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

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Abstract

This paper evaluates the extent to which a DSGE model can account for the impact of tax policy shocks. We estimate the response of macroeconomic aggregates to anticipated and unanticipated tax shocks in the U.S. and find that unanticipated tax cuts have persistent expansionary effects on output, consumption, investment and hours worked. Anticipated tax cuts give rise to contractions in output, investment and hours worked prior to their implementation, while stimulating the economy when implemented. We show that a DSGE model can account quite successfully for these findings. The main features of the model are adjustment costs, consumption durables, variable capacity utilization and habit formation.

JEL classification: E20, E32, E62, H30

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1 Introduction

This paper studies the aggregate dynamic macroeconomic effects of tax liability changes. Studying post World War II US time series, we find that implemented tax cuts provide a major stimulus to the economy. Pre-announced tax cuts instead lead to declines in economic activity prior to implementation while providing a stimulus similar to that of unanticipated tax cuts when implemented. We confront a DSGE model with this empirical evidence and demonstrate how it can account for the key features of the estimated effects of tax changes. These findings are important because they indicate that DSGE models are meaningful for the evaluation of the dynamic adjustment to tax policy interventions.

The empirical analysis builds on Mertens and Ravn (2009). The measurement of tax shocks is based on Romer and Romer’s (2008a) narrative account of federal US tax liability changes for the postwar period. We study the impact of those changes in tax liabilities that Romer and Romer (2008a) classify as exogenous and we introduce a timing convention that facilitates a distinction between anticipated and unanticipated tax changes. To be precise, our timing convention is based on the observed implementation lag, the difference between the date at which the tax liability change was implemented and the date that it became law. When this implementation lag exceeds (is shorter than) 90 days, we define the tax change as anticipated (unanticipated).

The anticipated and unanticipated tax shocks are embedded in vector autoregressions (VARs) in order to derive estimates of the dynamic effects of tax policy shocks. We find that unanticipated tax cuts give rise to significant increases in output, consumption, and investment, and a gradual increase in hours worked. Assuming that anticipated tax shocks are announced 6 quarters before their implementation, the median anticipation horizon in the data, we find that an anticipated tax cut is associated with a pre-implementation drop in output, investment and hours worked, while consumption remains roughly constant during the pre-implementation period. Once the tax change is implemented, we find that its impact is very similar to the effects of an unanticipated tax change. Thus, we find significant responses to tax news.

We then construct a dynamic stochastic general equilibrium (DSGE) model in which anticipated and unanticipated variations in distortionary capital and labor income tax rates give rise to changes in tax liabilities. The key features of the benchmark model are consumer durables, habit formation, variable capacity utilization, and
inclusion adjustment costs. Key structural parameters are estimated by indirect inference.

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

Another important insight relates to the anticipation effects on consumption of nondurable goods and services. Our empirical results from the U.S. data agree with earlier studies of the consumption response to anticipated tax changes. Poterba (1988) tests whether aggregate U.S. consumption reacts to announcements of future tax changes and fails to find robust evidence in favor of this hypothesis.1 Parker (1999) and Souleles (1999, 2002) study Consumer Expenditure Survey (CEX) data and show that consumption responds to the implementation of tax changes rather than to their announcements.2 Similarly, Heim (2007) studies announcements effects of state tax rebates on household consumption using CEX data and also finds no response of consumption to tax announcements. These results are often interpreted as evidence in favor of the presence of binding liquidity constraints or against forward looking behavior. For this reason we introduce into the model rule-of-thumb consumers next to intertemporally maximizing agents and find that their estimated share in total consumption is a relatively modest 14.6 percent. We find a low estimate of the share of rule-of-thumb agents because, when the share of rule-of-thumb consumers is large, the model cannot account for the impact of tax news on aggregate investment and hours worked.

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1Poterba (1988) identifies five such episodes: February 1964, June 1968, March 1975, August 1981, and August 1986. We exclude the second and third of these episodes because Romer and Romer (2008a) categorize these tax changes as endogenous.

Our results contribute to the existing literature on the macroeconomic effects of tax changes, such as Baxter and King (1993), Braun (1994) and McGrattan (1994), and tax foresight, such as Yang (2005) and House and Shapiro (2006, 2008). Yang (2005) builds a simple DSGE model and shows that in response to an anticipated cut in the labor tax rate, consumption rises during the pre-implementation period while output, investment and hours worked contract; in response to an anticipated cut in the capital income tax rate instead, the opposite pattern is implied. We demonstrate that, in an economy with a more rigorous modeling of production and preference structures and with reasonable adjustment costs, the anticipation effects of capital income and labor income tax changes can be quite similar. We conduct a Hicksian decomposition of hours worked and consumption responses to changes in taxes into wealth effects and substitution effects that derive from changes in wages and interest rates. The responses of consumption and hours worked are dominated by substitution effects, while the wealth effects are very small. The key to understanding the sluggish hours response to surprise changes in taxes are the opposing substitution effects due to wages and interest rates.

The remainder of this paper is structured as follows. The next section describes our estimation approach and discusses the dynamic effects of tax shocks. Section 3 contains the description of the DSGE model. The estimation of the structural parameters is contained in Section 4. In Section 5 we discuss and analyze the results and Section 6 provides some extensions and robustness exercises. Finally, Section 7 concludes.

2 Reduced Form Evidence on the Effects of Tax Shocks

In this section we present VAR evidence on the impact of anticipated and unanticipated tax shocks. The methodology is based on Mertens and Ravn (2009), but the results presented here are obtained from a larger dimensional VAR. We refer the reader to that paper for a more detailed analysis of the data as well as extensive robustness analysis.

2.1 Empirical Specification and Identification

We identify tax shocks using Romer and Romer’s (2008a) narrative account of historical US legislated federal tax liability changes. Based on analyses of official government documents, presidential speeches, and Congressional documents, these authors identify 51 legislated federal tax acts in the period 1947-2006 and a total of 110
separate changes in tax liabilities. We focus on the tax liability changes that Romer and Romer (2008a) classify as exogenous and are motivated either by long run growth objectives or by concerns about inherited debt. This results in a time series of 70 tax liability changes in total.

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

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

\[
X_t = A + Bt + C(L)X_{t-1} + D(L)\tau_u^t + F(L)\tau^a_{t,0} + \sum_{i=1}^{K} G_i \tau^a_{t,i} + \epsilon_t
\]  

(1)

where \(X_t\) is a vector of endogenous variables, \(A\) and \(B\) control for a constant term and a linear trend, \(C(L)\) is a \(P\)-order lag polynomial, and \(D(L)\) and \(F(L)\) are \((R+1)\)-order lag polynomials. \(\tau_u^t\) denotes unanticipated tax shocks which we measure as the dollar changes in tax liabilities as a percentage of current price GDP at the implementation date. \(\tau^a_{t,i}\) are the pre-announced tax changes which are known at date \(t\) and which are to be implemented at date \(t+i\). This variable is the sum of all tax liability changes announced today or in the past which have the same implementation date. The regression model therefore allows \(X_t\) to depend on lags of current and past changes in taxes through the terms \(D(L)\tau_u^t\) and \(F(L)\tau^a_{t,0}\), and on currently known, but not yet implemented, changes in taxes through the terms \(\sum_{i=1}^{K} G_i \tau^a_{t,i}\). This latter term therefore captures directly the effects of tax news shocks.

We study US quarterly data for the sample period 1947:1 - 2006:4 for \(X_t = [y_t, c_t, d_t, i_t, h_t]'\), where \(y_t\) denotes

\(^3\)In order to measure these we assume that pre-announced tax shocks enter agents’ information sets at the earliest \(M\) quarters before their implementation. We set \(M\) equal to 16, i.e. 4 years.
the logarithm of US 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 1.

A key assumption is that the Romer and Romer tax liability changes that we examine can be treated as observable exogenous shocks. The fact that the tax shocks are treated as observable allows us to derive the representation of the observables in (1) controlling directly for moving average terms in the implemented tax shocks through the polynomials \( D(L) \) and \( F(L) \). As we will show later, this also allows us to obtain precise estimates of the impulse responses for low orders of \( C(L) \). However, this does mean that exogeneity of the tax shocks is crucial. Recall from above that we eliminate all tax changes that Romer and Romer (2008a) categorize as endogenous. However, one may still question the extent to which Romer and Romer’s (2008a) classification scheme leads to truly exogenous tax innovations. In Mertens and Ravn (2009) we test formally whether past values of observables have predictive power for the tax liability changes and conclude there is no strong evidence of predictability.\(^4\) This does not exclude the possibility that tax liability changes are simply contemporaneous responses to variations in \( X_t \). It is extremely difficult to tell this hypothesis apart from our hypothesis that tax changes affect \( X_t \) contemporaneously. In practice, we believe that legislative lags make it very likely that contemporaneous causality runs from changes in tax legislation to observables and not vice versa.

### 2.2 Empirical Results

We set \( K = 6 \), which corresponds to the median implementation lag in the data that we study, \( R = 12 \), and \( P = 1 \) (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 10,000 replications. The impulse response functions are shown for a forecast horizon of 24 quarters for unanticipated tax liability shocks, and for 6 quarters before its implementation to 24 quarters after the implementation in the case of anticipated shocks.

Column (a) of Figure 1 shows the impact of an unanticipated tax liability cut. The decrease in taxes sets off

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\(^4\)In contrast, repeating these tests for tax liability changes that Romer and Romer (2008a) deem endogenous leads to clear rejection of the null no predictability from past observables.
a large expansion in the economy characterized by persistent and hump shaped dynamics of the endogenous variables. Investment and consumer durables purchases display by far the largest elasticities to the cut in tax liabilities. Investment increases by around 1 percent point in the first quarter and continues to rise until 10 quarters after the change in tax liabilities where it peaks at 7.7 percent above trend. Consumer durables purchases respond much the same way and peaks at 7.3 percent above trend 9 quarters after the tax cut. Output increases more moderately and reaches a peak increase of 2.2 percent above trend 10 quarters after the tax cut. The impact on hours worked, instead, is estimated to be close to zero until around a year and a half after the change in taxes. After that, hours worked increase gradually to a peak at 1.1 percent above trend 10 quarters after the tax shock. Consumption of nondurables and services adjusts a bit faster to the tax cut and reaches a peak response of 1.1 percent 9 quarters after the tax cut.

Column (b) of Figure 1 shows the impact of an anticipated tax liability cut. The results provide evidence for anticipation effects: The announcement (by legislation) of a future tax liability reduction sets off a downturn in the economy that lasts until the tax cut is eventually implemented. Investment falls 4.5 percent below trend one year before the tax cut is implemented. The peak drop in investment is statistically significant. Output drops 1.1 percent four quarters before the tax liability cut is implemented. The decrease in output is statistically significant from zero during almost the entire pre-implementation period. Hours worked also drop significantly below trend throughout the announcement period down to 1.9 percent below trend 4 quarters before the tax cut. We find a 2.7 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 is 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. The absence of a strong news effect on consumption of nondurables and services are consistent with previous studies examining how anticipated tax changes affect consumption choices.

The actual implementation of the anticipated tax cut is associated with an expansion in the economy similar to the impact of an unanticipated tax cut. Apart from hours worked, the increase in activity occurs slightly faster than in response to unanticipated tax cuts. At forecast horizons beyond two years, anticipated and unanticipated changes in taxes have very similar effects. The maximum increase in output (a 1.7 rise above trend) occurs 9 quarters after the tax cut is implemented, while investment peaks at 7.5 percent above trend (also 9 quarters
after the cut in the taxes). As in the case of unanticipated tax cuts, the consumption response reaches its new higher level relatively quickly. The response of hours worked is somewhat weaker than the other variables in the post-implementation period (and imprecisely estimated). The sizes of the implementation-to-peak responses of the endogenous variables in response to the anticipated tax cut are very similar to the peak impacts in response to unanticipated tax cuts. Thus, the main differences between the impact of an implemented anticipated and unanticipated tax cut is that the peak response occurs somewhat earlier in the latter case.

In deriving these results, we have assumed that pre-announced tax changes can have an impact on $X_t$ from a maximum of 6 quarters before their implementation. Panel (a) in Figure 2 illustrates the impact of an anticipated tax liability cut when we vary $K$, the maximum anticipation horizon, between 4 and 10 quarters. For values of $K$ in this range, there is always an output decline prior to implementation and an output expansion after implementation of the tax cut. The depth of the pre-implementation downturn and the size of the post-implementation expansion are sensitive to $K$: the longer the anticipation horizon (amongst the values that we examine), the deeper is the pre-implementation downturn and the milder is the post-implementation expansion. In Section 4 we will examine whether these results are consistent with economic theory.

In the literature that has estimated the impact of fiscal shocks using vector autoregressions, c.f. Blanchard and Perotti (2002), it has been argued that the impact of tax shocks are much smaller in the post-1980’s sample than in the earlier parts of the sample. We have examined these issues and the results turn out to depend much upon the specification of the empirical model. Reestimating equation (1) directly for data starting in 1980:1 implies a much smaller impact of surprise tax shocks but not substantially smaller (or different) effects of anticipated tax shocks. However, this change in the estimates of the impact of surprise tax shocks may be due to the fact that the empirical model implies that a large amount of parameters are estimated with relatively few datapoints thus leading to few degrees of freedom and more pertinent small sample problems.\(^5\) Moreover, it turns out that most of the larger and more informative surprise tax changes occur in the pre-1980 sample. An alternative check on the stability of the results is to exclude certain tax legislations from the sample. As discussed in Mertens and Ravn (2009) this exercise points towards stability of the results.

\(^5\)The empirical model implies that 37 parameters are estimated for each observable. In the post 1980’s sample there are 108 observations.
3 Theory

In this section we investigate whether a dynamic stochastic general equilibrium model can account for the empirical results derived above. We extend earlier DSGE models of distortionary taxation, such as Baxter and King (1993), Braun (1994) and McGrattan (1994), by introducing features such as habit formation, adjustment costs, durables consumption, and variable capacity utilization. Burnside, Eichenbaum and Fisher (2004) stress the importance of habit formation and adjustment costs for accounting for the impact of fiscal policy shocks. The model also builds on other DSGE models of fiscal policy with anticipation effects, such as Yang (2005), House and Shapiro (2006), Leeper and Yang (2006) and Ramey (2009).

3.1 The Benchmark Model

Households There is a large number of identical, infinitely lived households. We will later allow for heterogeneous households to study the role of limited asset market participation. The representative household’s preferences are given by:

\[
U_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{x_t^{1-\sigma} - 1}{1 - \sigma} - z_t^{1-\sigma} \frac{\omega}{1 + \kappa} n_t^{1+\kappa} \right)
\]

\(\mathbb{E}_t\) is the mathematical expectations operator conditional on all information available at date \(t\), \(0 < \beta < 1\) is a discount factor, \(\sigma > 0\) is a curvature parameter, \(\omega > 0\) is a preference weight, \(1/\kappa \geq 0\) is the Frisch elasticity of labor supply, and \(n_t\) denotes hours worked. \(z_t\) denotes the level of labor augmenting technology which we assume grows at a constant rate, \(z_t/z_{t-1} = \gamma z\). The term \(z_t^{1-\sigma}\) that affects the disutility of work is introduced to allow for a balanced growth path. The variable \(x_t\) is a habit-adjusted consumption basket defined as

\[
x_t = C_t^\vartheta V_t^{1-\vartheta} - \mu C_{t-1}^\vartheta V_{t-1}^{1-\vartheta}
\]

where \(\vartheta \in [0,1]\) is a share parameter, \(\mu \in [0,1]\) is a habit persistence parameter, \(C_t \geq 0\) denotes consumption of consumer nondurables and \(V_t \geq 0\) denotes the stock of consumer durables.
The representative household maximizes (2) subject to the following set of constraints:

\begin{align*}
V_{t+1} &= (1 - \Phi_v(D_t/D_{t-1})) D_t + (1 - \delta_v) V_t \quad (4) \\
K_{t+1} &= (1 - \Phi_k(I_t/I_{t-1})) I_t + (1 - \delta_k - \Psi_k(u_{k,t})) K_t \quad (5) \\
C_t + D_t + I_t &\leq (1 - \tau_{n,t}) w_t n_t + (1 - \tau_{k,t}) r_t u_{k,t} K_t + \Lambda_t + TRA_t \quad (6)
\end{align*}

Equation (4) is the law of motion for the stock of consumer durables. \( D_t \) denotes purchases of new consumer durables, \( \Phi_v(D_t/D_{t-1}) \) captures consumer durables adjustment costs, and \( \delta_v \) is the rate of depreciation of the consumer durables stock. Adjustment costs are assumed to be convex but zero along the balanced growth path implying the restrictions \( \Phi''_v \geq 0 \) and \( \Phi'_v(\gamma_z) = \Phi''_v(\gamma_z) = 0 \). Equation (5) is the law of motion for the stock of capital, \( K_t \geq 0 \), which households rent out to firms. We allow for variable capital utilization, \( u_{k,t} \geq 0 \), and assume that capital services are given by \( u_{k,t} K_t \). \( \Phi_k(I_t/I_{t-1}) \) denotes investment adjustment costs and \( \Psi_k(u_{k,t}) \) 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 we also introduce the restrictions that \( \Psi_k(1) = \Phi_k(\gamma_z) = \Phi'_k(\gamma_z) = 0 \). \( \delta_k \) is therefore the depreciation rate of the capital stock along the balanced growth path. Equation (6) is the flow budget constraint in period \( t \). The left hand side of this equation is household expenditure on both types of consumption goods and on physical capital. The right hand side is the income flow net of taxes. The term \( (1 - \tau_{n,t}) w_t n_t \) denotes after-tax labor income, the product of hours worked and the real wage \( w_t \), net of labor income taxes. \( \tau_{n,t} \) is the labor income tax rate. \( (1 - \tau_{k,t}) r_t u_{k,t} K_t \) is after-tax income from renting capital stock. \( r_t \) denotes the rental rate of capital services and \( \tau_{k,t} \) is the capital income tax rate. \( \Lambda_t \) and \( TRA_t \) denote depreciation allowances and lump-sum government transfers, respectively.

Following Auerbach (1989), we specify depreciation allowances as

\[ \Lambda_t = \tau_{k,t} \sum_{s=1}^{\infty} \delta_t (1 - \delta_t)^{s-1} I_{t-s} \quad (7) \]

where \( \delta_t \) denotes the rate of depreciation for tax purposes. Note that this specification allows the depreciation rate for tax purposes \( \delta_t \) to differ from \( \delta_k \).
The first-order conditions for the household’s problem are given as:

\[ C_t = \lambda_{c,t} = (x_t - \mu \beta \pi x_{t+1}) \cdot (V_t / C_t)^{1-\delta} \]  
\[ n_t = \zeta_t^{1-\delta} \omega n_t = \lambda_{c,t} (1 - \tau_{n,t}) w_t \]  
\[ K_{t+1} = \lambda_{c,t} q_{k,t} = \beta \mathbb{E}_t \lambda_{c,t+1} [(1 - \tau_{k,t+1}) r_{t+1} u_{k,t+1} + q_{k,t+1} (1 - \delta_k - \Psi_k (u_{k,t+1}))] \]  
\[ V_{t+1} = \lambda_{c,t} q_{v,t} = \beta \mathbb{E}_t \lambda_{c,t+1} [(1 - \delta) C_{t+1}]/(\delta V_{t+1}) + q_{v,t+1} (1 - \delta_v)] \]  
\[ I_t = 1 - q_{k,t} (1 - \Phi_k (I/I_{t-1}) - \Phi_k' (I/I_{t-1}) I/I_{t-1}) = \beta \mathbb{E}_t \frac{\lambda_{c,t+1}}{\lambda_{c,t}} q_{k,t+1} \Phi_k' (I_{t+1}/I_t) (I_{t+1}/I_t)^2 + \Gamma_t \]  
\[ D_t = 1 - q_{v,t} (1 - \Phi_v (D/D_{t-1}) - \Phi_v' (D/D_{t-1}) D/D_{t-1}) = \beta \mathbb{E}_t \frac{\lambda_{c,t+1}}{\lambda_{c,t}} q_{v,t+1} \Phi_v' (D_{t+1}/D_t) (D_{t+1}/D_t)^2 \]  
\[ u_{k,t} = (1 - \tau_{k,t}) r_t = q_{k,t} \Psi_k' (u_{k,t}) \]  

where \( \lambda_{c,t} \) is the multiplier on (6), \( \lambda_{c,t} q_{k,t} \) is the multiplier on (5) and \( \lambda_{c,t} q_{v,t} \) is the multiplier on (4). The variable \( r_t \) that enters equation (12) is the expected present value of depreciation allowances on new investments. It is determined recursively as

\[ \Gamma_t = \beta \delta \mathbb{E}_t \left[ \frac{\lambda_{c,t+1}}{\lambda_{c,t}} \tau_{k,t+1} \right] + \beta (1 - \delta_v) \mathbb{E}_t \left[ \frac{\lambda_{c,t+1}}{\lambda_{c,t}} \Gamma_{t+1} \right] \]  

Equation (8) sets \( \lambda_{c,t} \) equal to the marginal utility of consumption of nondurables (which depends on both current and future consumption due to habit persistence). Equation (9) equates the marginal rate of substitution between consumption and leisure with the after-tax real wage. Equation (10) equates the shadow value of new capital, \( q_{k,t} \), to the expected present value of the stream of future rental rates net of depreciation. Equation (11) determines the shadow value of new consumer durables, \( q_{v,t} \), as the expected present value of the utility stream generated by the durables stock net of depreciation. The first-order condition for investment in market capital in equation (12) implies that the change in investment is determined by the expected discounted present value of current and future levels of \( q_{k,t} \) and \( \Gamma_t \). When the shadow value of new capital or the value of depreciation allowances rise above their steady state values, the growth rate in investment rises. Similarly, equation (13) determines the growth rate of consumer durables as a function of the expected present discounted value of the stream of shadow values of the consumer durables stock. Equation (14) defines implicitly the optimal utilization rate of market capital as a function of its current net return relative to the shadow value of the capital stock.
Firms  There is a continuum of identical competitive firms with Cobb-Douglas production functions:

\[ Y_t = v (u_k K_t)^\alpha (z_t n_t)^{1-\alpha} \]  

(16)

where \( Y_t \) denotes output, \( v > 0 \) 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. The factor demand functions are given by:

\[ w_t = (1 - \alpha) z_t v (u_k K_t)^\alpha (z_t n_t)^{-\alpha} \]  

(17)

\[ r_t = \alpha v (u_k K_t)^{\alpha-1} (z_t n_t)^{1-\alpha} \]  

(18)

Government  The government purchases goods \( G_t \) from the private sector which it finances with capital and labor income taxes. The government runs a balanced budget,

\[ G_t + TRA_t = T_t \]  

(19)

where \( T_t = \tau_n w_t n_t + \tau_k r_t u_k K_t \) - \( \Lambda_t \) is total income tax revenue (net of depreciation allowances). The process for government spending \( G_t \) is

\[ G_t = (\gamma_T) G_0 (\zeta T_t / Y_t)^{\pi_G} \]  

(20)

where \( \zeta \) is such that \( \zeta T / Y = 1 \) along the balanced growth path. We assume that lump-sum transfers \( TRA_t \) adjust endogenously in response to variations in total tax revenue and in government spending to ensure a balanced budget. By Ricardian equivalence, the results are identical if we instead allow for debt financing. The government spending rule in (20) allows for feedback from total tax revenue \( T_t \) through the parameter \( \pi_G \). This parameter is important for determining the ultimate wealth effects of changes in distortionary tax rates. When \( \pi_G = 0 \), changes in distortionary taxes on labor and capital income are countered by changes in lump-sum taxes and wealth effects in equilibrium only reflect the change in distortions that occur due to replacing (or augmenting) distortionary factor income taxes with lump-sum taxes. When \( \pi_G \neq 0 \), changes in distortionary taxes directly change the present value of current and future government spending.

Labor income and capital income tax rates are assumed to be stochastic. There are two types of innovations to the tax rate processes, unanticipated shocks, \( \epsilon^n_t \) and \( \epsilon^k_t \), and anticipated shocks, \( \xi^n_{t,j} \) and \( \xi^k_{t,j} \) where the latter are
revealed at date $t$ but implemented at date $t + j$. Here we will assume that $j = b$ at the announcement date so that anticipated tax changes are announced with a fixed implementation lag of $b$ periods. The capital income and labor income tax rates evolve according to the stochastic processes:

$$
t_{n,t} = (1 - \rho_{n,1} - \rho_{n,2}) t_n + \rho_{n,1} t_{n,t-1} + \rho_{n,2} t_{n,t-2} + \epsilon_n^t + \xi_{n,t}^b \quad \text{(21)}
$$

$$
t_{k,t} = (1 - \rho_{k,1} - \rho_{k,2}) t_k + \rho_{k,1} t_{k,t-1} + \rho_{k,2} t_{k,t-2} + \epsilon_k^t + \xi_{k,t}^b \quad \text{(22)}
$$

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 $|\rho_{n,1} + \rho_{n,2}| < 1$ and $|\rho_{k,1} + \rho_{k,2}| < 1$. The innovations to the tax rates are assumed to be iid with zero mean, $\epsilon_t \sim iid(0, \Omega_\epsilon)$ and $\xi_t \sim iid(0, \Omega_\xi)$ where $\epsilon_t = [\epsilon_n^t, \epsilon_k^t]'$ and $\xi_t = [\xi_n^b, \xi_k^b]'$. The innovations to both types of tax rates are allowed to be correlated but we assume that $\epsilon_t$ and $\xi_t$ are orthogonal.

**Equilibrium**  
Goods market clearing requires

$$C_t + D_t + I_t + G_t = Y_t \quad \text{(23)}$$

A competitive equilibrium consists of allocations $\{C_t, Y_t, K_{t+1}, V_{t+1}, I_t, D_t, n_t, u_{k,t}\}^{\infty}_{t=0}$, (shadow) prices $\{\lambda_{c,t}, q_{v,t}, q_{k,t}, r_t, w_t\}^{\infty}_{t=0}$ and policies $\{G_t, T R A_t, \tau_{n,t}, \tau_{k,t}\}^{\infty}_{t=1}$ that solve equations (4), (5), (8)-(14) and (16)-(23) subject to the usual boundary conditions.

**Equilibrium Dynamics**  
Variations in $\tau_{n,t}$ and $\tau_{k,t}$ affect the economy through wealth and substitution effects. There are two sources of wealth effects. First, if $\pi_G \neq 0$, shocks to distortionary tax rates affect government spending, change the present discounted value of the taxes required to finance the altered path of government spending and therefore affect household lifetime wealth. Second, changes in distortionary taxes alter households’ expected lifetime utility through Harberger triangles, which in classical utility analysis translates into a wealth effect, see e.g. King (1989). Higher 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 the ratio $\sigma/\kappa$. The higher the Frisch elasticity of labor supply, $1/\kappa$, and the higher is $\sigma$, the larger

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6 In the web appendix we also examine the more flexible case where anticipated taxes are announced with any anticipation lag between 1 and $b$ periods.
is the decline in labor supply relative to the increase in consumption. Substitution effects occur due to changes in relative prices but these effects depend greatly on how taxes are changed and on the model parameters.

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

\[
n^k_t = \beta y_t^{1-\sigma} \left[ \frac{(1-\tau_{n,t}) w_t}{(1-\tau_{n,t+1}) w_{t+1}} R_{k,t+1} n^k_{t+1} \right]
\]

where \( R_{k,t+1} = [(1-\tau_{k,t+1}) r_{t+1} u_{k,t+1} + q_{k,t+1} (1-\delta - \Psi_k (u_{k,t+1}))]/q_{k,t} \) is the expected net return on market capital. A cut in labor income taxes may increase or decrease current labor supply relative future labor supply depending on its impact on after-tax wages. If \((1-\tau_{n,t}) w_t \) increases relative to \((1-\tau_{n,t+1}) w_{t+1} \), current labor supply will rise relative to future labor supply and vice versa.\(^7\) 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 interacts with the response of investment in market capital. A log-linearization of the first-order conditions implies that:

\[
\hat{i}_t - \hat{i}_{t-1} = \frac{1}{\Phi''(\gamma)} \frac{E_t}{\gamma} \sum_{s=0}^{\infty} \left( \beta y_t^{1-\sigma} \right)^s \left( q_{k,t+s} + \Gamma \hat{\Gamma}_t + \Gamma \hat{\epsilon}_t \right)
\]

where \( \hat{\epsilon}_t = \ln \left( (I_t/z_t) / (I/z) \right) \) denotes the percentage deviation of detrended investment from its steady state value and \( \hat{\Gamma}_t \) is defined analogously. When labor supply rises in response to a cut in labor income taxes, the shadow value of capital increases (see equation (10)) which stimulates current investment.

The announcement of a future cut in labor income taxes has effects distinct from the implementation of a cut in labor income taxes. Due to the rise in wealth and the expected future increase in after-tax real wages, labor supply may drop during the pre-implementation period. If this occurs, the drop in hours worked lowers the return on capital goods which depresses investment (see equation (25)) 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

\(^7\) 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.
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, $\mu$, 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, our model does not automatically predict 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 boosts investment. The impact on labor supply is ambiguous since the wealth effect and the intertemporal substitution effects are oppositely signed. The rise in the real interest rate implies that the hours worked profile must be decreasing, which moderates the positive wealth effect on consumption, see Braun (1994). Thus, depending on parameters, labor supply and consumption may increase or decrease in response to a cut in capital income taxes. As discussed by Auerbach (1989), adjustment costs are key for understanding the impact of the announcement of a future cut in capital income tax rates. When adjustment costs are small, investment will tend to fall abruptly when a future capital income tax rate cut is announced until the period immediately before the tax rate cut is implemented. This is because lower expected future capital income tax rates make current investment unattractive. When adjustment costs are high, it may instead be optimal to increase investment immediately in order to increase the capital stock gradually so that the high returns on capital income can be harvested when the tax rate is eventually adjusted.

In summary, the response of the model to changes in tax rates depends crucially on parameters that determine wealth and substitution effects, on the importance of consumer durables and habit persistence, and on adjustment costs. In the next section, we estimate the structural parameters that are most important in determining these features.

4 Model Estimation

We partition the set of parameters into two subsets: $\Theta = [\Theta_1', \Theta_2']'$ where $\Theta_1$ is a vector of calibrated parameters and $\Theta_2$ is a vector of parameters to be estimated. $\Theta_1$ contains those parameters for which there are good grounds
for selecting values by calibration. A model period corresponds to one quarter. \( \beta \gamma^\sigma \), the effective subjective discount factor, is calibrated to match a 3 percent annual real interest rate. \( \omega \), the preference weight on the disutility of work, is calibrated so that hours worked is on average equal to 25 percent of the time endowment. We set the share parameter \( \theta \) such that durables consumption expenditure accounts for 11.9 percent of total consumption expenditure, which matches the corresponding number in the US during for the post WWII sample. Steady state output (divided by the level of labor augmenting technology) is normalized to 1. We calibrate the constant \( \nu \) in equation (16) to match this normalization. The rate of labor augmenting technological progress, \( \gamma_z \), is assumed to be equal to 1.005 which implies an average annual output growth rate of approximately 2 percent, the average growth rate of real per capita US 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 \( \alpha \) equal to 36 percent, which produces income shares close to those observed in the US, and set \( \Psi_k'(1) \) to normalize the steady state value of capacity utilization to unity.

In the benchmark estimation we assume that \( \pi_G = 0 \) such that government spending is not affected by changes in income taxes. We later relax this assumption. The steady state level of government spending is set to 20.1 percent of GDP, matching the post WWII government spending share in the US. The announcement horizon \( b \) is equal to 6 quarters. We set the steady state tax rates, \( \tau_n \) and \( \tau_k \), equal to 26 percent and 42 percent, respectively, which are the average effective US tax rates for labor and capital income found by Mendoza, Razin and Tesar (1994). Following Auerbach (1989) we set the depreciation rate for tax purposes, \( \delta_v \), 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 in practice affect the taxation of both types of income. Table 2 summarizes the calibration of \( \Theta_1 \).

For the benchmark model, the vector of parameters to be estimated is \( \Theta_2 = [\sigma, \mu, \kappa, \phi_v, \phi_k, \psi_k, \rho_{n.1}, \rho_{n.2}, \rho_{k.1}, \rho_{k.2}]' \) where \( \phi_k = \Phi_k''(\gamma_z) \), \( \phi_v = \Phi_v''(\gamma_z) \), and \( \psi_k = \Psi_k''(1)/\Psi_k'(1) \). We estimate \( \Theta_2 \) by matching the empirical impulse responses from Section 2 to impulse responses generated by the theoretical model. The latter are obtained from a VAR identical to (1) estimated in model generated artificial samples. We use a simulation approach rather than theoretical impulse response matching because the empirical VAR imposes constraints that do not generally hold in the model. In Appendix A, we show that the vector of observables in the theoretical model has a time series
representation

\[ X_t = \tilde{A} + \tilde{B}t + \tilde{C}X_{t-1} + \sum_{i=0}^{\infty} \tilde{D}_i \eta^n_{t-i} + \sum_{i=0}^{\infty} \tilde{F}_i \eta^a_{t-i,0} + \sum_{i=1}^{b} \tilde{G}_i \eta^a_{t,i} \]  

(26)

where \( \eta^n_t = [\varepsilon^n_t, \varepsilon^k_t] \), \( \eta^a_{t,0} = [\xi^n_{t-b,b}, \xi^k_{t-b,b}] \) and \( \eta^a_{t,i} = [\xi^n_{t-b+i,b}, \xi^k_{t-b+i,b}] \). This representation involves moving average terms in the tax shocks, which are assumed to be observable when estimating the empirical VAR. Under conditions laid out in appendix A, this representation is general for linearized DSGE models.

The main difference between the representation of the observables in equation (26) and the empirical model in (1) is that the latter restricts the order of moving average polynomials of implemented tax changes to be finite rather than infinite. The lag polynomials \( \tilde{D}(L) \) and \( \tilde{F}(L) \) depend on a dampening matrix \( \Gamma_{WW} \) (see the appendix for details) with roots that are determined by the persistence of the tax processes. When the tax processes are very persistent, distant innovations to the tax rates may potentially have important impact on the current value of the observables and in that case, the need to constrain the order of the moving average terms could be too restrictive.\(^8\) Because of this, in addition to standard issues related to small sample uncertainty, the empirical VAR based estimates of the response to tax shocks are approximations to the data generating process implied by the theoretical model.

We confront this problem by applying a simulation estimator.\(^9\) We estimate \( \Theta_2 \) as the vector of variables that solves the following minimization problem:

\[ \hat{\Theta}_2 = \arg\min_{\Theta_2} \left[ \left( \tilde{\Lambda}_T^d - \Lambda_T^m(\Theta_2|\Theta_1) \right)^\prime \Sigma^{-1}_d \left( \tilde{\Lambda}_T^d - \Lambda_T^m(\Theta_2|\Theta_1) \right) \right] \]  

(27)

where \( \tilde{\Lambda}_T^d \) denotes the vectorized empirical responses, \( \Lambda_T^m(\Theta_2|\Theta_1) \) are the equivalent estimates from the theoretical model and \( \Sigma^{-1}_d \) is a weighting matrix. As in the empirical section, we set the implementation lag equal to 6 quarters for the anticipated shocks. 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. For the benchmark case, the vector \( \tilde{\Lambda}_T^d \) contains 280 moments which are used to estimate the 10 structural model parameters contained in \( \Theta_2 \). Unless

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\(^8\)There is another subtle difference which has to do with the possible truncation of the anticipation horizon. In the empirical VAR we truncate anticipated tax shocks at \( K = 6 \) quarters due to the lack of a sufficient number of observations of tax changes with longer anticipation lags. In the model economy, agents may receive news with longer anticipation horizons unless we assume that \( b = K \). Our benchmark estimates will impose this condition. In the web-appendix we relax this assumption.

\(^9\)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.
mentioned otherwise, the model equivalent of the empirical impulse responses in $\Lambda^m_T(\Theta_2|\Theta_1)$ is constructed as follows:

1. Draw 100 sequences of tax innovations from the Romer and Romer (2008a) data (with replacement) each with a length of 228 quarters assuming that anticipated tax shocks have an anticipation horizon of 6 quarters. Simulate the economy in response to these sequences of tax innovations. This produces 100 artificial sample paths of the vector $X$. Denote this collection of vectors by $X^j(\Theta_2|\Theta_1)$ where $j = 1, \ldots, 100$ denotes the $j$-th replication.

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

3. For each artificial dataset, estimate the following model:

$$\tilde{X}^j_t(\Theta_2|\Theta_1) = \Xi^j + \Psi^j t + \Theta^j (L) \tilde{X}^j_{t-1}(\Theta_2|\Theta_1) + \Xi^j (L) \tilde{\tau}^u_{j,t} + \Xi^j (L) \tilde{\tau}^a_{j,t} + \sum_{i=1}^K \theta^j_{i} \tilde{\tau}^a_{j,t,i} + \tilde{e}^j_t \quad (28)$$

where $\tilde{\tau}^u_{j,t}$ and $\tilde{\tau}^a_{j,t,i}$ 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 shocks resulting in a one percent cut in tax liabilities and denote them by $\Lambda^m_T(\Theta_2|\Theta_1)^j$. Finally, average the impulse responses over the 100 replications, yielding $\Lambda^m_T(\Theta_2|\Theta_1)$.

Several features of the above procedure merit further discussion. First, the VAR applied to the simulated data in (28) to obtain $\Lambda^m_T(\Theta_2|\Theta_1)$ is identical to the VAR in (1) used to compute $\hat{\Lambda}^T_T$. Second, in the benchmark case we abstract from any non-tax shocks. To avoid stochastic singularity, we instead add a small white noise measurement error in the second step algorithm. To maintain focus on the transmission of tax shocks, we prefer to avoid parametrizing other shock processes. As part of robustness analysis, we have repeated the estimation for a model with technology, labor supply and government spending shocks (the results are available in the companion web appendix to the paper). Finally, the representation in (26) expresses $X_t$ as a function of the structural shocks to marginal tax rates. In the Romer and Romer (2008a) data as well as in (28), the tax shocks are instead measured in terms of changes in total tax revenues projected at the date of legislation as a percentage of GDP at the time of implementation. For consistency, the size of the innovations to the tax rates are computed such that

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10Our empirical approach uses limited information. Estimating the parameters of other shocks processes would either require including more data moments or switching to a full information approach, both of which are beyond the scope of this paper.
they induce a ceteris paribus one percent change in tax revenues relative to GDP for the implementation date. In the robustness analysis, we analyze sensitivity to the source of the tax liability change by looking at the polar cases of either only labor tax or only capital income tax rate shocks.

Following Hall, Inoue, Nason and Rossi (2009), we compute the standard errors of the vector $\Theta_2$ from an estimate of its asymptotic covariance matrix as

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

where

$$
\Lambda_{\Theta_2} = \left[ \frac{\partial \Lambda_m^m(\Theta_2|\Theta_1)}{\partial \Theta_2}' \Sigma_d^{-1} \frac{\partial \Lambda_m^m(\Theta_2|\Theta_1)}{\partial \Theta_2} \right]^{-1}, \quad \Sigma_d = \Sigma + \frac{1}{100^2} \sum_{j=1}^{100} \Sigma_j
$$

$\Sigma$ denotes the full covariance matrix of the impulse responses estimated in Section 2 ($\Sigma_d$ contains the diagonal elements of $\Sigma$), and $\Sigma_j$ is the covariance matrix of the $j$’th replication of the model based impulse responses.

### 5 Benchmark Results

Table 3 reports the parameter estimates of the benchmark model as well as estimates of the parameters pertaining to a number of robustness analyses. We will here first discuss the benchmark results. The last column of this table gives the value of the quadratic loss function in equation (27) evaluated at $\hat{\Theta}_2$. Along with the parameter estimates we also illustrate the resulting impulse responses together with their empirical counterparts. For each impulse response function we illustrate two measures of the impact of taxes in the model economy. Lines with circles are the exact theoretical model impulse responses while the model impulse responses estimated by imposing the empirical model on the artificial data are illustrated with dashed lines. The latter are those that we match with the empirical impulse responses when estimating the structural parameters.

The parameters pertaining to preferences are estimated with great precision. The point estimate of $\sigma$, the curvature parameter in the utility function, is 3.762. This estimate is at the upper end of the range of values usually considered plausible.\(^{11}\) The point estimate of the habit parameter $\mu$ is 0.880, a value that is similar to e.g. the estimate of Christiano, Eichenbaum and Evans (2005) (Burnside, Eichenbaum and Fisher (2004) adopt a very

\(^{11}\)Due to habit formation, however, this parameter should not be interpreted as the inverse of the intertemporal elasticity of substitution in consumption.
similar calibration in their analysis of fiscal policy).

Our point estimate of the inverse Frisch elasticity is 0.976. This estimate is within the range of values typically assumed in the macroeconomic literature while a bit lower than values typically estimated in the microeconomic literature. House and Shapiro (2006, 2008) assume a somewhat higher value of this parameter in their calibration of a DSGE model applied to the simulation of the impact of tax changes. This estimate implies that labor supply reacts quite elastically to changes in wages and in real interest rates.

The estimates of the adjustment cost parameters indicate that investment adjustment costs are relevant for both capital stocks but matter slightly more for the market capital stock than for consumer durables. Our point estimate of $\phi_k$ is 8.488, while the point estimate of $\phi_v$ is 7.795. We find some role for fluctuations in the utilization rate of the market capital stock. The point estimate of $\psi_k$ is 0.619 which implies that changes in the utilization rate have a moderate impact on the gross depreciation rate of the capital stock.\(^{12}\)

The estimates for the autoregressive parameters pertaining to the tax processes, $\rho_{n,1} = 1.483$, $\rho_{n,2} = -0.484$, $\rho_{k,1} = 1.707$ and $\rho_{k,2} = -0.729$, indicate high persistence of the tax processes and that tax rates rise for a few periods before returning to their initial level following a tax rate innovation. The estimates also imply that the largest root of $\Gamma_{WW}$, the dampening matrix discussed above, is very close to one. Therefore, it might potentially be important to take into account that the empirical model imposes a finite moving average structure on the implemented tax shocks.

Figure 3 illustrates the dynamics of the two tax rates following a one percent decrease in tax liabilities. We also show the dynamics of total tax liabilities relative to GDP. In the case of an unanticipated tax liability cut, the resulting initial change in the two tax rates corresponds to a 1.4 percentage points drop in the two distortionary tax rates. The labor income tax rate continues to fall for another year and a half eventually falling by around 2.6 percentage point after at which it remain low for a very long period. The capital income tax rate displays a more volatile pattern reaching a maximum decline of 4 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

\(^{12}\)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 approximately constant in equilibrium.
during the pre-implementation period, but the implied initial change in tax rates at the implementation date is practically identical to the case of an unanticipated tax cut. The high persistence of the labor income tax rate appears consistent with substantial amounts of tax smoothing.

Figure 4 illustrates the impact of a one percent tax liability cut in the model economy given the parameter estimates just discussed. The left column of Figure 4 shows the response to a one percent surprise tax liability cut (relative to GDP), while the right column shows the impact of a one percent anticipated tax liability cut.

The model is quite successful in accounting for the main features of the empirical estimates. In particular, as in the US data:

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

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

The model is also 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 US 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.

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13 Notice that we are estimating many fewer parameters (10) than the number of moments (280). Thus, there is absolutely no guarantee that the model can account for the empirical impulse responses.
Recall that consumption of nondurables and services basically does not respond to announcements of future tax changes. The model presented in Section 3 implies a steady, but small, increase in consumption of nondurables and services to an anticipated tax cut during the pre-implementation period. The rise in consumption is sufficiently small that it is inside the confidence interval of the empirical estimates during much of the pre-implementation period. This result appears counterintuitive. For that reason, we examine this aspect of our results in some detail in Section 6 below.

Comparing the two measures of the theoretical impulse responses shows that they are very similar for the forecast horizons that we consider (but not at very long forecast horizons). Therefore, although the roots of the tax processes are very persistent, the approximation error due to the finite MA specification of the empirical model appears to be of limited concern for the short to medium term impact of tax liability changes.

In the US data, the size of the pre-implementation contraction in output in response to an anticipated tax cut is smaller the shorter the assumed implementation lag (see Figure 2). We now examine whether the DSGE model is consistent with this finding by computing the impulse response of output varying the parameter \( b \) in equations (21) and (22) from 4 to 10 quarters. The result is illustrated in panel (b) of Figure 2. The model reproduces exactly the same result as the empirical VAR: The shorter is the anticipation horizon, the smaller is the pre-implementation contraction of output. This result derives from the presence of adjustment costs. Households are forward looking and wish to increase the capital stock when the returns on it eventually increase. In the presence of adjustment costs, the process of building up the capital stock starts early in order to economize on adjustment costs. This implies a deeper pre-implementation recession the longer the implementation lag (for moderate values of \( b \)).

### 5.1 Accounting For the Consumption Response

Perhaps somewhat surprising is that the theoretical model, while leaving room for improvement, is not completely at odds with the data in accounting for the lack of a strong response of nondurables consumption to the announcement of future tax changes. Moreover, we have found a rather sluggish response of hours worked to tax

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14These effects are not monotone in the anticipation horizon, \( b \). When \( b \) becomes very long, anticipated tax changes have little impact on output until the implementation date gets nearer.
changes despite the Frisch labor supply elasticity being quite large. To shed some light on the sources of these results and we conduct 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)).

Let the initial steady state allocation be denoted by \((C, V, n)\) with associated after-tax factor prices \(((1 - \tau_n) \bar{w}, (1 - \tau_k) \bar{r})\) and denote by \(U_{0}^{SS}\) the discounted lifetime utility associated with this allocation. Let the path of the economy following a one percent tax liability cut be given by the allocation \((C_t, V_t, n_t)_{t=0}^{\infty}\) with associated factor prices \(((1 - \tau_{n,t}) w_t, (1 - \tau_{k,t}) r_t)_{t=0}^{\infty}\) and define \(U_1\) as the present discounted utility associated with this path.

The wealth effect is then computed as the constant levels of consumption (of nondurables and of durables) and hours worked such that, at the initial steady state prices, \(U(C_1, V_1, n_1) = U_1\). We decompose the substitution effect into a real wage effect, a rental rate effect, and a wedge which we compute residually. The latter arises because of the costs of adjusting the durables stock and the stock of capital.\(^{15}\) The wage and rental rate effects are computed as the optimal paths of consumption and hours worked when households are faced with the price sequences \(((1 - \tau_{n,t}) w_t, (1 - \tau_{k,t}) r_t)_{t=0}^{\infty}\) and \(((1 - \tau_n) \bar{w}, (1 - \tau_k) \bar{r})_{t=0}^{\infty}\), respectively, under the constraint that present discounted utility associated with these allocations is equal to \(U_{0}^{SS}\).

Figure 5 illustrates the paths of after-tax real wages and real rental rates together with the decompositions of the responses consumption of nondurables and hours worked after a one percent cut in tax liabilities. After an unanticipated tax cut, after-tax real wages and real rental rates both rise following bell shaped patterns. The maximum increase in after-tax real wages occurs 6 quarters after the tax cut while the maximum increase in the after-tax rental rate takes place 7 quarters after the tax cut.

Since we assume that \(\pi_G = 0\), the wealth effects derive from Harberger triangles since lower factor income taxes temporarily reduce the inefficiency induced by distortionary taxes. Since both leisure and consumption are normal goods, a tax cut implies a positive wealth effect on consumption and a drop in hours worked. Quantitatively, the wealth effects are small for both hours worked and nondurables consumption. Moreover, since the

\(^{15}\)In the absence of adjustment costs, the laws of motion for the capital stock and for the consumer durables stock can be substituted into the household’s budget constraint. Iterating this constraint forward (and imposing transversality conditions) gives rise to a single life-time budget constraint for expenditure on the two consumption goods which depends only on initial wealth, on the stream of transfers and depreciation allowances and on the two relative prices. When there are adjustment costs, the two laws of motion cannot be eliminated since adjustment costs introduce a wedge between the (after-tax) real interest rate and the intertemporal marginal rate of substitution.
wealth effect is constant along the adjustment path, the dynamics derive entirely from substitution effects.

The substitution effects are more intricate. The rising profile of the after-tax real wage profile implies a gradual rise in hours worked. This effect is countered by the impact of the profile of the after-tax real rental rate which implies a gradual fall in hours worked in the immediate aftermath of the tax cut. These two effects together lead to the slow rise in hours worked implied by the model.

The rise in after tax real wages gives rise to an increasing time profile of nondurables consumption. The hump-shaped pattern of the wage trajectory, however, implies that consumption grows very gradually over time. Moreover, the persistent rise in after-tax real interest rates lowers current consumption relative to future consumption implying a bell-shaped increase in nondurables consumption. Finally, the presence of adjustment costs implies some initial substitution towards consumption as the implied growth in investment lowers the relative consumption price. Thus, the combination of the wage and rental rate effects and the wedge implied by adjustment costs account for the solid growth in consumption that follows the tax cut.

An anticipated tax cut lowers (increases) the after-tax rental rate (real wage) very marginally during the pre-implementation period while the paths of these prices after implementation of the tax cut are very similar to the paths that follow an unanticipated tax cut. As above, we find that the wealth effects are small quantitatively.

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

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

In summary, we find that the adjustment paths of consumption and labor supply are dominated by substitution effects. Equilibrium wealth effects are relative minor and, since they are constant, do not help understanding the intertemporal adjustments.

6 Extensions and Robustness Analysis

In this section we examine the robustness of our results. We look at three different issues. First we examine the extent to which the results - especially those relating to the impact of tax changes on consumption - are sensitive to our preference specification which allows for two sources of intertemporal non-separabilities. Secondly, we look at the sensitivity to the modeling of the processes of taxes and of government spending. Finally, we extend the model to allow for rule-of-thumb consumers in order to evaluate the potential importance of liquidity constraints.

6.1 Habit Formation and Consumer Durables

The model that we have examined incorporates two sources of intertemporal non-separabilities, habit formation and consumer durables. Habit formation has received quite a lot of attention in the business cycle literature and is generally accepted as being important for accounting for the impact of monetary policy shocks, see e.g. Christiano, Eichenbaum and Evans (2005). The role of consumer durables has received somewhat less attention in this part of the literature. In this section, we examine in more detail how both these features matter for understanding the impact of tax changes.

The second row of Table 3 reports the parameter estimates of $\Theta_2$ when we exclude consumer durables from the model.\footnote{In this case, we estimate the structural parameters by matching the moments of a version of the VAR in equation (1) in which the vector of endogenous variables, $X_t$, does not include the purchases of consumer durables.} Eliminating consumer durables leads to a large increase in the estimate of the Frisch labor supply elasticity and leads to an estimate of the parameters of the labor tax process which imply a sudden and very persistent change in labor income taxes following a tax innovation. There are also some changes in the parameters relating to habit formation and capital adjustment costs both of which fall marginally. The value of the minimized
quadratic form indicates that this version of the model fits the estimated impulse responses significantly worse than the benchmark model thus indicating that consumer durables are an important factor for understanding how tax changes affect the economy.

The reason for this can be understood more clearly from Figure 6, which shows the impact of a 1 percent tax liability cut using the parameter estimates from this version of the model. As is clear, although the model is still successful in accounting for the output response to the tax shock, this version of the model has more difficulty accounting for the adjustments of nondurables consumption and hours worked. In particular, the elasticity of nondurables consumption to the tax cut implied by the model is now significantly smaller than the empirical estimates for both unanticipated and anticipated tax liability changes. This indicates that the complementarity between durables and nondurables consumption is an important aspect of the model. Moreover, despite the higher Frisch labor supply elasticity, this version of the model implies a less elastic response of hours worked to anticipated tax changes due to complementarity between the consumption of leisure and of consumption goods.

The third row of Table 3 reports the parameter estimates when we restrict the habit parameter to be equal to zero, $\mu = 0$. When habit formation is excluded, the point estimate of $\sigma$ increases from 3.76 to 7.18, which is above values usually considered reasonable. We also find a substantial increase in the estimate of investment adjustment costs. Moreover, the fit of the model deteriorates substantially as indicated by the value of the minimized quadratic form which increases by more than 40 percent when we set $\mu = 0$. Figure 7 shows that the elimination of habits has rather serious consequences for the extent to which the model can account for the impact of tax changes on nondurables consumption. Perhaps surprisingly, the main problem is not that consumption jumps to a new higher level when there are anticipated future tax cuts - in fact when there are no habits the model is consistent with a flat response of nondurables consumption throughout the pre-implementation period - but rather that consumption jumps upon implementation of tax cuts. This feature of the model with no habits is at odds with the empirical estimates of the consumption response and this also explains why we find a much higher value $\sigma$ when habits are eliminated; For low values of this parameter, consumption adjusts even faster to tax changes.

Thus, time-non-separabilities in the utility function seem important for understanding the adjustment of the main macroeconomic aggregates to tax changes. Without such features it is hard to explain the gradual response of consumption to tax changes and the size of consumption and hours worked adjustments following tax shocks.
6.2 Fiscal Feedback

The benchmark model assumes that government consumption grows at a constant rate and is unaffected by changes in distortionary taxes. We now relax this assumption and allow for changes in distortionary taxes to affect government consumption. An important consequence of this extension is that it introduces additional wealth effects after a change in tax rates, which could be important for the initial impact of tax changes.

We reestimate the model allowing $\pi_G$ to differ from zero. Since tax liabilities fall after the decrease in tax rates (see Figure 3), a positive value of $\pi_G$ indicates a stronger positive wealth effect while a negative value of $\pi_G$ instead lowers the wealth effect. The fourth row of Table 3 reports the parameter estimates for this alternative scenario. The point estimate of $\pi_G$ is 0.221, which implies that the wealth effects are stronger in this model than in the benchmark model. Introducing this feature also has some impact on other parameter estimates most notably on those relating to preferences. In particular, allowing for an endogenous response of government spending gives rise to more moderate estimates of the utility curvature $\sigma$, a somewhat higher estimate of the Frisch labor supply elasticity as well as an even more persistent habit effect than in the benchmark model. With this new feature, the model also appears to fit the data considerably better than the benchmark model. All in all, the elasticity of government spending to tax changes is nonetheless relatively small, which squares well with Romer and Romer (2008b) who find little impact of tax changes on government spending. According to their results, if anything, tax cuts appear to increase government spending. The implied responses to the tax shocks, shown in Figure 8, are very similar to the benchmark model, although the fit of the hours response is somewhat better than in the benchmark model.

6.3 Capital Income Taxes vs. Labor Income Taxes

In the benchmark model, a change in tax liabilities is assumed to result from simultaneous changes in labor income taxes and capital income taxes (including depreciation allowances). It is natural to verify the sensitivity of our results to alternatively assuming that tax liability changes are due only one of these two tax rates. To examine this, Table 3 contains the parameter estimates when we allow for changes in the labor income tax rate only (row 5), or in the capital income tax rate only (row 6). Figures 9 and 10 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 we allow for variations in only one of the
two tax rates. 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 fall
dramatically as does the impact of variations in capital utilization on the depreciation rate (therefore implying
large variations in the utilization rate). Alternatively, when we allow for changes only in the capital income tax
rate, the Frisch labor supply elasticity goes to infinity and the estimate of $\sigma$ falls to 0.41. Thus, the parameter
estimates indicate somewhat high sensitivity to the modeling of taxes and the values minimized quadratic form
show that allowing for variations in both capital and labor income tax rates produce a much better fit than any of
the alternative models.

Nonetheless, the impulse response functions show that allowing for variations in only one of the two tax rates still
allows the model to fit the estimated impact of tax changes quite well qualitatively. In particular, both alternative
versions of the model are able to account for the expansionary impact of an implemented tax cut and for the neg-
ative 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. Hence, we conclude that allowing for variations in
both labor income and capital income tax rates is very important for the quantitatively, but not necessarily for the
finding that tax cuts are expansionary when implemented and recessionary during the pre-implementation period.

6.4 Rule-Of-Thumb Behavior

The absence of a strong aggregate consumption response to tax news is consistent with previous microecono-
metric evidence on the impact of pre-announced tax changes on household consumption referenced in the in-
troduction. Mankiw (2000) argues on the basis of this evidence for introducing rule-of-thumb consumers as a
standard feature of macroeconomic models and estimates the share of these consumers to be close to 50 percent.
Galí, López-Salido and Vallés (2007) show that the presence of rule-of-thumb consumers may be important for
accounting for evidence on the impact of government spending shocks. It seems natural to extend our benchmark
model with rule-of-thumb consumption behavior and verify its role in accounting for the aggregate responses
to tax changes. As in Campbell and Mankiw (2004) and Galí, López-Salido and Vallés (2007), we assume that
rule-of-thumb consumers can neither borrow nor save and simply consume their income period-by-period. For
simplicity, we assume that rule-of-thumb households have intertemporally separable preferences and that they do
not value durable goods. This latter assumption makes the model more similar to previous contributions since it implies that rule-of-thumb households have no way of smoothing utility intertemporally but through labor supply.

There is a continuum of households. A fraction \( \zeta \) are households identical to those in Section 3. A fraction \( 1 - \zeta \) are rule-of-thumb households with preferences

\[
U^*_0 = E_t \sum_{i=0}^{\infty} \beta^i \left( \frac{C^*_i 1-\sigma - \epsilon^*_i 1-\sigma}{1-\sigma} \omega^* \frac{\omega^* n^*_1}{1+\kappa} \right)
\]

where \( C^*_i \) denotes consumption of nondurables of rule-of-thumb consumers and \( n^*_i \) is their labor supply. These households face the budget constraint

\[
C^*_i \leq (1 - \tau n_i) w_i n^*_i + TRA^*_i
\]

where and \( TRA^*_i \) are government transfers to the rule-of-thumb households.

Galí, López-Salido and Vallés (2007) argue that rule-of-thumb behavior alone does not suffice to account for the positive consumption response to government spending shocks usually found in fiscal VARs, but must be combined with imperfectly competitive labor markets. Following Galí, López-Salido and Vallés (2007), we assume that wages are set by labor unions. Suppose there is a continuum of unions, each representing workers of a certain type indexed by \( j \). Suppose that both consumer types are uniformly distributed across worker types and \( n_i(j) \) denotes the labor supply of household of type \( j \). The typical union sets the wage of its members to maximize (see Galí, López-Salido and Vallés (2007) for details):

\[
\frac{\zeta}{\omega} \left( \lambda_{c,i}(1 - \tau n_j)w_i(j)n_i(j) - \omega^* \frac{\omega^* (n_i(j))^{1+\kappa}}{1+\kappa} \right) + \frac{1 - \zeta}{\omega^*} \left( \lambda_{c,i}(1 - \tau n_j)w_i(j)n_i(j) - \omega^* \frac{\omega^* (n_i(j))^{1+\kappa}}{1+\kappa} \right)
\]

subject to demand by firms for labor of type \( j \) given by

\[
n_i(j) = \left( \frac{w_i(j)}{w_i} \right)^{-\rho} N_i, \quad \rho > 1
\]

where \( \lambda_{c,i}^j \) and \( \lambda_{c,i}^s \) denote the marginal utility of nondurable consumption for optimizing and rule-of-thumbs consumers, \( w_i = \left( \int_0^1 w_i(j) \, dj \right)^{(1/(1-\rho))} \) and \( N_i \) is aggregate labor demand. Firms allocate labor demand uniformly
across different workers of type $j$, independently of their household type. Assuming symmetry, in equilibrium $N_t = n_t = n^*_t$ and
\[
\left( \frac{\zeta}{\omega} \lambda^{j}_c + \frac{1 - \zeta}{\omega} \lambda^{*}_c \right) \left( 1 - \tau_{n,t} \right) w_t = \frac{\rho}{\rho - 1} \varepsilon^{1 - \sigma} n^*_t
\]  
(31)

In the system of equilibrium conditions of the model with rule-of-thumb households, this labor supply equation replaces the old one in (9) while the following equations are added
\[
\lambda^{j}_c = \left( C^*_t \right)^{-\sigma} \tag{32}
\]
\[
C^*_t = (1 - \tau_{n,t}) w_t n_t + TRA_t \tag{33}
\]
where we have assumed that both types of households receive the same transfers, $TRA_t = TRA^*_t$. Finally, the aggregate resource constraint, production function and government budget constraint are now
\[
Y_t = \zeta (C_t + D_t + I_t) + (1 - \zeta) C^*_t + G_t \tag{34}
\]
\[
Y_t = \nu \left( u_{k,t} \zeta K_t \right)^{\alpha} (\zeta n_t)^{1 - \alpha} \tag{35}
\]
\[
G_t + TRA_t = \tau_{n,t} w_t n_t + \tau_{k,t} r_t u_{k,t} \zeta K_t - \zeta \Lambda_t \tag{36}
\]

We set $\omega^*$ such that the marginal rate of substitution between consumption and hours worked equalize across the two types of agents along the balanced growth path. We choose $\omega \rho / (\rho - 1)$ such that the average hours worked is 25 percent of the time endowment on average. As a result, the extended model has only one additional parameter relative to the benchmark model, the fraction of rule-of-thumb households $1 - \zeta$.

The last row of Table 3, reports the estimates of the augmented model. According to these estimates, the share of rule-of-thumb consumers $(1 - \zeta)$ is around 15.2 percent, which translates into a 14.6% average share in total consumption or a 16.6% average share in total nondurable consumption. This is considerably smaller than the values used in most of the literature. Moreover, the standard error of the point estimate of $\zeta$ is relatively small.

The remaining parameter estimates are quite similar to those of the benchmark model with the exception of the Frisch labor supply elasticity which increases from just above 1 to approximately 3.5. We note from the value of the quadratic form that this model appears to fit the data substantially better than the benchmark model and any of the other alternative variations that we have considered.
Figure 11 illustrates the implied impulse responses of this model. The results are very informative: The introduction of rule-of-thumb consumers allows for a significantly better fit of the response of nondurables consumption to changes in taxes, in particular regarding the absence of a strong consumption response to pre-announced tax cuts together with the partial consumption response to implemented tax cuts. The main reason the estimated share of rule-of-thumb agents is relatively low compared to other studies is explained by two features of the response to tax shocks. First, too large a share of rule-of-thumb consumers makes it harder to account for the elastic response of investment to tax changes. Note that even the benchmark model implies a somewhat smaller peak response of investment to tax changes than our empirical estimates. This is because adjustment costs are needed to explain the response of investment to pre-announced tax changes but, at the same time, also imply a less elastic investment response to implemented tax changes. When we introduce rule-of-thumb consumers, this problem becomes even worse since investment is undertaken by the optimizing households only. Second, a large share of rule-of-thumb consumers makes it more difficult to account for the hours response to pre-announced tax changes. When the share of rule-of-thumb consumers is large it is hard to explain the drop in hours during the pre-announcement period, regardless of whether the labor market is competitive or not. We conclude that introducing rule-of-thumb consumers leads to a better fit of the model, but only when the share of these agents is relatively small.

7 Conclusions and Directions For Future Research

Estimates based on a reduced form model indicate that implemented tax cuts result in a major expansion in aggregate output, consumption, investment and hours worked. On the other hand, announcements of future tax cuts give rise to drops in output, investment and hours worked until the tax cut is eventually implemented, but consumption shows little change prior to implementation. We argue that a relatively standard DSGE model, with adjustment costs, consumer durables, variable capacity utilization, and consumption habits, can account relatively well for these empirical findings. Substitution effects are key for understanding the dynamic adjustment of the economy to changes in tax while wealth effects are less important. Introducing rule-of-thumb consumption behavior helps accounting for the weak consumption response to an announced tax cut. At the same time, the implied share of these agents must be substantially lower than what is most often assumed in the literature to explain the effects of anticipated tax changes.
There are in our view several promising avenues for future research. First, it would be interesting to examine more disaggregated tax measures in order to derive finer estimates of the impact of changes in particular taxes. Second, it is interesting to investigate whether similar results hold true for other countries than the US. Third, our analysis has made some substantial simplifying assumptions about fiscal rules that could be relaxed in future work, in particular regarding how government spending policies and debt stabilization requirements affect tax dynamics. This is obviously highly relevant over the coming years as major fiscal adjustments will be required following the current economic downturn.

Finally, we emphasize that our analysis depends importantly on the assumption that the Romer and Romer (2008a) narrative tax changes are exogenous. While we have defended this assumption, much future work is needed, based on alternative reduced form models and identification schemes as well as alternative DSGE models and structural empirical approaches, to further improve our understanding of the macroeconomic effects of tax changes.

References


Kehoe, Patrick J., 2006. “How to Advance Theory with Structural VARs: Use the Sims-Cogley-Nason Ap-


**Romer, Christina D., and David H. Romer**, 2008a, “A Narrative Analysis of US Postwar Tax Changes” University of California, Berkeley, manuscript.

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


**A Deriving Equation (26)**

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 the model can be represented by the following state space model:

\[
Z_{t+1} = \Gamma_{ZZ}Z_t + \Gamma_{ZW}W_t \quad (A-1)
\]

\[
W_t = \Gamma_{WW}W_{t-1} + \Gamma_{WE}\eta_t \quad (A-2)
\]

\[
U_t = \Gamma_{UZ}Z_t + \Gamma_{UW}W_t \quad (A-3)
\]

where \(Z_{t+1}\) is the vector of endogenous states, \(W_t\) is the vector of exogenous states, \(\eta_t\) is the vector of innovations, and \(U_t\) is the vector of controls. Let \(\tilde{X}_t\) denote a vector of observable and appropriately detrended endogenous variables \(\tilde{X}_t\) with dynamics described by

\[
\tilde{X}_t = \Gamma_{XZ}Z_t + \Gamma_{XW}W_t \quad (A-4)
\]

The vector \(\tilde{X}_t\) is generally a subset (or combination) of the set of variables contained in \(U_t\) and \(Z_{t+1}\). It follows from equation (A-1) that

\[
Z_t = (I - \Gamma_{ZZ}L)^{-1}\Gamma_{ZW}W_{t-1} \quad (A-5)
\]

provided \(\Gamma_{ZZ}\) has all eigenvalues less than one in modulus. Combining (A-4) and (A-5) yields

\[
\tilde{X}_t = \Gamma_{XZ}(I - \Gamma_{ZZ}L)^{-1}\Gamma_{ZW}W_{t-1} + \Gamma_{XW}W_t \quad (A-6)
\]
Assuming that \( \text{dim}(\hat{X}) = \text{dim}(Z) \) and \( \Gamma_{XZ} \) is invertible,

\[
(I - \Gamma_{ZZ}L)\Gamma_{XZ}^{-1}X_t = \Gamma_{ZW}W_{t-1} + (I - \Gamma_{ZZ}L)\Gamma_{XZ}^{-1}\Gamma_{XW}W_t
\]  
(A-7)

such that

\[
\tilde{X}_t = \Gamma_{XZ}\Gamma_{ZZ}\Gamma_{XZ}^{-1}\tilde{X}_{t-1} + \Gamma_{XW}W_t + \Gamma_{XZ} (\Gamma_{ZW} - \Gamma_{ZZ}\Gamma_{XZ}^{-1}\Gamma_{XW}) W_{t-1}
\]  
(A-8)

From equation (A-2) and assuming \( \Gamma_{WW} \) has all eigenvalues less than one in modulus, we have

\[
W_t = (I - \Gamma_{WW}L)^{-1}\Gamma_{WE}\eta_t
\]

Combining with (A-9) yields a \( \text{VARMA}(1,\infty) \) representation for the observables \( \hat{X}_t \),

\[
\hat{X}_t = \hat{C}\hat{X}_{t-1} + M(L)\eta_t
\]  
(A-9)

where \( C = \Gamma_{XZ}\Gamma_{ZZ}\Gamma_{XZ}^{-1} \) and \( M(L) = M_0 + M_1L + M_2L^2 + \ldots \) where

\[
M_0 = \Gamma_{XW}\Gamma_{WE} , \ M_i = (\Gamma_{XW}\Gamma_{WW} + \Gamma_{XZ} (\Gamma_{ZW} - \Gamma_{ZZ}\Gamma_{XZ}^{-1}\Gamma_{XW})) \Gamma_{WW}^{-1}\Gamma_{WE} \text{ for } i > 0
\]

where we note that \( \Gamma_{WW} \) is a dampening matrix. The smaller are the roots of this matrix, the stronger the discounting of past shocks. We note that this depends on the persistence of the tax shocks.

In the context of our model but looking at the more general case where there are tax news shock with anticipation of 1 through \( b \) periods, the vector of exogenous shocks is \( \eta_t = [\varepsilon^n_t, \varepsilon^k_t, \xi^n_{t,1} , \xi^n_{t,2}, \xi^k_{t,1}, ..., \xi^k_{t,b}]' \). Defining \( \eta_t^n = [\varepsilon^n_t, \varepsilon^k_t] , \eta^n_{t,0} = [\sum_{j=1}^{b} \xi^n_{t-j,j}, \sum_{j=1}^{b} \xi^k_{t-j,j}] \) and \( \eta_{t,i}^n = [\sum_{j=1}^{b-i} \xi^n_{t-j,j+i}, \sum_{j=1}^{b-i} \xi^k_{t-j,j+i}] \), the representation (A-9) may be rewritten as

\[
X_t = \hat{C}\hat{X}_{t-1} + \sum_{i=0}^{\infty} \tilde{D}_i\eta^n_{t-i} + \sum_{i=0}^{\infty} \tilde{F}_i\eta^n_{t-i,0} + \sum_{i=1}^{b} \tilde{G}_i\eta^n_{t,i}
\]

where \( \tilde{D}_i = M_0S_1, \tilde{F}_i = M_{i+b}S_1, \tilde{G}_i = M_iS_3 \) and \( S_1, S_2 \) and \( S_3 \) are the appropriate selection matrices. Converting this representation for the detrended/demeaned variables \( \hat{X}_t \) to one for observed trending variables \( X_t \) by adding a linear trend and a constant, as well as assuming only a single news shock with horizon \( b \), yields representation (26) in the main text. We look at the general case of tax news shocks with horizon 1 through \( b \) in a web appendix.
The derivation of the representation in (26) relies on (a) the fact that we treat the tax shocks as observable, and (b) on the assumptions that $\Gamma_{ZZ}$ and $\Gamma_{WW}$ have no eigenvalues greater than or equal to one in modulus. This latter set of assumptions amounts to the requirement that all model variables are (trend) stationary processes. More special is the additional assumption that $\dim(X) = \dim(Z)$ and $\Gamma_{XZ}$ is invertible, which requires the number of observables included in $X_t$ to be equal to the number of endogenous state variables. In our application, this condition is fulfilled and invertibility of $\Gamma_{XZ}$ is easily verified in practice.
Table 1: Data Definitions and Sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>Nominal GDP divided by its implicit deflator and by population</td>
<td>Bureau of Economic Analysis</td>
</tr>
<tr>
<td>Consumption</td>
<td>Consumers nominal expenditure on nondurables divided by its deflator and expenditure on services divided by its deflator and by population</td>
<td>Bureau of Economic Analysis</td>
</tr>
<tr>
<td>Durables</td>
<td>Consumers nominal expenditure on durables divided by its deflator and by population</td>
<td>Bureau of Economic Analysis</td>
</tr>
<tr>
<td>Purchases</td>
<td>Divided by its deflator and by population</td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td>Sum of private sector gross investment divided by its deflator and government investment divided by its deflator. The sum is divided by population.</td>
<td>Bureau of Economic Analysis</td>
</tr>
<tr>
<td>Hours worked</td>
<td>Product of hours per worker and civilian non-farm employment divided by population combined with and Francis and Ramey (2002) hours worked series.</td>
<td>Bureau of Economic Analysis and Francis and Ramey (2002)</td>
</tr>
</tbody>
</table>

Table 2: Calibrated Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Interpretation</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 - \alpha$</td>
<td>0.64</td>
<td>Labor input elasticity of output</td>
<td>64% labor share of income</td>
</tr>
<tr>
<td>$\gamma_c$</td>
<td>1.005</td>
<td>Growth rate of technology</td>
<td>2% average growth of real GDP per capita</td>
</tr>
<tr>
<td>$\beta Y^\sigma$</td>
<td>1.03^{-0.25}</td>
<td>Subjective discount factor</td>
<td>3% annual interest rate</td>
</tr>
<tr>
<td>$\delta_k$</td>
<td>0.025</td>
<td>Steady state depreciation rate of capital</td>
<td>-</td>
</tr>
<tr>
<td>$\delta_r$</td>
<td>0.025</td>
<td>Depreciation rate of durable goods</td>
<td>-</td>
</tr>
<tr>
<td>$\psi_k'(1)$</td>
<td>0.032</td>
<td>Capital utilization parameter</td>
<td>Steady state capital utilization of unity</td>
</tr>
<tr>
<td>$\omega$</td>
<td>2.79 \times 10^4</td>
<td>Preference parameter</td>
<td>Steady state hours equal to 0.25</td>
</tr>
<tr>
<td>$G/Y$</td>
<td>0.201</td>
<td>Steady state government spending to output ratio</td>
<td>Average government spending to GDP ratio</td>
</tr>
<tr>
<td>$\delta_c$</td>
<td>0.05</td>
<td>Depreciation rate for tax purposes</td>
<td>-</td>
</tr>
<tr>
<td>$\tau_c$</td>
<td>0.42</td>
<td>Steady state capital income tax rate</td>
<td>Estimate of average effective capital income tax rate by Mendoza, Razin and Tesar (1994)</td>
</tr>
<tr>
<td>$\tau_n$</td>
<td>0.26</td>
<td>Steady state labor income tax rate</td>
<td>Estimate of average effective labor income tax rate by Mendoza, Razin and Tesar (1994)</td>
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Table 3: Estimation Results

<table>
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<th>Model</th>
<th>$\sigma$</th>
<th>$\mu$</th>
<th>$\kappa$</th>
<th>$\phi_k$</th>
<th>$\phi_l$</th>
<th>$\psi_l$</th>
<th>$\rho_{\kappa,1}$</th>
<th>$\rho_{\phi,2}$</th>
<th>$\rho_{\phi,1}$</th>
<th>$\rho_{\psi,2}$</th>
<th>$\pi_G$</th>
<th>$\zeta$</th>
<th>Obj.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Benchmark</td>
<td>3.762</td>
<td>0.880</td>
<td>0.976</td>
<td>8.488</td>
<td>7.795</td>
<td>0.619</td>
<td>1.483</td>
<td>-0.484</td>
<td>1.707</td>
<td>-0.729</td>
<td>–</td>
<td>–</td>
<td>78.77</td>
</tr>
<tr>
<td></td>
<td>(0.198)</td>
<td>(0.008)</td>
<td>(0.116)</td>
<td>(0.355)</td>
<td>(0.448)</td>
<td>(0.060)</td>
<td>(0.032)</td>
<td>(0.032)</td>
<td>(0.015)</td>
<td>(0.015)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) No Durables</td>
<td>3.058</td>
<td>0.747</td>
<td>0.125</td>
<td>5.966</td>
<td>–</td>
<td>0.611</td>
<td>0.999*</td>
<td>0*</td>
<td>1.654</td>
<td>-0.684</td>
<td>–</td>
<td>–</td>
<td>95.28</td>
</tr>
<tr>
<td></td>
<td>(0.145)</td>
<td>(0.020)</td>
<td>(0.036)</td>
<td>(0.184)</td>
<td></td>
<td>(0.044)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.011)</td>
<td>(0.012)</td>
<td></td>
</tr>
<tr>
<td>(3) No Habits</td>
<td>7.183</td>
<td>–</td>
<td>1.103</td>
<td>10.786</td>
<td>7.995</td>
<td>0.626</td>
<td>1.564</td>
<td>-0.565</td>
<td>1.724</td>
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<td>–</td>
<td>–</td>
<td>113.22</td>
</tr>
<tr>
<td></td>
<td>(0.201)</td>
<td>(0.130)</td>
<td>(0.445)</td>
<td>(0.430)</td>
<td>(0.044)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.011)</td>
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<tr>
<td>(4) Endogenous G</td>
<td>1.829</td>
<td>0.926</td>
<td>0.477</td>
<td>6.032</td>
<td>7.265</td>
<td>0.459</td>
<td>1.102</td>
<td>-0.103</td>
<td>1.671</td>
<td>-0.698</td>
<td>0.221</td>
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<td>68.15</td>
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<td></td>
<td>(0.176)</td>
<td>(0.006)</td>
<td>(0.058)</td>
<td>(0.274)</td>
<td>(0.448)</td>
<td>(0.0530)</td>
<td>(0.071)</td>
<td>(0.071)</td>
<td>(0.016)</td>
<td>(0.016)</td>
<td>(0.026)</td>
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<td>(5) Fixed Capital Tax</td>
<td>2.651</td>
<td>0.926</td>
<td>1.334</td>
<td>3.010</td>
<td>1.866</td>
<td>0.011</td>
<td>1.597</td>
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<td>–</td>
<td>145.01</td>
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<td></td>
<td>(0.134)</td>
<td>(0.007)</td>
<td>(0.116)</td>
<td>(0.252)</td>
<td>(0.184)</td>
<td>(0.007)</td>
<td>(0.018)</td>
<td>(0.018)</td>
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<tr>
<td>(6) Fixed Labor Tax</td>
<td>0.411</td>
<td>0.906</td>
<td>0*</td>
<td>2.179</td>
<td>3.201</td>
<td>4.377</td>
<td>–</td>
<td>1.392</td>
<td>-0.406</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>110.46</td>
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<tr>
<td></td>
<td>(0.021)</td>
<td>(0.006)</td>
<td></td>
<td>(0.097)</td>
<td>(0.158)</td>
<td>(0.084)</td>
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<td>(0.009)</td>
<td>(0.008)</td>
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<tr>
<td>(7) Rule-Of-Thumb</td>
<td>3.328</td>
<td>0.917</td>
<td>0.287</td>
<td>6.752</td>
<td>6.712</td>
<td>0.512</td>
<td>1.388</td>
<td>-0.389</td>
<td>1.707</td>
<td>-0.728</td>
<td>–</td>
<td>0.848</td>
<td>66.74</td>
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<td>Households</td>
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<td>(0.007)</td>
<td>(0.071)</td>
<td>(0.317)</td>
<td>(0.392)</td>
<td>(0.049)</td>
<td>(0.026)</td>
<td>(0.026)</td>
<td>(0.013)</td>
<td>(0.013)</td>
<td>(0.006)</td>
<td></td>
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Standard errors are given in parentheses.

*: The parameter was against the boundary of the parameter space.
Figure 1: The Response to Tax Shocks in the US

Anticipated tax shocks are announced at date -6 and implemented at date 0
Figure 2: The Effects of Anticipated Tax Cuts for Alternative Anticipation Horizons

Anticipated tax shocks are announced at date -K and implemented at date 0

Figure 3: Dynamics of Taxes in the Benchmark Model

Anticipated tax shocks are announced at date -6 and implemented at date 0
Anticipated tax shocks are announced at date -6 and implemented at date 0.
Figure 5: Decomposition of Nondurables Consumption and Hours Response

Anticipated tax shocks are announced at date -6 and implemented at date 0.
Anticipated tax shocks are announced at date -6 and implemented at date 0.
Figure 7: Model without Consumption Habits

Anticipated tax shocks are announced at date -6 and implemented at date 0.
Figure 8: Model with Endogenous Government Spending

Anticipated tax shocks are announced at date -6 and implemented at date 0.
Figure 9: Model with Constant Capital Income Tax Rates

Anticipated tax shocks are announced at date -6 and implemented at date 0.
Anticipated tax shocks are announced at date -6 and implemented at date 0.
Anticipated tax shocks are announced at date -6 and implemented at date 0.