actual U.S. output is 53 percent. The standard deviation of the counterfactual investment time series when we allow for both types of two shocks is 2.65 percent which corresponds to approximately 47 percent of the standard deviation (or 22 percent of the variance) of the actual time series for investment.

6 Conclusions

We have investigated the dynamic effects of U.S. tax liability changes and examined its congruency with macroeconomic theory. Our empirical analysis provides evidence in favor of the idea that phased-in tax changes give rise to anticipation effects, a hypothesis explored by a number of authors in earlier theoretical papers that, however, lacked empirical evidence of such anticipation effects. Our approach to estimating the impact of tax policy shocks combines the use a narrative approach to identifying tax liability changes and the introduction of timing assumptions to distinguish between unanticipated and anticipated tax shocks. Since one can meaningfully assume that agents become informed about tax liability changes when they became law (i.e. when the President signed the law), our methodology allows us to include information about future taxes when estimating the impact of tax shocks on the economy and this makes it possible to identify anticipation effects. This apporach circumvents the non-invertibility problem associated with structural VAR approaches in the presence of policy foresight.

Our empirical estimates imply that there are large macroeconomic effects of changes in tax liabilities. The implementation of a change in tax liabilities sets off large and persistent dynamic adjustment of output, consumption, investment and hours worked. We find that tax cuts boost the economy with investment being particularly sensitive to changes in tax liabilities. In contrast, the announcement of a future tax liability cut leads to a drop in output, investment and hours worked during the pre-implementation period while consumption is roughly unaltered until taxes eventually are adjusted. These results may also have some relevance for the recent interest into the "news" views of business cycles, see e.g. Beaudry and Portier (2004, 2006), Cochrane (1994), Danthine, Donaldson and Johnsen (1998), den Haan and Kaltenbrunner (2006), or Jaimovich and Rebelo (2006). An important obstacle to empirical tests for news driven business cycle is that expectations are inherently difficult to estimate as they are unobserved by the econometrician but we overcome this difficulty in our application to fiscal policy. Our finding that a pre-announced tax cut gives rise to a pre-implementation contraction in the economy may be important for understanding how news shocks help shape fluctuations in the economy.

The empirical estimates provides a quantitative measure of the impact of tax liability changes that facilitates an analysis of the extent to which the results are consistent with macroeconomic theory. We showed that a DSGE model with habit persistence, durables consumption, and adjustment costs can account for both the quantitative impact of the implementation of tax liability changes and for the pre-implementation dynamics in the case of anticipated tax liability changes. We also analyzed in detail the sources of adjustment to changes in taxes on the basis of Hicksian decomposition of the consumption and hours response.

An important implication from our analysis is that tax liability changes are empirically relevant as impulses to the U.S. business cycle. Tax liability changes account for a non-trivial fraction of output volatility at the business cycle frequencies. Moreover, anticipation effects have played an important role in some of the U.S. postwar business cycles. In particular, we find that the early 1980's recession to a large extent can be accounted for by the negative concurrent impact of anticipated future tax cuts. Thus, our results are supportive of Braun (1994) and McGrattan (1994) who find that tax shocks are important impulses to the U.S. business cycles.

7 References

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8 Appendix 1: Data: Definitions and Sources

Table A.1: Tax Liability Changes

Name	Signed	Effective	Type	Size
1. Social Security Amendments of 1947	August 1947	1950 Q1	Anticipated	0.27
2. Revenue Act of 1948	April 1948	1948 Q2	Surprise	-3.74
	April 1948	1948 Q3	Surprise	1.82
3. Social Security Amendments of 1950	August 1950	1954 Q1	Anticipated	0.35
4. Expiration of Excess Profits and Temporary Income Tax	October 1951	1954 Q1	Anticipated	-0.35
5. Internal Revenue Code of 1954	August 1954	1954 Q3	Surprise	-1.13
	August 1954	1954 Q4	Surprise	0.72
6. Tax Rate Extension Act of 1958	June 1958	1958 Q3	Surprise	-0.11
7. Social Security Amendments of 1958	August 1958	1960 Q1	Anticipated	0.36
8. Federal-Aid Highway Act of 1959	September 1959	1959 Q4	Surprise	0.12
9. Social Security Amendments of 1961	Jun 1961	1963 Q1	Anticipated	0.33
10. Changes in Depreciation Guidelines	July 1962	1962 Q3	Surprise	-0.68
and Revenue Act of 1962	July 1962	1962 Q4	Surprise	0.45
	October 1962	1962 Q4	Surprise	-0.61
	October 1962	1963 Q1	Surprise	0.45
	October 1962	1963 Q1	Surprise	0.10
11. Revenue Act of 1964	February 1964	1964 Q2	Surprise	-2.55
	February 1964	1964 Q3	Anticipated	1.25
	February 1964	1965 Q1	Anticipated	-0.65
12. Excise Tax Reduction of 1965	June 1965	1965 Q3	Surprise	-0.24
	June 1965	1966 Q1	Anticipated	-0.23
13. Tax Adjustment Act of 1966	March 1966	1966 Q2	Surprise	0.12
14. Public Law 90-26	June 1967	1967 Q3	Surprise	-0.66
	June 1967	1967 Q4	Anticipated	0.46

Table A.1 continued

Name	Signed	Effective	Type	Size
15. Social Security Amendments of 1967	January 1967	1971 Q1	Anticipated	-0.33
16. Tax Reform Act of 1969	December 1969	1971 Q1	Anticipated	-0.09
	December 1969	1972 Q1	Anticipated	-0.09
17. Reform of Depreciation Rules	January 1971	1971 Q1	Surprise	-0.25
18. Revenue Act of 1971	December 1971	1972 Q1	Surprise	-1.23
	December 1971	1972 Q2	Anticipated	0.55
19. 1972 Changes to Social Security	October 1972	1978 Q1	Anticipated	0.13
20. Tax Reform Act of 1976	October 1976	1976 Q4	Surprise	0.13
	October 1976	1977 Q1	Surprise	-0.04
21. Social Security Amendments of 1977	December 1977	1979 Q1	Anticipated	0.36
	December 1977	1980 Q1	Anticipated	0.06
	December 1977	1981 Q1	Anticipated	0.56
	December 1977	1982 Q1	Anticipated	0.05
22. Revenue Act of 1978	November 1978	1979 Q1	Surprise	-0.77
23. Crude Oil Windfall Profit	April 1980	1980 Q2	Surprise	0.30
Tax Act of 1980	April 1980	1981 Q1	Anticipated	0.13
	April 1980	1982 Q1	Anticipated	0.13
24. Economic Recovery Tax Act	August 1981	1981 Q3	Surprise	-0.84
of 1981	August 1981	1981 Q4	Surprise	0.56
	August 1981	1982 Q1	Anticipated	-1.53
	August 1981	1983 Q1	Anticipated	-1.69
	August 1981	1984 Q1	Anticipated	-1.28
25. Tax Equity and Fiscal	September 1982	1983 Q1	Anticipated	0.78
Responsibility Act of 1982				

Name	Signed	Effective	Type	Size
26. Social Security Amendments	April 1983	1984 Q1	Anticipated	0.32
of 1983	April 1983	1985 Q1	Anticipated	0.21
	April 1983	1986 Q1	Anticipated	0.10
	April 1983	1988 Q1	Anticipated	0.31
	April 1983	1990 Q1	Anticipated	0.18
27. Deficit Reduction Act of 1984	July 1984	1984 Q3	Surprise	0.20
28. Tax Reform Act of 1986	October 1986	1986 Q4	Surprise	0.50
	October 1986	1987 Q1	Surprise	-0.31
	October 1986	1987 Q3	Anticipated	-0.42
29. Omnibus Budget Reconcialiation	December 1987	1988 Q1	Surprise	0.22
Act of 1987				
30. Omnibus Budget Reconcialiation	November 1990	1991 Q1	Surprise	0.60
Act of 1990				
31. Omnibus Budget Reconcialiation	August 1993	1993 Q3	Surprise	1.02
Act of 1993	August 1993	1993 Q4	Surprise	-0.59
	August 1993	1994 Q1	Anticipated	0.19
32. Tax Payer Relief Act and	August 1997	2000 Q1	Anticipated	0.02
Balanced Budget Act of 1997	August 1997	2002 Q1	Anticipated	0.01
33. Economic Growth and Tax Relief	June 2001	2002 Q1	Anticipated	-0.80
Reconciliation Act of 2001				
34. Jobs and Growth Tax Relief	May 2003	2003 Q3	Surprise	-2.86
Reconciliation Act of 2003	May 2003	2004 Q3	Anticipated	1.70
	May 2003	2005 Q1	Anticipated	0.56

Source: Romer and Romer, 2007a and Bureau of Economic Analysis. Tax liability changes with more than 90 days difference between the signing of the legislation and their implementation are classified as anticipated tax liability changes. Sizes are measured by the implied tax liability impact divided by that quarter's current price GDP at the annual rate.

Table A.2: 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 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

9 Appendix 2: Deriving Equation (27)

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:

$$Z_s = \Lambda_Z Z_{s-1} + \Xi_Z W_s \tag{30}$$

$$W_s = \Xi_W W_{s-1} + \Gamma_W \eta_s \tag{31}$$

$$U_s = \Lambda_U Z_{s-1} + \Xi_U W_s \tag{32}$$

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:

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

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 '$\sim$' 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:

$$Y_s = \Lambda_Y Z_{s-1} + \Xi_Y W_s \tag{33}$$

where Y_s is a subset of the control and state variables. It follows from equation (30) that:

$$Z_s = \left(I - \Lambda_Z L\right)^{-1} \Xi_Z W_s \tag{34}$$

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 $(33) - (34)$ imply that

$$Y_s = \Lambda_Y \Lambda_Z \Lambda_Y^{-1} Y_{s-1} + \left(\Phi_Y + \Lambda_Y \Xi_Z\right) W_s + \Lambda_Z \Xi_Y W_{s-1} \tag{35}$$

Note that in our application, $\dim(Y) = \dim(Z)$ making invertibility straightforward to check. From equation (31) 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 (35) we find that:

$$\begin{aligned} Y_s &= AY_{s-1} + \sum_{i=0}^{\infty} B_i \eta_{s-i} \\ A &= \Lambda_Y \Lambda_Z \Lambda_Y^{-1},\ B_0 = (\Xi_Y + \Lambda_Y \Xi_Z)\,\Gamma_W \\ B_i &= \left[(\Xi_Y + \Lambda_Y \Xi_Z)\,\Xi_W + \Lambda_Z \Xi_Y\right] \Xi_W^{i-1} \Gamma_W \text{ for } i \geq 1 \end{aligned} \tag{36}$$

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 $\left|\rho_1^n + \rho_2^n\right| < 1$ and $\left|\rho_1^k + \rho_2^k\right| < 1$. Finally, in order to derive equation (27) note that, $\eta_{s-j} = \begin{bmatrix} \widetilde{\varepsilon}_{s-j}^n & \widetilde{\varepsilon}_{s-j}^k & \widetilde{\xi}_{s-j,b-j}^n & \widetilde{\xi}_{s,b-j}^k \end{bmatrix}'$ for $j < b$ while $\eta_{s-j} = \begin{bmatrix} \widetilde{\varepsilon}_{s-j}^n & \widetilde{\varepsilon}_{s-j}^k & \widetilde{\xi}_{s+b-j,0}^n & \widetilde{\xi}_{s+b-j,0}^k \end{bmatrix}'$. Thus, the process for the observables can be expressed as:

$$Y_s = AY_{s-1} + \sum_{i=0}^{\infty} B_i^{\varepsilon} \eta_{s-i}^u + \sum_{i=0}^{\infty} B_{i+b}^{\xi} \eta_{s-i}^a + \sum_{i=0}^{b-1} B_i^{\xi} \eta_{s-i}^{\xi} \tag{37}$$

where:

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

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	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	71.008
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)		

Standard errors are given in the parentheses.

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

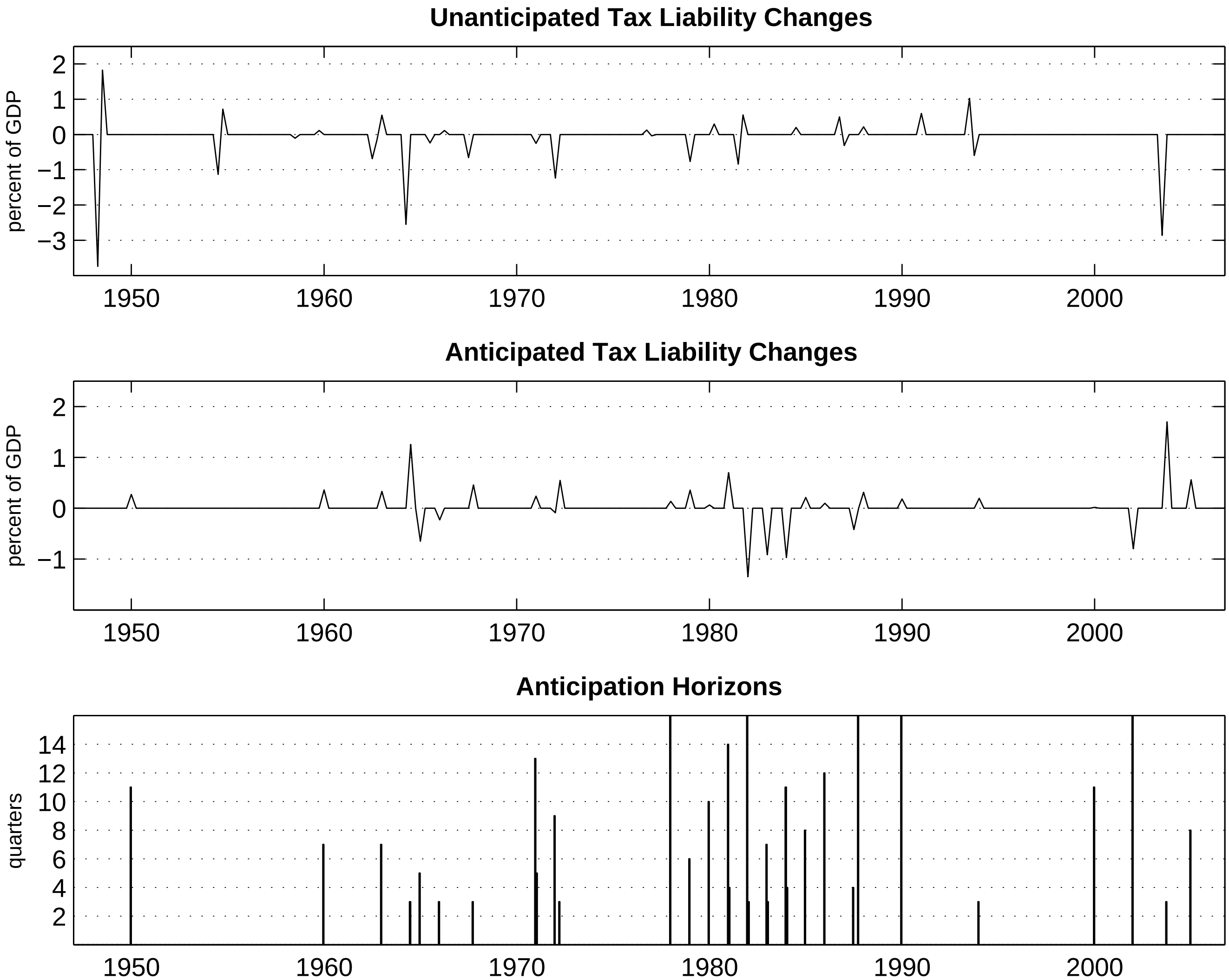

Figure 1: Tax Liability Changes

Unanticipated Tax Shock   Anticipated Tax Shock

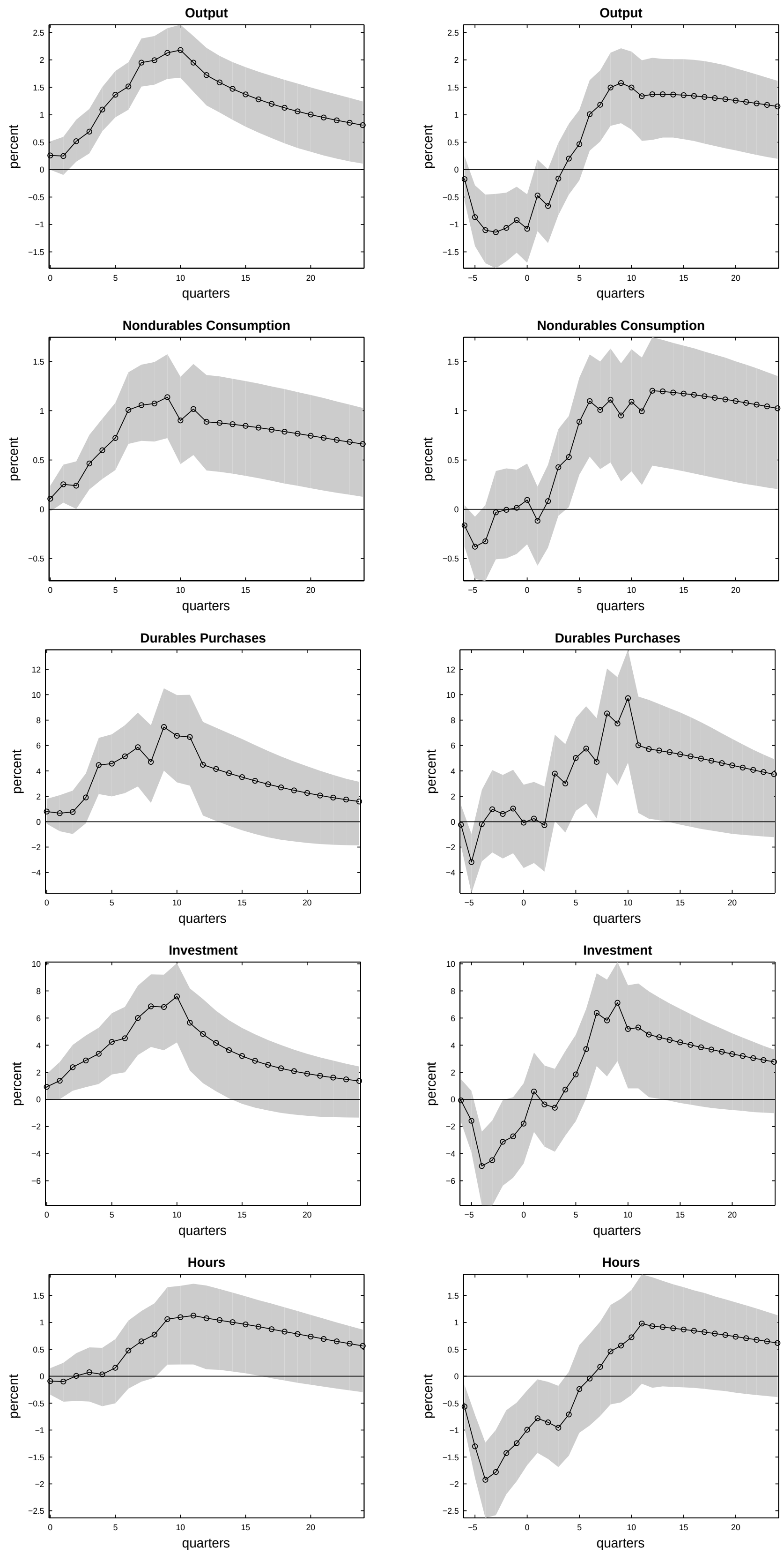

Figure 2: The Responses to Tax Shocks in the U.S.

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

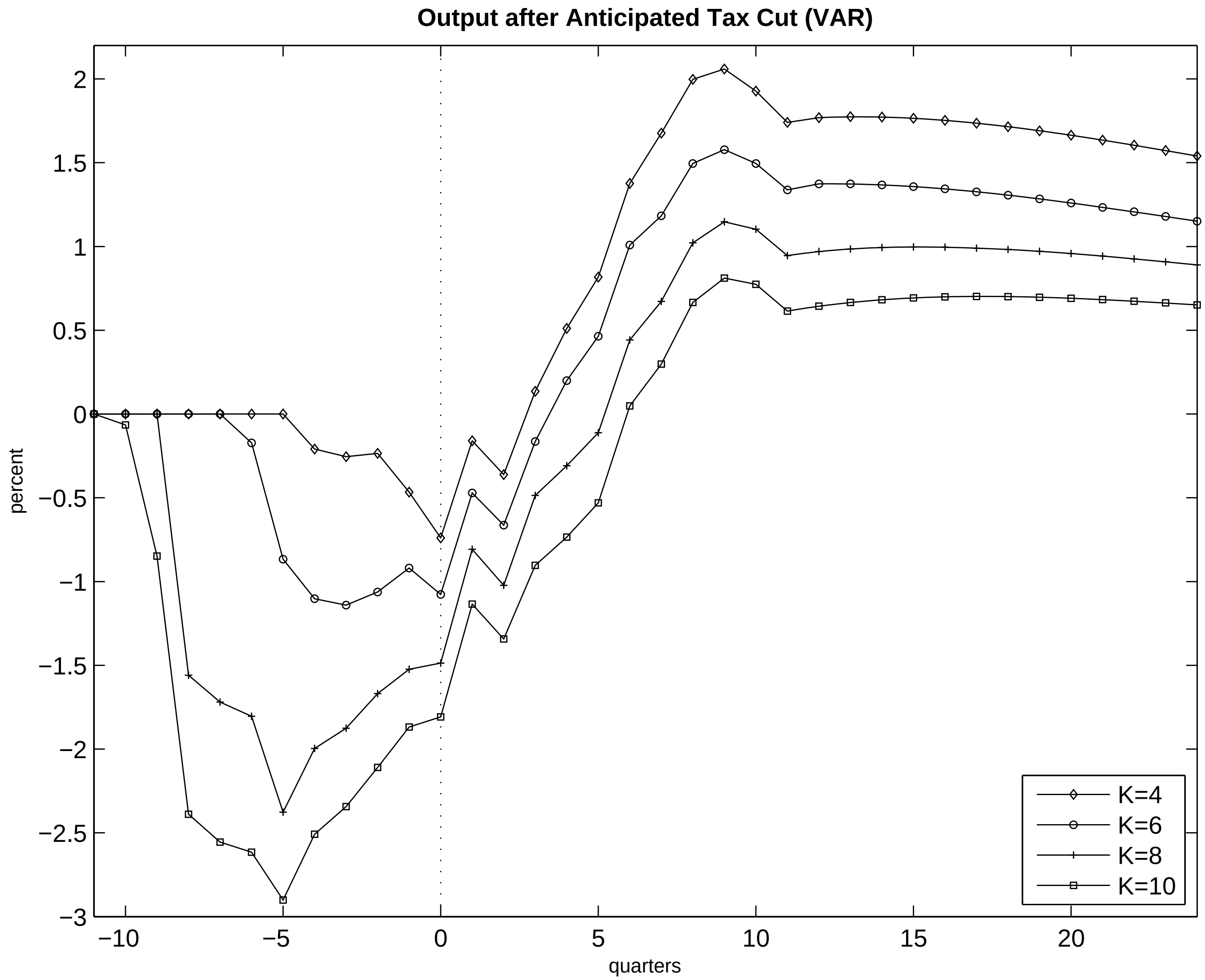

Figure 3: The Effects of Anticipated Tax Cuts for Alternative Anticipation Horizons.

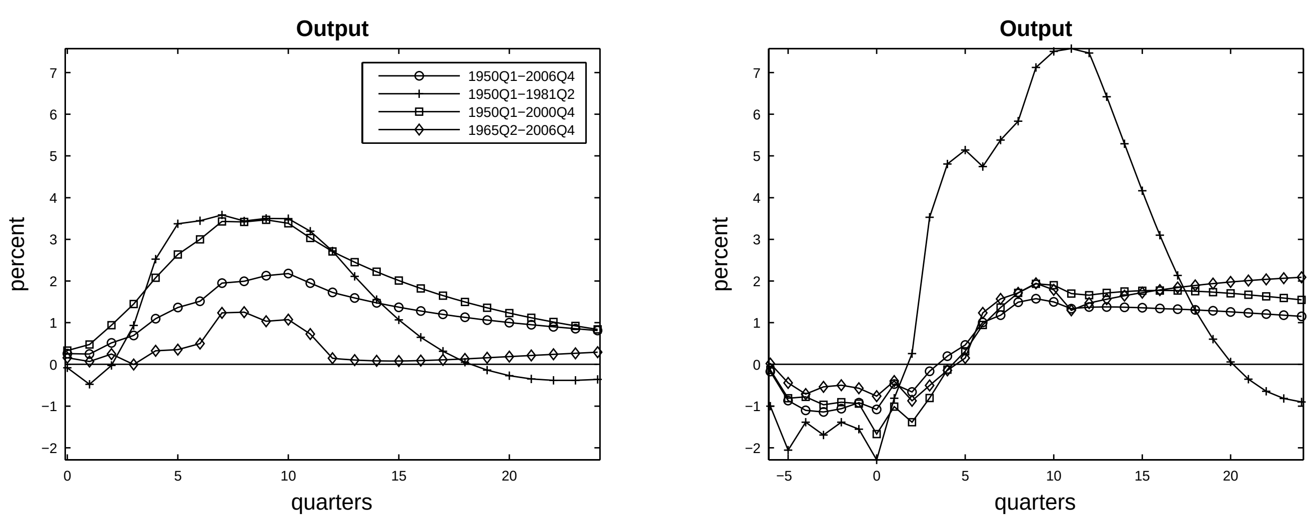

Figure 4. The Effects of Tax Shocks for Alternative Sample Periods

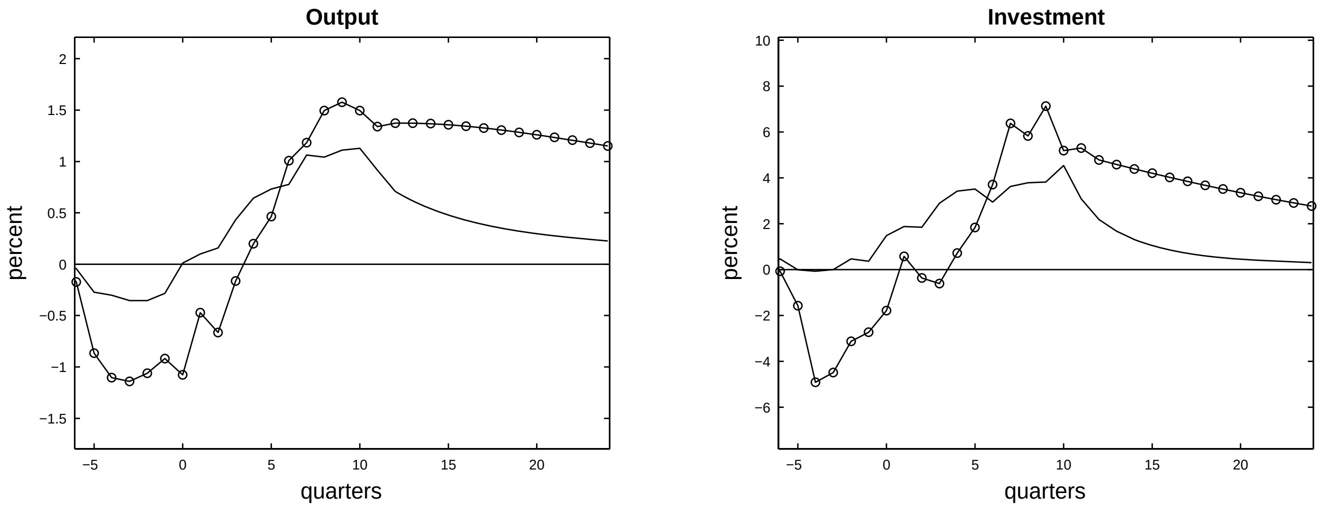

Figure 5: The Response to Leads of Surprise Tax Liability Changes

(full drawn lines show the response to leads of surprise tax liability changes estimated from equation (3); lines with circles show the response to anticipated tax liability changes)

Unanticipated Tax Laibility Cut | Anticipated Tax Liability Cut

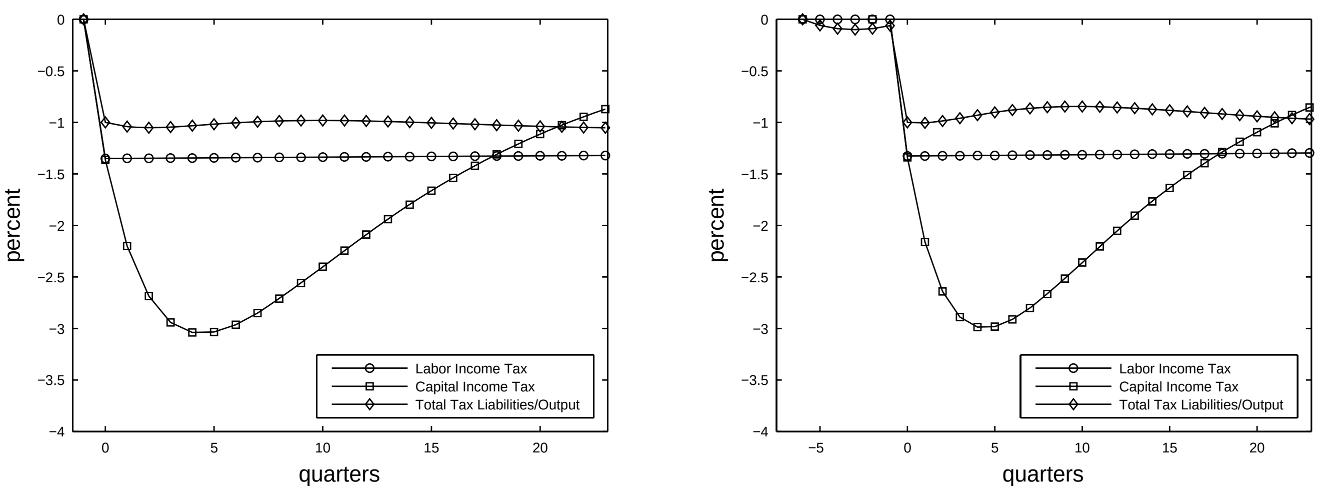

Figure 6: The Dynamics of Taxes in the Model Economy

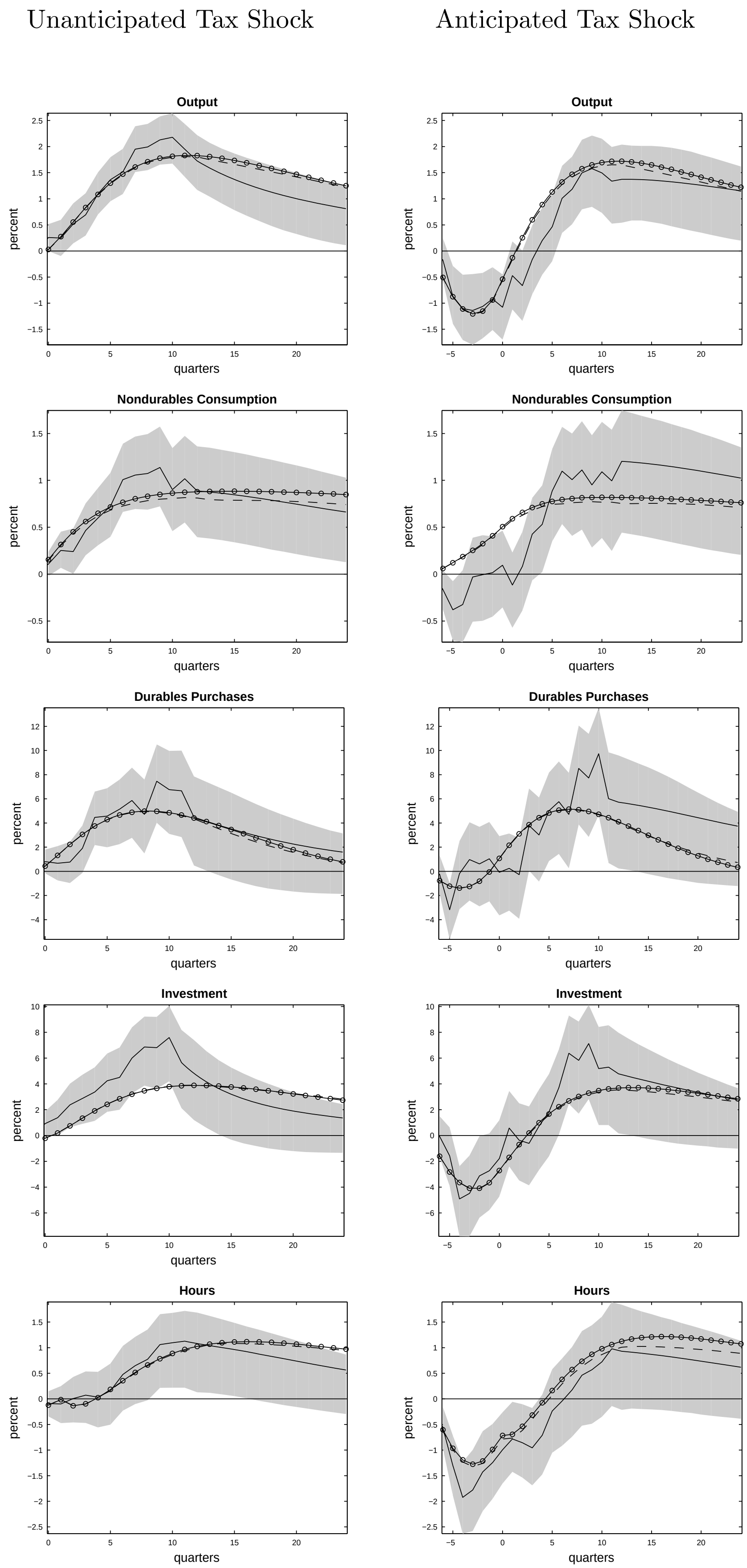

Figure 7: The Impulse Responses of the Benchmark Model (full drawn lines: empirical IRs, dotted lines: the model IRs imposing a VAR, lines with circles: the exact model IRs)

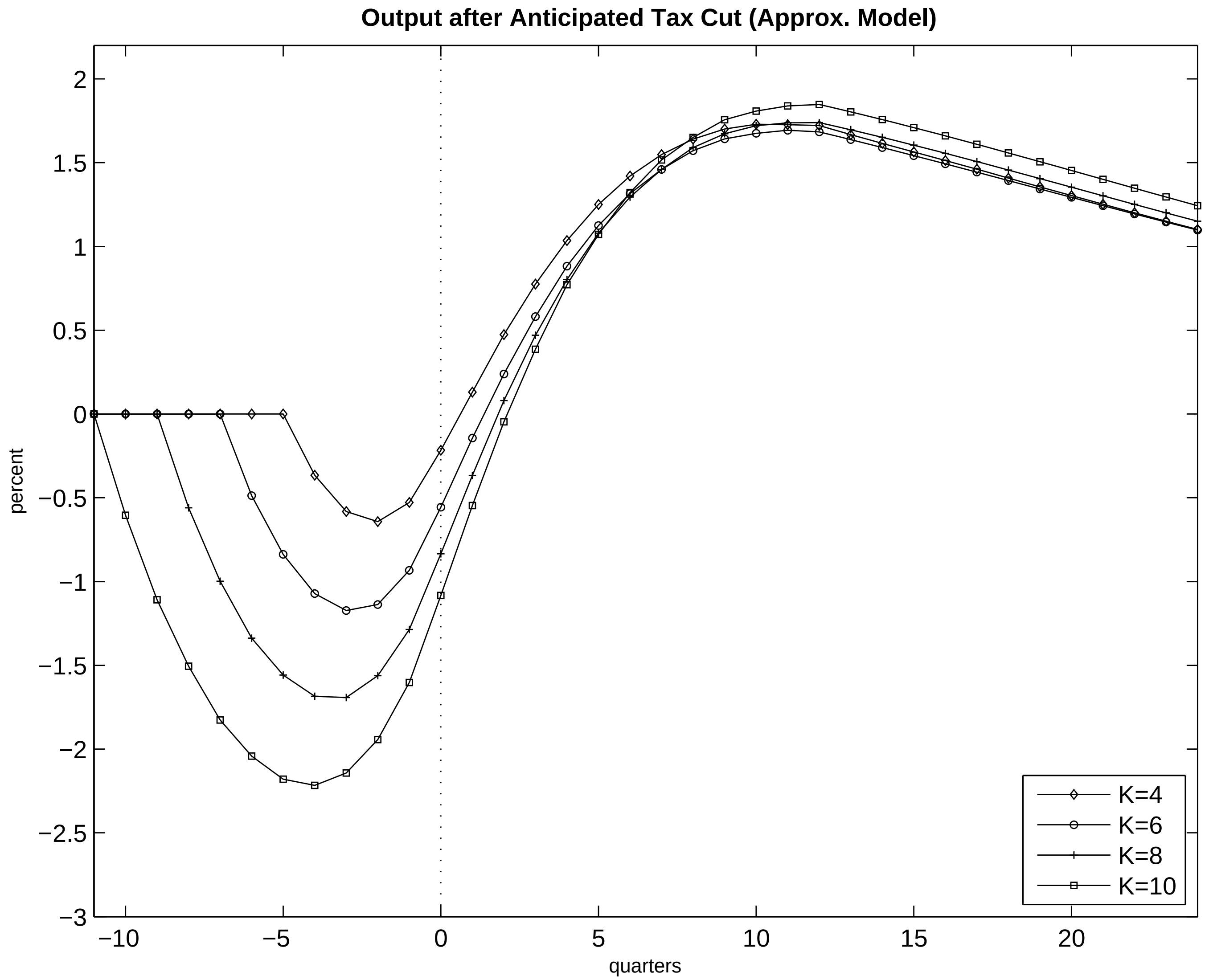

Figure 8: The Dependence of the Dynamics of Output on the Anticipation Horizon in the Model

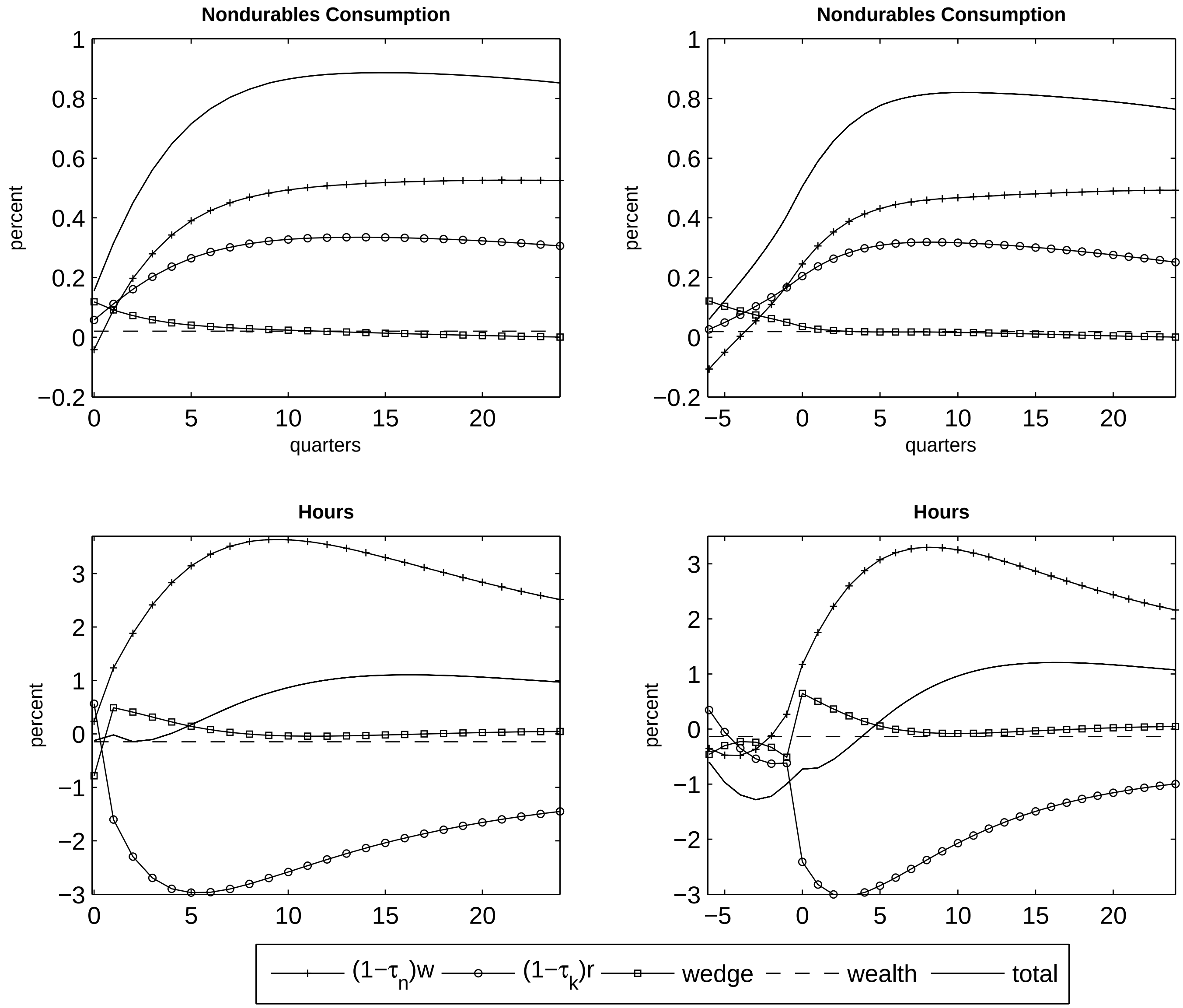

Figure 9. The Decomposition of the Consumption and Hours Response

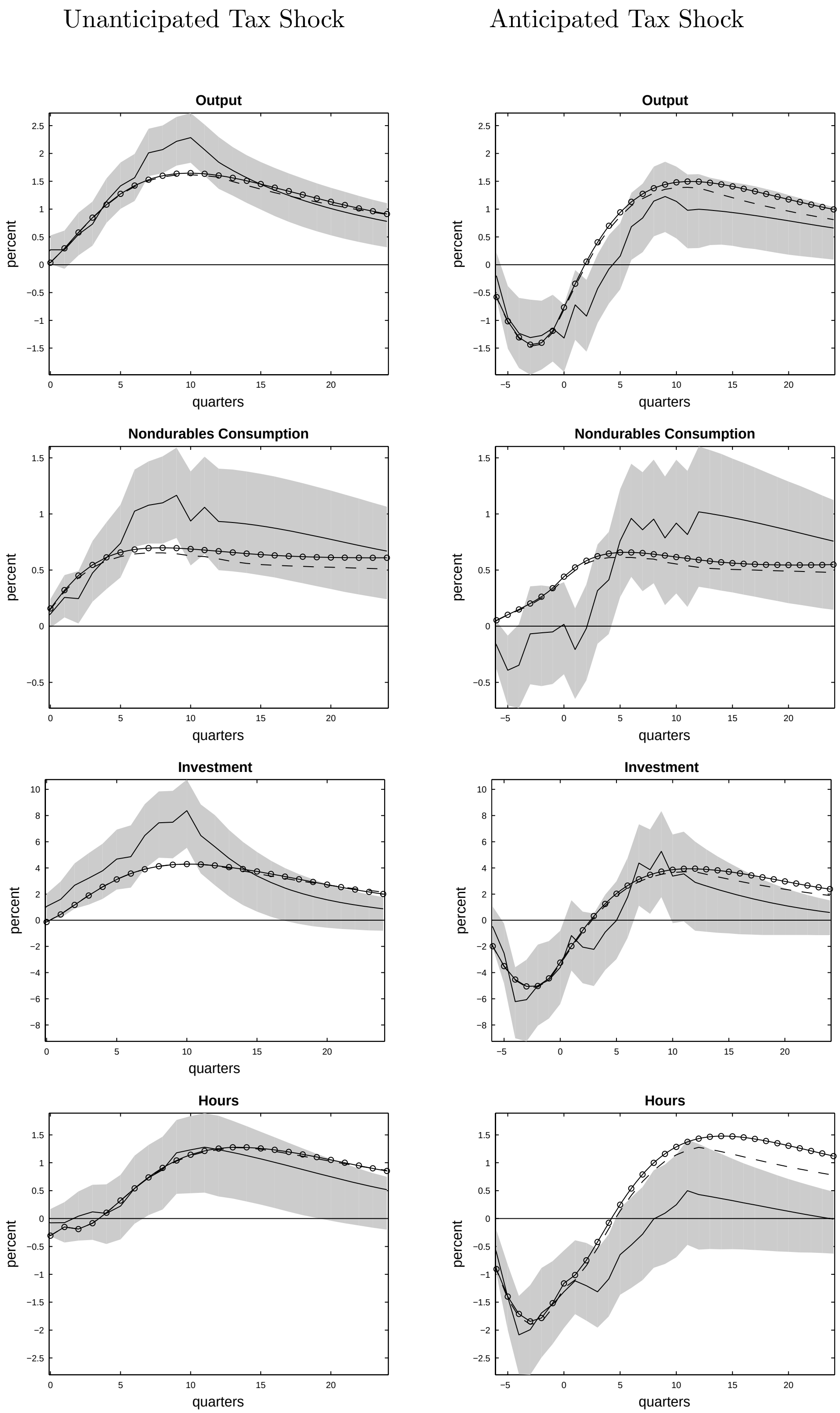

Figure 10: The Model with no Durable Consumption Goods

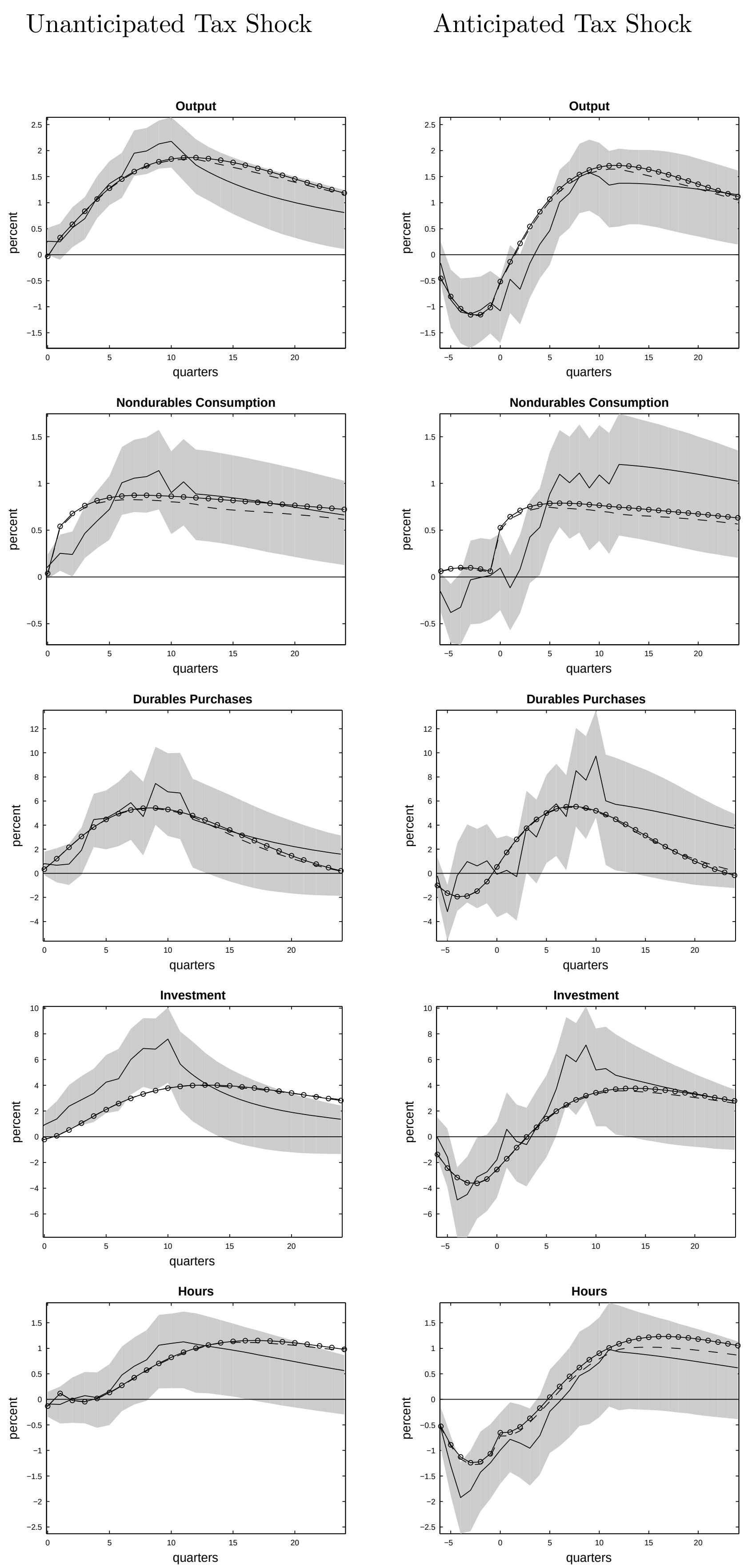

Figure 11: The Model with no Habit Formation

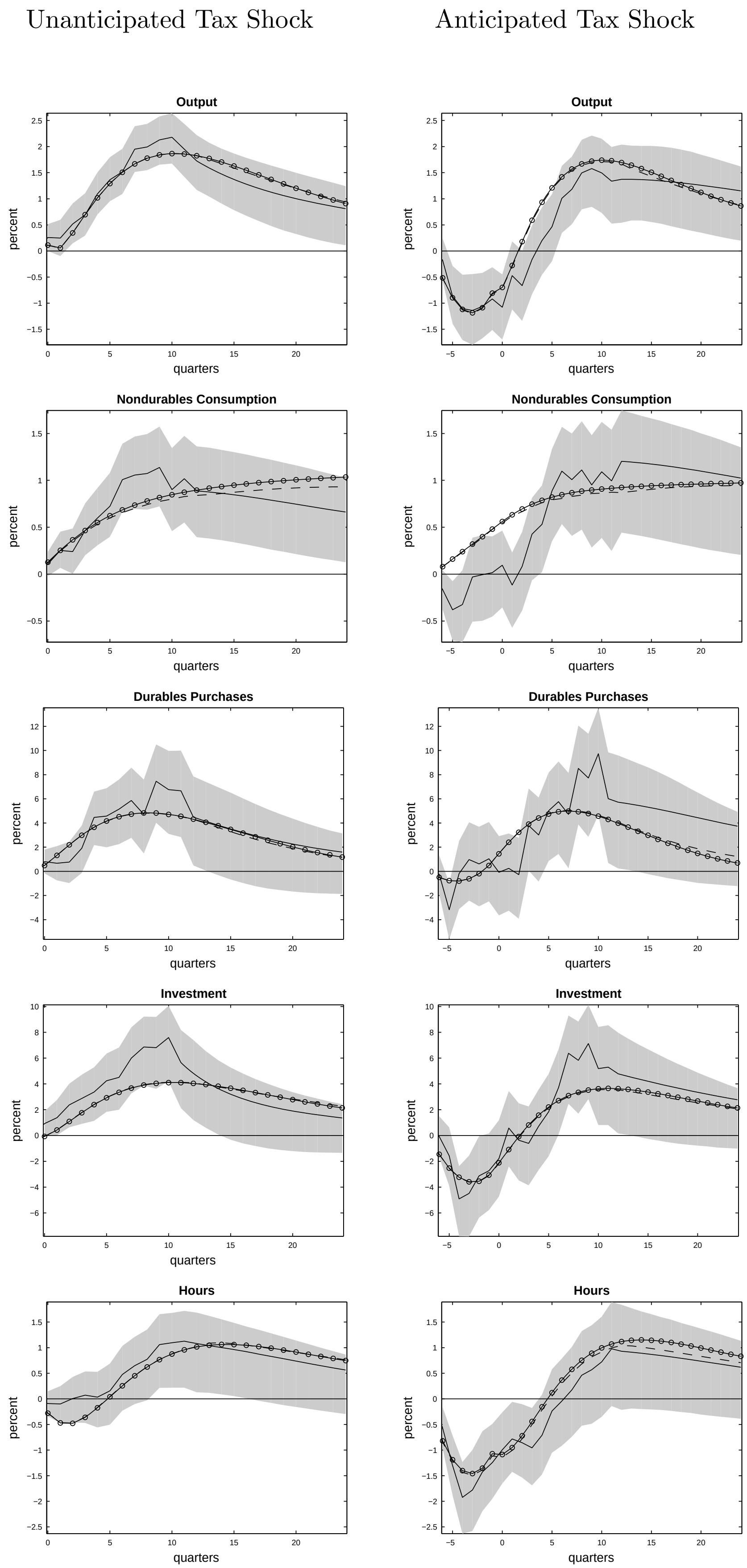

Figure 12: The Model with Endogenous Government Spending

Unanticipated Tax Shock Anticipated Tax Shock

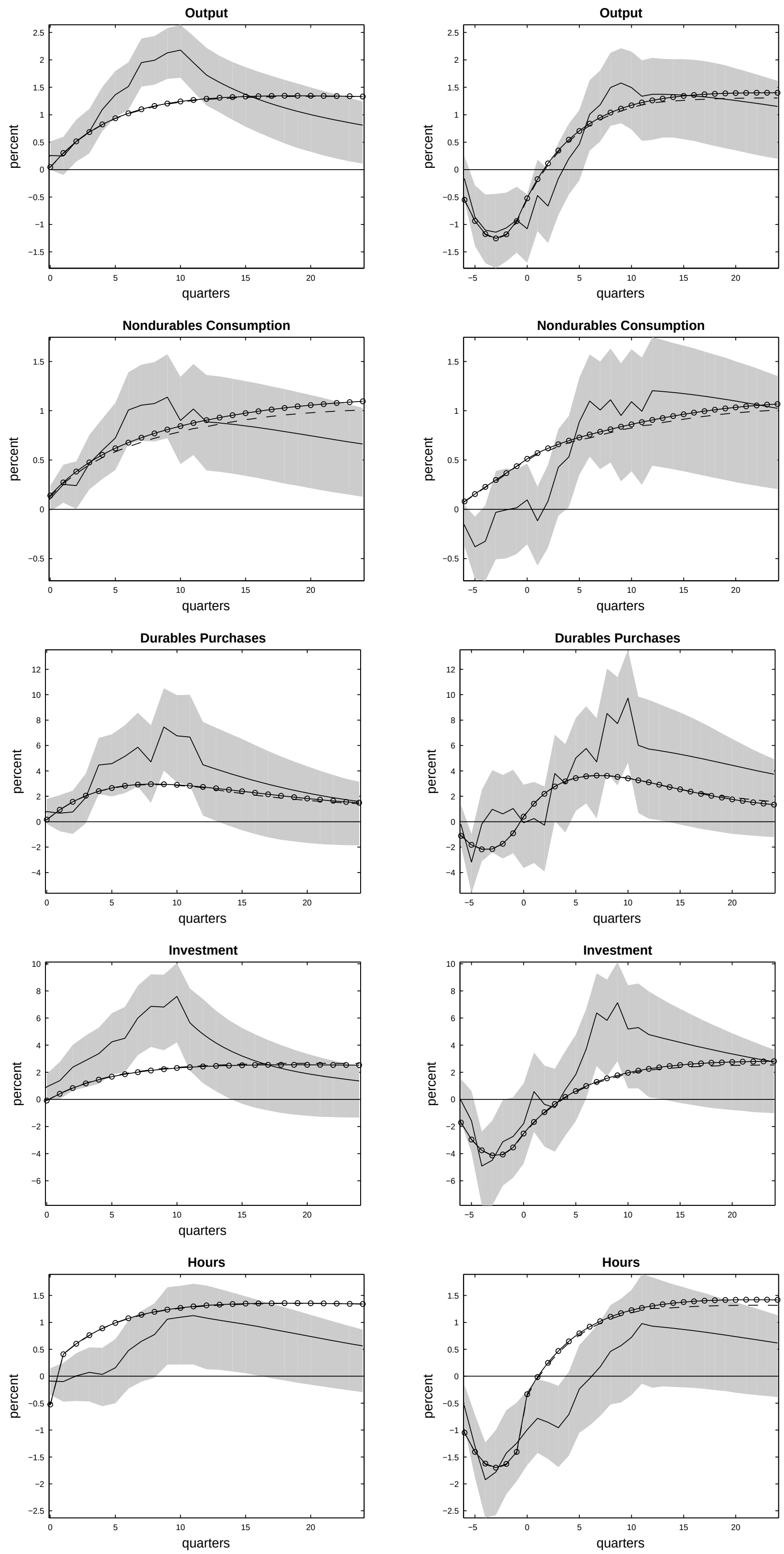

Figure 13: The Model with Constant Capital Income Taxes

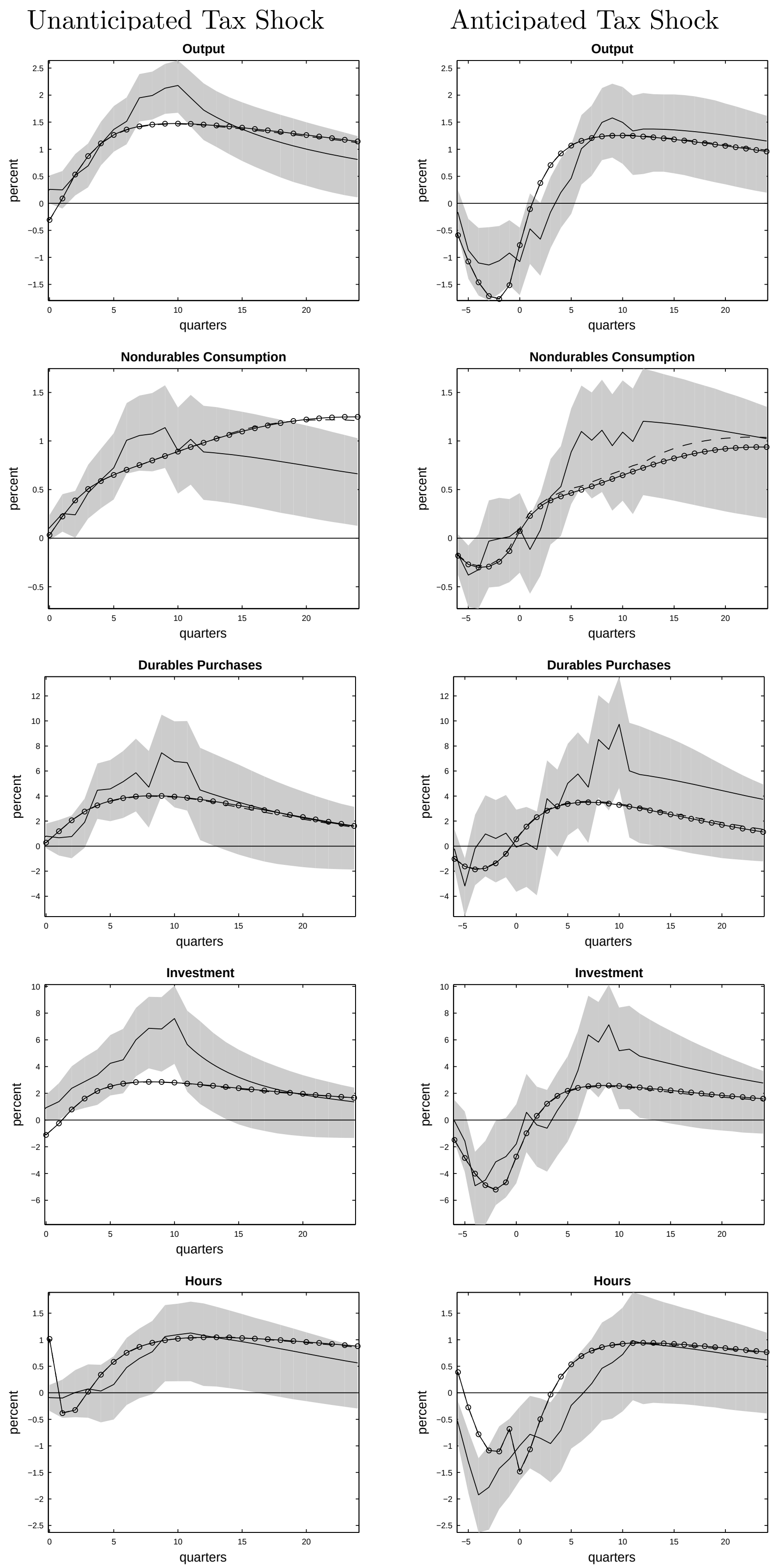

Figure 14: The Model with Constant Labor Income Taxes

A. Surprise Tax Changes B. Anticipated Tax Changes

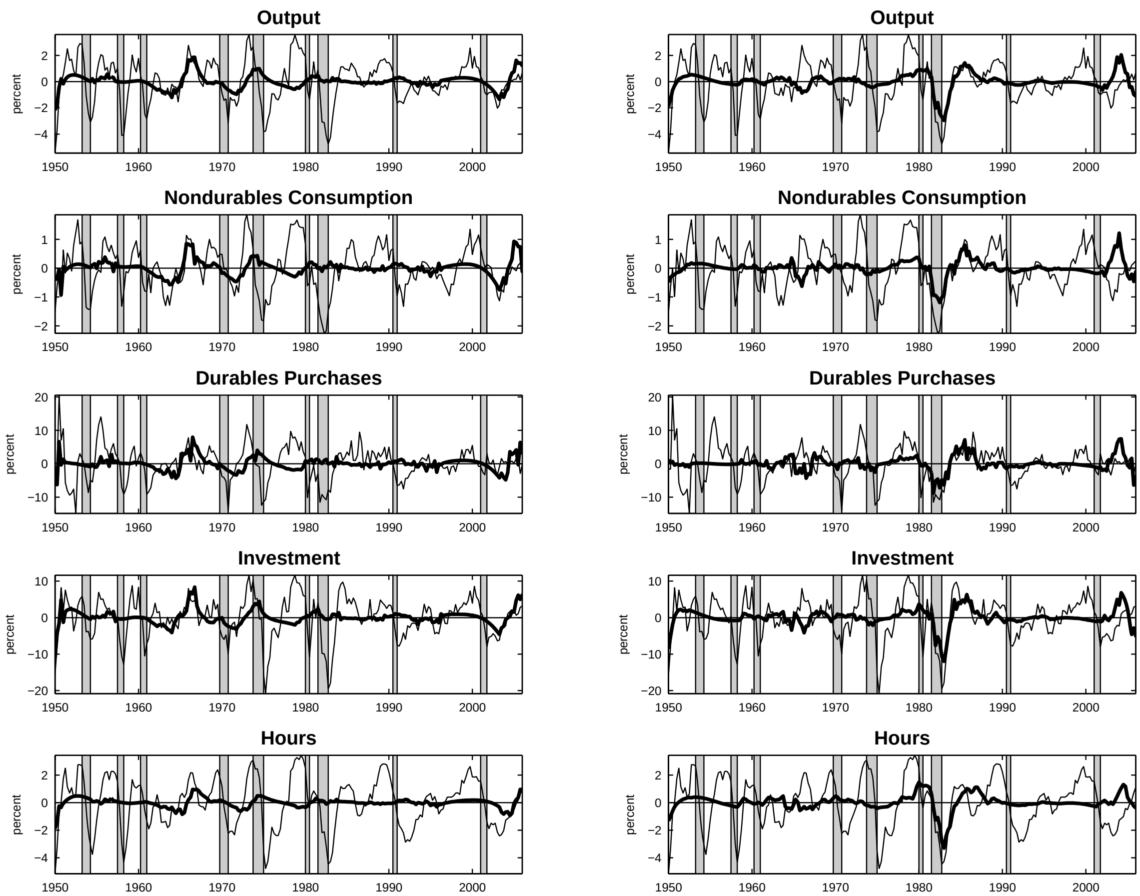

Figure 15: Actual and Counterfactual Time Series

(the thin lines show the actual time series, the thick lines show the counterfactual time series, all time series have been HP-filtered; Shaded areas indicate NBER recessions)

C. All Tax Changes

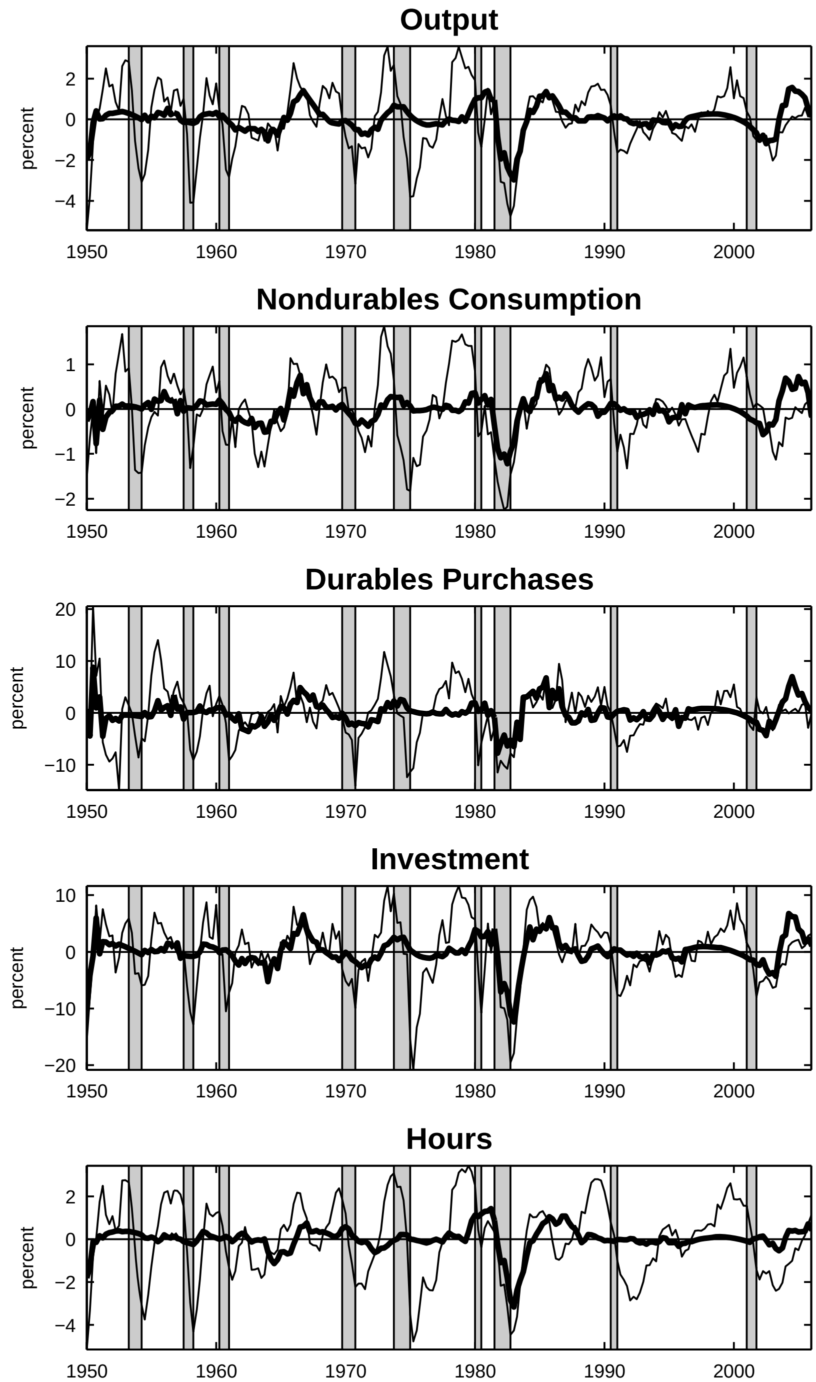

Figure 15: Actual and Counterfactual Time Series

(the thin lines show the actual time series, the thick lines show the counterfactual time series, all time series have been HP-filtered; Shaded areas indicate NBER recessions)