State-Dependent Output and Welfare Effects of Tax Shocks*

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Abstract

This paper studies the output and welfare effects of shocks to distortionary tax rates in an estimated dynamic stochastic general equilibrium (DSGE) model with a number of real and nominal frictions. Solving the model using a second order approximation allows us to examine how these effects vary over different states of the business cycle. The tax output multiplier is defined as the change in output for a one dollar change in tax revenue caused by a shock to tax rates on consumption, labor income, or capital income. We define the tax welfare multiplier as the consumption equivalent change in welfare for the same change in tax revenue. We find that magnitudes of tax multipliers vary considerably across the type of tax and the state of the business cycle. The output multipliers for all three tax cuts tend to be largest in states of the economy in which output is low. Output multipliers tend to be positively correlated with welfare multipliers for all three kinds of tax changes. On average, changes in capital tax rates have the largest effects on both output and welfare, shocks to labor income tax rates are in between, and changes in consumption taxes are the least effective means of stimulating output or welfare.

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1 Introduction

This paper studies the output and welfare effects of changes in distortionary tax rates in an estimated medium scale dynamic stochastic general equilibrium (DSGE) model. Our paper differs from the existing literature along two key dimensions. First, whereas most papers focus only on how much tax cuts can stimulate output, we also look at the effects of tax rate changes on welfare. Second, our solution methodology allows for tax changes to have state-dependent effects. While using higher order approximations to solve DSGE models is not new, this allows us to explore interesting questions concerning how the effects of tax cuts vary across states of the business cycle.

Our theoretical framework is a conventional medium scale DSGE model, similar to the frameworks laid out in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). The model features both nominal price and wage rigidity and several real frictions, such as habit formation and investment adjustment costs. The fiscal authority finances an exogenous amount of spending with a mix of lump sum taxes, one-period bonds, and distortionary tax rates on consumption, labor, and capital.[1] Each of the three tax rates obey persistent stochastic processes subject to random shocks. We fit the model to US data by estimating a subset of the model parameters via Bayesian maximum likelihood.

We define the "tax output multiplier" as the change in output for a one dollar change in total tax revenue resulting from a shock to one of the distortionary tax rates. We focus on multipliers at two horizons: on "impact" (in the period of the tax cut) and the "maximum" multiplier (the maximum change in output for a one dollar change in revenue in the period of the shock). These are standard definitions within the literature. Similarly to Sims and Wolff (2014), we define the "tax welfare multiplier" as the one period consumption equivalent change in welfare due to a one dollar change in tax revenue from a shock to one of the tax rates. "Welfare" is taken to mean the present discounted value of flow utility of the representative household in the model. These multipliers are computed by simulating impulse responses to a tax shock in the model, where a recursive representation of household welfare is included as an equilibrium condition. We solve the model using a second-order approximation. The higher-order allows for the impulse response functions, and therefore the magnitudes of the multipliers, to depend on the initial state in which a shock hits.

We simulate several thousand periods of data from the model and compute both output and welfare multipliers for each of the three tax rates at each point in the simulated state space. The average value of the capital tax output multiplier in the simulations is slightly above one.[2] In other words, a one dollar change in revenue from a cut in the tax rate on capital income stimulates output

[1] The existences of non-zero government spending could be justified by assuming that households receive a utility flow from government spending. As long as utility from government spending is additively separable from utility from consumption and leisure, there would be no effect on the equilibrium of the model.

[2] Here and throughout the remainder of the Introduction, when we refer to the "output multiplier" we mean the "maximum output multiplier" as defined in the paragraph above. Also, we always multiply the multipliers by negative one, so that multipliers are positive. As defined, for tax changes multipliers in our model are always negative, since any tax change that stimulates output results in less tax revenue (e.g. we are always to the left of the peak of the "Laffer curve").

by slightly more than one dollar. A one dollar change in revenue from a cut in either the labor or consumption tax rate stimulates output by roughly 50 cents on average.[3] Cuts in each of three tax rates lead to significant welfare improvements.[4]

For each of the three tax rates, there is significant variation in the magnitudes of both output and welfare multipliers across states of the business cycle. For example, the capital tax output multiplier ranges from as low as 0.7 to as high as 1.4 in the simulations. The output multipliers for all three kinds of tax cuts are negatively correlated with the simulated level of output. That is, the output effectiveness of tax cuts is highly countercyclical – tax cuts are more effective at stimulating output during a downturn than in an expansion. The welfare multiplier for each of the three tax rates is also estimated to be countercyclical. The output and welfare multipliers are strongly positively correlated with one another. This means that periods where it is relatively advantageous to cut taxes from the perspective of stimulating output are also advantageous from the perspective of improving welfare. The intuition for these results relates to time-varying inefficiency. In the model, the overall level of inefficiency tends to be high when output is low. This makes cutting taxes especially attractive from a welfare perspective, but also results in more output stimulus, since resources are relatively underutilized in states where the economy is highly distorted. This result stands in contrast to the output and welfare effects of government spending shocks. In Sims and Wolff (2014) we find that the output and welfare multipliers for government spending shocks tend to be negatively correlated across states of the business cycle.

We also conduct an historical simulation of the estimated model. Rather than simulating states from the model with a series of randomly drawn i.i.d. shocks, we use the Kalman smoother and the observable variables in our Bayesian estimation to extract "smoothed" retrospective estimates of the states. This allows us to construct historical estimates for the magnitudes of the output and welfare multipliers for each of the three tax rates at each point in time. While the basic conclusions from the historical simulation mirror those from the regular simulation, there are nevertheless some interesting insights. For example, we estimate that all three tax output multipliers (as well as the corresponding welfare multipliers) have been at historical highs since the midway mark of the recent Great Recession.

We consider several robustness extensions on our benchmark quantitative exercises. These include incorporating anticipation lags into the tax processes, considering different methods of fiscal

[3]Some care must be taken when interpreting the magnitudes of the output multipliers. We assume that each tax rate follows a first order autoregressive process. The estimated persistence in each of the three tax processes is not the same – in our estimation, the consumption tax process is estimated to be far more persistent (AR parameter of 0.97) than either the labor or capital tax processes (AR parameters of 0.89 each). If we were to fix the persistence of tax shocks across the three types of taxes to an intermediate value (e.g. an AR parameter of 0.95), the capital and labor tax multipliers would be significantly larger than they are in our baseline estimation, and the consumption multiplier would be smaller.

[4]Similarly to the output multipliers, the persistence of the estimated tax processes plays an important role in the magnitude of the welfare multiplier. In our baseline estimation, a consumption tax cut is most effective at stimulating welfare, a capital tax cut second most effective, and the labor tax cut the least effective. If we were to fix the autoregressive parameters in the three tax processes to be the same, however, this ordering would be changed: a capital tax cut would result in the largest welfare improvement, a labor tax cut the second largest, and a consumption tax cut would be the least effective means to increase welfare.

finance (e.g. are tax cuts financed with lump sum tax increases, or future increases in distortionary tax rates?), and assigning different values of some of the key parameters. Our basic conclusions are, for the most part, unchanged: all three tax multipliers tend to be highest when output is low, and all three tend to co-move positively with their corresponding welfare multiplier. One important robustness exercise that we do is to fix the autoregressive parameters in the tax processes to a common value (whereas in our benchmark exercises these parameters are estimated). When we do this, magnitudes of both the output and the welfare multipliers are highest for capital taxes, second highest for labor taxes, and lowest for consumption taxes.

There is a long literature on the economic effects of tax changes. Early contributions include Friedman (1948), Ando and Brown (1963), Hall (1971), and Barro (1979). Judd (1987) and McGrattan (1994) both look at the welfare costs of taxation. Steigerwald and Stuart (1997), Chun and Yang (2005), House and Shapiro (2006), Leeper, Walker, and Yang (2011), Mertens and Raven (2011), and Mertens and Raven (2012) all study the implications of anticipation lags for the transmission of tax shocks. Chun and Yang (2005) and Mountford and Uhlig (2009) highlight the importance of the method of fiscal finance in the transmission of government spending and shocks into the real economy. Our paper is also related to a small but growing literature which acknowledges the potential state-dependence of fiscal policy multipliers. Auerbach and Gorodnichenko (2012), Bachmann and Sims (2012), and Mittnik and Semmler (2012) each find output multipliers to government spending increases to be strongly counter-cyclical, whereas Owyang, Ramey, and Zubairy (2013) find little evidence for state dependence. Ours is one of only a few papers which jointly focus on the output and welfare effects of tax shocks, and we are the only paper of which we are aware which computes state-dependent tax multipliers in a DSGE framework.

The remainder of the paper proceeds as follows. Section 2 describes the medium-scale DSGE model. Section 3 estimates the model parameters. In Section 4 we conduct our main simulation exercises to study the magnitude, state-dependence, and co-movement of tax multipliers. Section 5 consider a number of extensions and modifications to our basic framework. The final section concludes.

2 Medium-Scale DSGE Model

This section presents a medium-scale dynamic stochastic general equilibrium (DSGE) model in the spirit of Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2007), and Schmitt-Grohe and Uribe (2006). The model features a continuum of households, a continuum of intermediate good producers, and a single final good producer. In addition, we incorporate a government with a rich array of financing options including distortionary consumption, labor, and capital taxes, lump sum taxes, and non-state contingent bonds. Among the numerous real frictions present in the model are monopolistic competition, investment adjustment costs, habit formation, variable capital utilization, and the aforementioned distortionary taxes. The model also contains nominal frictions in the form of price and wage stickiness as well as price and wage indexation. Below, we describe the optimization problem of each agent, and conclude the section with a full definition of an equilibrium in this model.

2.1 Household

There exists a representative household with preferences over consumption and leisure. Welfare is the present discounted value of flow utility:

$$V_0 = E_0 \sum_{t=0}^{\infty} \beta^t \nu_t U \left(C_t - bC_{t-1}, 1 - N_t\right) \tag{1}$$

The flow utility function is increasing and concave in both arguments, and allows for non-separability between consumption and leisure. The time endowment is normalized to unity, and N_t represents labor hours, so $1 - N_t$ is leisure. The parameter $0 \leq b < 1$ measures the degree of internal habit formation in consumption. The discount factor is $0 < \beta < 1$, and ν_t is a preference shock.

The household accumulates physical capita via:

$$K_{t+1} = Z_t \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t + (1-\delta)K_t \tag{2}$$

The capital stock is denoted by K_t and investment by I_t. The function $S(\cdot)$ is an investment adjustment cost function modeled after Christiano, Eichanebaum, and Evans (2005). It has the properties that $S(1) = S'(1) = 0$, and $S''(1) = \kappa \geq 0$. Capital depreciates at rate $0 < \delta < 1$. Z_t is a stochastic shock to the marginal efficiency of investment, as in Justiniano, Primiceri, and Tambalotti (2010).

Nominal wage rigidity is introduced as in Schmitt-Grohe and Uribe (2006). The household supplies labor to a continuum of differentiated labor markets indexed by $h \in (0, 1)$. Each period, there is a fixed probability, $(1 - \theta_w)$ with $\theta_w \in (0, 1)$, that the household can re-optimize the wage charged in a market. Non-optimized wages can be indexed to lagged inflation at $\zeta_w \in (0, 1)$. The demand for labor in a particular market is:

$$N_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\epsilon_w} N_{d,t}, \quad \epsilon_w > 1 \tag{3}$$

The parameter ϵ_w is the elasticity of demand for labor. $W_t(h)$ is the real wage charged in market h, W_t is the aggregate real wage, and $N_{d,t}$ is a measure of aggregate labor demand from firms. The aggregate real wage is given by:

$$W_t^{1-\epsilon_w} = \int_0^1 W_t(h)^{1-\epsilon_w} dh \tag{4}$$

Total labor supply is the integral of labor supplied in each market:

$$N_t = \int_0^1 N_t(h) dh \tag{5}$$

Combining (5) with (3), one arrives at an expression for aggregate labor supply in terms of wages and aggregate labor demand:

$$N_t = N_{d,t} \int_0^1 \left(\frac{W_t(h)}{W_t} \right)^{-\epsilon_w} dh \tag{6}$$

The real flow budget constraint of the representative household is:

$$(1+\tau_t^c)\, C_t + I_t + \Gamma(u_t) \frac{K_t}{Z_t} + \frac{B_t}{P_t} \leq \cdots \tag{7}$$

$$(1-\tau_t^n) \int_0^1 W_t(h) N_t(h) dh + (1-\tau_t^k) r_t^k u_t K_t + (1+i_{t-1}) \frac{B_{t-1}}{P_t} + \Pi_t - T_t \tag{8}$$

Here P_t is the nominal price of goods. With its income the household can consume, invest in new capital, and accumulate bonds, B_t. Bonds accumulated in period t pay off in period $t+1$ at nominal interest rate i_t. The household pays a resource cost for capital utilization, u_t. The resource cost is given by the function $\Gamma(u_t)$, which has the properties that $\Gamma(1) = 0$, $\Gamma'(1) = \psi_0 > 0$ and $\Gamma''(1) = \psi_1 \geq 0$. The cost is expressed in units of physical capital; division by Z_t expresses this in terms of consumption units (the numeraire). The household earns income from labor supplied in the continuum of labor markets and from capital services leased to firms at rental rate r_t^k, where capital services is the product of utilization and the physical capital stock. There are distortionary and time-varying tax rates on consumption, labor income, and capital income given by τ_t^c, τ_t^n, and τ_t^k. Real profit distributed from ownership in firms is given by Π_t, and T_t is a lump sum tax/transfer from the government.

Each period, the household chooses consumption, investment, capital utilization, bond-holding, and aggregate labor supply to maximize the present discounted value of flow utility subject to the flow budget constraint, (7); the capital accumulation equation, (2); and the condition that aggregate labor supply equals demand, (6). The first order optimality conditions are:

$$(1+\tau_t^c)\, \mu_{1,t} = \nu_t U_C(C_t - bC_{t-1}, 1-N_t) - \beta b E_t \nu_{t+1} U_C(C_{t+1} - bC_t, 1-N_{t+1}) \tag{9}$$

$$\left(1-\tau_t^k\right) r_t^k = \frac{\Gamma'(u_t)}{Z_t} \tag{10}$$

$$1 = q_t Z_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right) \frac{I_t}{I_{t-1}} \right] + \beta E_t \frac{\mu_{1,t+1}}{\mu_{1,t}} q_{t+1} Z_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right) \left[\frac{I_{t+1}}{I_t}\right]^2 \tag{11}$$

$$q_t = \beta E_t \frac{\mu_{1,t+1}}{\mu_{1,t}} \left[\left(1-\tau_{t+1}^k\right) r_{t+1}^k u_{t+1} - \frac{\Gamma(u_{t+1})}{Z_{t+1}} + (1-\delta) q_{t+1} \right] \tag{12}$$

$$\mu_{1,t} = \beta(1+i_t) E_t \mu_{1,t+1} (1+\pi_{t+1})^{-1} \tag{13}$$

$$U_L(C_t - bC_{t-1}, 1-N_t) = \mu_{3,t} \tag{14}$$

In these first order conditions, $\mu_{1,t}$ is the multiplier on the budget constraint, $\mu_{2,t}$ is the multiplier on the accumulation equation, and $\mu_{3,t}$ is the multiplier on the labor supply constraint. We define $q_t \equiv \frac{\mu_{2,t}}{\mu_{1,t}}$ to denote the marginal value of an installed unit of capital expressed in units of consumption goods. The inflation rate is defined as $\pi_t \equiv \frac{P_t}{P_{t-1}} - 1$.

Each period, the household can update the wage it charges in a randomly chosen fraction of labor markets, $1 - \theta_w$. It can index non-updated wages at ζ_w. In setting the wage in a particular market, it takes into account the probability that it will be stuck with that wage in the future. The optimized wage will be the same in all updated markets, and is given by the recursive expression:

$$W_t^{\#} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{F_{1,t}}{F_{2,t}} \tag{15}$$

$$F_{1,t} = U_L(C_t - bC_{t-1}, 1 - N_t) W_t^{\epsilon_w} N_{d,t} + \theta_w \beta (1 + \pi_t)^{-\epsilon_w \zeta_w} E_t (1 + \pi_{t+1})^{\epsilon_w} F_{1,t+1} \tag{16}$$

$$F_{2,t} = \mu_{1,t} (1 - \tau_t^n) W_t^{\epsilon_w} N_{d,t} + \theta_w \beta (1 + \pi_t)^{\zeta_w (1 - \epsilon_w)} E_t (1 + \pi_{t+1})^{\epsilon_w - 1} F_{2,t+1} \tag{17}$$

2.1.1 Final Goods Firm

There exists a perfectly competitive final goods firm that bundles differentiated intermediate outputs into a final good. The intermediate outputs are indexed by $j \in (0, 1)$. The technology transforming intermediate outputs into the final good is:

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon_p - 1}{\epsilon_p}} dj \right)^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{18}$$

The elasticity of substitution between intermediates is given by $\epsilon_p > 1$. Profit maximization results in the demand schedules:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon_p} Y_t \quad \forall\, j \in (0, 1) \tag{19}$$

The aggregate price index is given by:

$$P_t = \left(\int_0^1 P_t(j)^{1 - \epsilon_p} dj \right)^{\frac{1}{1 - \epsilon_p}} \tag{20}$$

2.1.2 Intermediate Goods Firm

Intermediate good firms use labor, $N_{d,t}(j)$, and capital services, $\widetilde{K}_t(j) = u_t K_t(j)$, to produce output, $Y_t(j)$:

$$Y_t(j) = A_t \widetilde{K}(j)^{\alpha} N_{d,t}^{1-\alpha}(j) \tag{21}$$

Here, $0 < \alpha < 1$ is capital's share an A_t is a common productivity shock. Intermediate good firms behave atomistically and take real factor prices and demand for their product (19) as given. Cost minimization results in the following marginal cost and input ratio conditions:

$$mc_t = \frac{W_t^{1-\alpha} (r_t^k)^{\alpha}}{A_t} (1 - \alpha)^{\alpha - 1} \alpha^{-\alpha} \tag{22}$$

$$\frac{\widetilde{K}_t(j)}{N_{d,t}(j)} = \frac{\alpha}{1-\alpha}\frac{W_t}{r_t^k} \tag{23}$$

Competitive factor markets and a common technology implies that all firms share a common real marginal cost. As a result, each firm will choose an identical capital services to labor ratio.

Each period, a fraction $(1-\theta_p)$ of firms are able to update prices where $\theta_p \in (0,1)$. The opportunity to update prices is independent of history. Non-updating firms can index their price in each period to lagged inflation with indexation parameter $\zeta_p \in (0,1)$. Prices are set to maximize the present discounted value of real profit returned to the household, where discounting is by the household's stochastic discount factor and takes into account the probability that a price chosen in a period may be in effect in the future. Given a common real marginal cost, all updating firms update to a common price, which we denote by $P_t^{\#}$. The optimal reset price can be written recursively in terms of inflation rates by defining $\pi_t^{\#} \equiv \frac{P_t^{\#}}{P_{t-1}} - 1$ as:

$$1+\pi_t^{\#} = \frac{\epsilon_p}{\epsilon_p - 1}(1+\pi_t)\frac{X_{1,t}}{X_{2,t}} \tag{24}$$

$$X_{1,t} = mc_t \mu_{1,t} Y_t + \theta_p \beta (1+\pi_t)^{-\zeta_p \epsilon_p} E_t (1+\pi_{t+1})^{\epsilon_p} X_{1,t+1} \tag{25}$$

$$X_{2,t} = \mu_{1,t} Y_t + \theta_p \beta (1+\pi_t)^{\zeta_p(1-\epsilon_p)} E_t (1+\pi_{t+1})^{\epsilon_p - 1} X_{2,t+1} \tag{26}$$

2.1.3 Government

The government's real flow budget constraint is given by:

$$G_t + i_{t-1}\frac{B_{t-1}^g}{P_t} = \tau_t^c C_t + \tau_t^n W_t N_d, t + \tau_t^k r_t^k \widetilde{K}_t + T_t + \frac{B_t^g - B_{t-1}^g}{P_t} \tag{27}$$

The government enters a period with a stock of nominal bonds given by B_{t-1}^g. Government spending plus interest payments on outstanding debt must equal tax revenue plus issuance of new debt. The tax instruments obey the following processes:

$$\tau_t^c = (1-\rho_c)\tau^c + \rho_c \tau_{t-1}^c + (1-\rho_c)\gamma_c^b (B_{t-1}^g - B^g) + s_c \varepsilon_{c,t} \tag{28}$$

$$\tau_t^n = (1-\rho_n)\tau^n + \rho_n \tau_{t-1}^n + (1-\rho_n)\gamma_n^b (B_{t-1}^g - B^g) + s_n \varepsilon_{n,t} \tag{29}$$

$$\tau_t^k = (1-\rho_k)\tau^k + \rho_k \tau_{t-1}^k + (1-\rho_k)\gamma_k^b (B_{t-1}^g - B^g) + s_k \varepsilon_{k,t} \tag{30}$$

$$T_t = T + \gamma_T^b (B_{t-1}^g - B^g) \tag{31}$$

The exogenous variables $\varepsilon_{c,t}$, $\varepsilon_{n,t}$, and $\varepsilon_{k,t}$ follow standard normal distributions; s_c, s_n, and s_k are the standard deviations of the shocks. The steady state values of the tax rates and government debt are marked by the absence of a time subscript. Because the exact timing of lump sum taxes is irrelevant, it is without loss of generality to omit an autoregressive term in (31). The parameters γ_c^b, γ_n^b, γ_k^b, and γ_T^b govern the extent to which taxes react to lagged debt. These parameter values must be such that the path of government debt is non-explosive.

Government spending follows an AR(1) process in the log. The variable $\varepsilon_{g,t}$ is a shock drawn from a standard normal distribution, and s_g is the standard deviation of the shock:

$$\ln G_t = (1-\rho_g)\ln G + \rho_g \ln G_{t-1} + s_g\varepsilon_{g,t} \tag{32}$$

Monetary policy is governed by a standard Taylor-type rule for the nominal interest rate:

$$i_t = (1-\rho_i)i + \rho_i i_{t-1} + (1-\rho_i)\left(\phi_\pi(\pi_t - \pi) + \phi_y(\ln Y_t - \ln Y_{t-1})\right) + s_i\varepsilon_{i,t} \tag{33}$$

The shock $\varepsilon_{i,t}$ is drawn from a standard normal distribution and s_i is the standard deviation of the shock. We restrict the parameters of the policy rule to the region with a determinate rational expectations equilibrium.

2.1.4 Exogenous Processes

In addition to the processes for the distortionary tax rates, the model features three other exogenous processes: productivity, marginal efficiency of investment, and a preference term. These all follow mean zero AR(1) processes in the log, with shocks drawn from standard normal distributions, with s_a, s_z, and s_ν the standard deviations of the shocks:

$$\ln A_t = \rho_a \ln A_{t-1} + s_a\varepsilon_{a,t} \tag{34}$$

$$\ln Z_t = \rho_z \ln Z_{t-1} + s_z\varepsilon_{z,t} \tag{35}$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + s_\nu\varepsilon_{\nu,t} \tag{36}$$

2.1.5 Market-Clearing

A competitive equilibrium for this economy is a set of prices and allocations for which all agents behave optimally and all markets clear, taking as given the laws of motions and values of the exogenous variables and initial values of endogenous state variables. Market-clearing necessitates that total labor demand from firms equals total labor used in production, that government debt is held by the household, and that capital services supplied by the household equals total demand:

$$N_{d,t} = \int_0^1 N_t(j)dj \tag{37}$$

$$B_t = B_t^g \tag{38}$$

$$\widetilde{K}_t = \int_0^1 \widetilde{K}_t(j)dj = u_t K_t \tag{39}$$

Imposing bond and labor market-clearing gives rise to the aggregate resource constraint:

$$Y_t = C_t + I_t + G_t + \Gamma(u_t)\frac{K_t}{Z_t} \tag{40}$$

Integrating over firm production functions and imposing labor market-clearing yields an aggregate production function:

$$Y_t = \frac{A_t \widetilde{K}_t^{\alpha} N_{d,t}^{1-\alpha}}{v_t^p} \tag{41}$$

The term v_t^p is a measure of price dispersion which arises due to staggered price-setting. It can be written recursively only depending on aggregate variables:

$$v_t^p = (1+\pi_t)^{\epsilon_p}\left[(1-\theta_p)(1+\pi_t^{\#})^{-\epsilon_p} + \theta_p(1+\pi_{t-1})^{-\epsilon_p\zeta_p} v_{t-1}^p\right] \tag{42}$$

Via the properties of Calvo (1983) price-setting, aggregate inflation evolves according to:

$$(1+\pi_t)^{1-\epsilon_p} = (1-\theta_p)(1+\pi_t^{\#})^{1-\epsilon_p} + \theta_p(1+\pi_{t-1})^{\zeta_p(1-\epsilon_p)} \tag{43}$$

Similarly, the aggregate real wage obeys:

$$W_t^{1-\epsilon_w} = (1-\theta_w)\left(W_t^{\#}\right)^{1-\epsilon_w} + \theta_w W_{t-1}^{1-\epsilon_w}(1+\pi_{t-1})^{\zeta_w(1-\epsilon_w)}(1+\pi_t)^{\epsilon_w-1} \tag{44}$$

Integrating over the different labor markets, aggregate labor supply can be expressed:

$$N_t = N_{d,t} v_t^w \tag{45}$$

The term v_t^w is a measure of wage dispersion arises due to the natured of staggered wage-setting. It can be expressed recursively as:

$$v_t^w = (1-\theta_w)\left(\frac{W_t^{\#}}{W_t}\right)^{-\epsilon_w} + \theta_w\left(\frac{W_t}{W_{t-1}}\right)^{\epsilon_w}\left(\frac{(1+\pi_{t-1})^{\zeta_w}}{1+\pi_t}\right)^{-\epsilon_w} v_{t-1}^w \tag{46}$$

We can write the welfare for the representative household recursively using (45) to eliminate N_t as:

$$V_t = \nu_t U(C_t, 1 - N_{d,t} v_t^w) + \beta E_t V_{t+1} \tag{47}$$

In writing the value function with a subscript t, it is implicitly conditional on the realization of a particular state and is assumed that the household has chosen consumption and labor optimally. We include this recursive representation of the value function as an equilibrium condition of the model, which allows us to examine how welfare reacts to changes in tax rates.

3 Estimation

In this section, we estimate a subset of the parameters of medium scale DSGE model presented in the previous section. We first discuss the functional forms for utility and the various costs associated with investment and capital utilization. We then discuss the estimation procedure used to parameterize the model and, lastly, we present our baseline estimation results. In Section 4, we take the estimated parameter values from this section and solve the model with higher order approximations to the policy function, which allows us to consider state-dependent effects of tax shocks.

3.1 Functional Forms

Following Christiano, Eichenbaum, and Rebelo (2011), we assume that period utility from consumption and leisure takes the following form:

$$U(C_t, 1-N_t) = \frac{(C_t^{\gamma}(1-N_t)^{1-\gamma})^{1-\sigma}-1}{1-\sigma}, \qquad \sigma > 0, \;\; 0 < \gamma < 1 \tag{48}$$

This functional form is consistent with balanced growth while also allowing for non-separability in consumption and leisure. For values of $\sigma > 1$, consumption and labor are complements. For the special case in which $\sigma = 1$, the utility function assumes the traditional log-log form of $\gamma \ln C_t + (1-\gamma)\ln(1-N_t)$ in which the marginal utilities of consumption and leisure are independent of one another.

The functional forms for the utilization cost and the investment adjustment cost are given by:

$$\Gamma(u_t) = \left(\psi_0(u_t-1) + \frac{\psi_1}{2}(u_t-1)^2\right) \tag{49}$$

$$S\left(\frac{I_t}{I_{t-1}}\right) = \left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right) \tag{50}$$

The value of ψ_0 in the utilization cost function is pinned down by the steady state normalization of utilization to unity.[5] The parameters ψ_1 and κ are free parameters.

3.2 Parameterization

In total, the model contains forty-three parameters. We calibrate eight parameters to match long run moments of the data, fix the values of the steady state tax rates to their historical averages, fix four parameters governing variable tax finance, fix the parameters governing the utilization cost function, and estimate the remaining twenty-six parameters via Bayesian maximum likelihood.

The calibrated parameters are $\{\alpha,\ \beta,\ \delta,\ \epsilon_p,\ \epsilon_w,\ \pi,\ G,\ B^g\}$. We set $\alpha = 1/3$ to match the long run labor's share of income. The discount factor is set to $\beta = 0.99$ and we assume zero trend

[5] From the household first order conditions, it is straightforward to see that $\psi_0 = \frac{1}{\beta} - (1-\delta)$ pins down steady state utilization to unity.

inflation, $\pi = 0$. Together, this implies a steady state risk free interest rate of about four percent annualized. The elasticity parameters ϵ_p and ϵ_w are both fixed at 10, implying steady state price and wage markups of approximately ten percent. We choose steady state government spending, G, so that it equals 20 percent of steady state output. Steady state government debt, B^g, is chosen so that the steady state debt-gdp ratio is 50 percent. The depreciation rate on physical capital is set to $\delta = 0.025$. Under this parameterization, investment is 17 percent of output in steady state and consumption is 63 percent of output.

To calibrate the steady state values of $\{\tau^c, \tau^n, \tau^k\}$, we construct historical tax rate series using data from the NIPA accounts following Leeper, Plante, and Traum (2010). These tax rates are created from dividing government tax revenue by source by the appropriate measure of total income (e.g. labor income tax revenue divided by total labor income). We calibrate the steady state tax rates to equal their average values over the period 1985-2010. This results in values of $\tau^c = 0.0164$, $\tau^n = 0.2090$, and $\tau^k = 0.1946$. These values are close to those in Leeper, Plante, and Traum (2010); small differences arise due to our focus on a slightly different sample period. As a baseline, we assume that distortionary tax rates do not react to debt, so that all variable government finance comes through lump sum taxes. In other words, $\gamma_c^b = \gamma_n^b = \gamma_k^b = 0$, and we set γ_b^T sufficiently large so that government debt is non-explosive.[6] While perhaps unrealistic, this assumption gives rise to a clean interpretation of the exercise of cutting a tax rate; if γ_b^c, γ_b^n, or γ_b^k were positive, tax cuts today would be followed by tax rate increases in the future. We nevertheless consider several robustness exercises in Section 5 in which lump sum taxes are shut down and government finance comes solely via endogenous changes in distortionary tax rates.

We estimate the remaining parameters of the model via Bayesian maximum likelihood. These parameters can be divided into two groups – those related to preferences, production technology, and monetary policy, $\{b, \sigma, \gamma, \kappa, \theta_p, \theta_w, \zeta_p, \zeta_w, \rho_i, \phi_\pi, \phi_y\}$; and those parameters which govern stochastic processes, $\{\rho_a, \rho_z, \rho_g, \rho_\nu, \rho_c, \rho_n, \rho_k, s_a, s_z, s_g, s_\nu, s_c, s_n, s_k, s_i\}$. We do not estimate the parameters of the utilization cost function, ψ_0 and ψ_1. As noted above, ψ_0 is pinned down by the steady state normalization of utilization to unity. Estimation of models such as the one in this paper typically drives ψ_1 to a very small number; following Christiano, Eichenbaum, and Evans (2005), we simply calibrate it at $\psi_1 = 0.01$, implying that the costs of utilization are very close to linear.

The observable variables used in our estimation cover the period 1985q1 through 2010q2. With eight shocks in the model, we use eight observable variables in the estimation. These include the quarter-over-quarter growth rates of output, investment, government spending, and labor hours, and the levels of inflation and the consumption, labor, and capital tax rates. Output and government spending are the headline numbers from the main NIPA tables. Investment is defined as as new expenditure on durables plus private fixed investment. These series are deflated by the GDP price deflator and are divided by the civilian non-institutionalized population before taking logs and

[6] In our baseline exercise, we set $\gamma_b^T = 0.05$. Since the exact timing of lump sum taxes is irrelevant given that distortionary tax rates do not react to debt, our results below would be identical with higher value of γ_b^T, or if we assumed that lump sum taxes adjusted to balance the government's budget period-by-period.

first differencing. Labor hours are defined as total hours worked in the non-farm business sector, divided by the population to be expressed in per capita terms. Inflation is the log first difference of the GDP price deflator. The tax rate series are as defined above. The prior distributions for the estimated parameters are based on the literature. Shock standard deviations have inverse gamma priors, parameters constrained to lie between 0 and 1 (such as autoregressive parameters) have beta distribution priors, and other parameters have normal prior distributions.

Table 1 shows the prior and posterior distributions of the estimated parameters. The posterior modes and means of the parameters are sensible relative to the existing literature. The estimated price stickiness parameter, $\theta_p = 0.86$, is high relative to micro estimates of price duration, but is in line with many other estimates based on similar models (e.g. Justiniano, Primiceri, and Tambalotti, 2012, who estimate $\theta_p = 0.84$). The wage rigidity parameter is significantly smaller at $\theta_w = 0.46$; but it is important to note that we introduce wage rigidity following Schmitt-Grohe and Uribe (2006), which permits non-separability between consumption and leisure. This setup results in a "flatter" wage Phillips curve for a given amount of wage rigidity than in a setup based on Erceg, Henderson, and Levin (2000) with separability, so it is natural that our estimated wage rigidity parameter is smaller than what is typically found in the literature. There is virtually no price indexation and a moderate amount of wage indexation. There are strong investment adjustment costs and a good deal of habit formation. Though the consumption tax process is estimated to be quite persistent, the autoregressive parameters in the labor and capital tax processes are relatively small ($\rho_n = 0.89$ and $\rho_k = 0.89$). The autocorrelation in the tax processes plays an important role in the magnitude of the tax multipliers, which we discuss more in the robustness section.

Overall, the estimated model fits the data well. The estimated volatility of output growth is a little more than 1 percent, consumption is about half as volatile as output, and investment is 2.5 times as volatile as output. The growth rates of output, consumption, and investment are all significantly autocorrelated, as in the data. As in Justiniano, Primiceri, and Tambalotti (2010), the shock to the marginal efficiency of investment is the dominant business cycle shock, accounting for about 45 percent of the unconditional variance of output growth. Monetary policy and preference shocks are the next two most important shocks, with neutral productivity and government spending shocks playing a less important role. The three tax shocks are estimated to have small effects on output and its components over the business cycle. This is not because of a built-in model features that prevents tax shocks from having large effects, but rather from the discipline imposed by including the tax rate series as observable variables in our estimation. In the data, the time series of tax rates are quite smooth, and so the estimated standard deviations of the tax shocks are accordingly small.

4 Baseline Results

In this section, we simulate the model using the modes of the estimated parameters to quantify the effects of tax cuts on output and welfare. We begin by briefly outlining the solution methodology which permits an investigation of state-dependent effects of tax shocks. We then define various multipliers and construct them via simulations of the model. Lastly, we take smoothed states from the estimation of the model to conduct an historical simulation to quantify the magnitudes of the output and welfare effects of tax shocks for the US over the last thirty years. We conclude the section with a brief summary of the results and some basic intuition.

4.1 Solution Methodology

Though a first order approximation has become the workhorse solution methodology for DSGE models, it results in impulse response functions which are independent of the initial state. As we wish to consider the state-dependent effects of tax shocks on output and welfare, we therefore consider a second-order approximation of the model. In addition to the linear components of the first-order approximation, a second-order approximation will contain a non-linear mapping to the cross product of state variables, the cross product of exogenous shocks, and to a cross-partial between state variables and shocks.

Let $\mathbf{x}_t$ denote a stacked vector of both state and control variables, $\mathbf{s}_t$ a vector of state variables, and ε_t a vector of shocks. The variables in these vectors are log differences from the non-stochastic steady state (exceptions include variables already in percent form, such as inflation and interest rates which are expressed as absolute deviations from steady state). The recursive expression for household welfare, V_t from (47), is included as one of the variables in $\mathbf{x}_t$. The second-order policy function described above can be expressed as follows:

$$\mathbf{x}_t = \frac{1}{2}\boldsymbol{\Psi}_0 + \boldsymbol{\Psi}_1\mathbf{s}_{t-1} + \boldsymbol{\Psi}_2\varepsilon_t + \frac{1}{2}\boldsymbol{\Psi}_3(\mathbf{s}_{t-1}\otimes\mathbf{s}_{t-1}) + \frac{1}{2}\boldsymbol{\Psi}_4(\varepsilon_t\otimes\varepsilon_t) + \boldsymbol{\Psi}_5(\mathbf{s}_{t-1}\otimes\varepsilon_t) \tag{51}$$

The matrixes Ψ_i for $i = 0, 1, 2, 3, 4,$ and 5 are the coefficient matrices mapping each respective term to the vector of endogenous variables. It is with policy functions of this style that we construct the model simulations in what follows. In a first-order approximation, all but $\boldsymbol{\Psi}_1$ and $\boldsymbol{\Psi}_2$ would be matrixes of zeros. The details for solving for these coefficient matrixes can be found in Schmitt-Grohe and Uribe (2004).

The impulse response function to a particular shock is defined as the change in expected value of $\mathbf{x}_{t+h}$ from period $h = 0$ to $h = H$ conditional on the realization of a one standard deviation shock to exogenous variable j at time t. Formally, $\mathbf{IRF}(h) = \{E_t\mathbf{x}_{t+h} - E_{t-1}\mathbf{x}_{t+h} \mid \varepsilon_{j,t} = \varepsilon_{j,t} + s_j, \mathbf{s}_{t-1}\}$. Given the estimated policy functions, we construct impulse responses as follows. Given a starting position of the state, $\mathbf{s}_{t-1}$, we draw values of the shocks from a standard normal distribution and simulate the vector $\mathbf{x}_t$ out to a horizon of $\mathbf{x}_{t+H}$. This process is repeated N times, and we average the realizations of $\mathbf{x}_{t+h}$ across the N simulations. Then, keeping the same draw of shocks and initial vector of states, we re-do this process, but add s_j to the realization of shock j at time t. The difference between the average realizations from the two simulations is the resulting impulse response function.

4.2 Multiplier Definitions

We compute impulse responses to one standard deviation shocks to each of the three distortionary tax rates. We define the tax output multiplier as the ratio of the change in output at some forecast horizon, h, to the change in total tax revenue on impact (forecast horizon 0) arising from a shock to one of the tax rates. Formally:

$$YM_j(h) = \frac{dY_{t+h}}{dTR_t}\bigg|\varepsilon_{j,t} = \varepsilon_{j,t} + s_j, \quad \text{for } j = c,\ n, \text{ or } k \tag{52}$$

This expression is interpretated as the change in output resulting from a one dollar change in total tax revenue due to a shock in one of the distortionary tax rates. As written, the multiplier is defined for many forecast horizons. We will focus on two horizons in particular: the "impact" multiplier, which sets $h = 0$; and the "max" multiplier, which is the maximum multiplier over the forecast horizon H.[7] To compute these multipliers, we simulate impulse responses, and compute ratios of the output response to a tax shock at different forecast horizons to the tax revenue response on impact. Since the impulse responses depend on the initial state, $\mathbf{s}_{t-1}$, so too do the multipliers.

Adopting terminology from Sims and Wolff (2014), we define the welfare multiplier as the consumption equivalent change in welfare, V_t, for a one dollar change in tax revenues. Formally:

$$VM_j = \frac{dV_t}{dTR_t}\frac{1}{U_C}\bigg|\varepsilon_{j,t} = \varepsilon_{j,t} + s_j, \quad \text{for } j = c,\ n, \text{ or } k \tag{53}$$

This expression is equal to the impact response of welfare to a tax shock divided by the tax revenue response on impact, all divided by the steady state marginal utility of consumption. Division by the steady state marginal utility of consumption puts the welfare multiplier into interpretable units: the units of steady state consumption equivalent to the change in welfare arising from a tax shock. Note here that there is no dependence of the multiplier upon h: since welfare is forward-looking, the impact response of welfare summarizes the welfare effect of a tax change.

4.3 Simulation

We simulate 10,000 periods of the model using randomly drawn shocks. The simulation begins at the non-stochastic steady state. We discard the first 100 periods of the simulation to avoid any bias arising from this starting position. At each point in the simulated state space, we construct impulse responses to one standard deviation shocks to each of the three distortionary tax rates.[8] We then use these to compute output and welfare multipliers at each point in the state space. We compute basic summary statistics for each of the three multipliers, and also examine how the output and welfare multipliers co-move with one another across states as well as how the output and welfare multipliers co-move with the simulated level of output.

[7]We compute impulse responses up to a horizon $H = 20$. The maximum output response to any of the three tax shocks typically occurs at horizons between $h = 8$ and $h = 12$.

[8]For this paper, we do not present results for government spending multipliers. For those results, please see Sims and Wolff (2014).

Table 2 contains the baseline results for these summary statistics. The table contains three main panels, each with three rows of multipliers; these include the impact and maximum output multipliers and the welfare multiplier. Given nominal rigidities and the large amount of real inertia in the model, the impact output multipliers are significantly smaller than the maximum multipliers. The maximum output response occurs at between five-to-six quarters for capital tax cuts, at about ten quarters for labor tax cuts, and at twelve-fourteen quarters for consumption tax shock. The average maximum multipliers across the simulation are 0.51 for consumption, 0.52 for labor, and 1.02 for capital. To take capital taxes as an example, this means that a cut in the capital tax that leads to a one dollar change in total tax revenue results in an increase in output of slightly more than one dollar on average. The relative magnitudes of the three tax cut multipliers accord with previous work in the literature – the capital tax multiplier is larger than for the labor tax, which is in turn larger than the consumption tax multiplier. Our estimated magnitudes of the multipliers, as well as the small difference between the consumption and labor tax multipliers, are smaller than what most other authors have found. These results are driven by the estimated autoregressive parameters of the tax processes. We return to this issue later in the robustness section.

To get a cleaner sense of the state-dependent effects of tax shocks, Table 1 plots a set of impulse responses. It shows the impulse responses of output to shocks to the labor, capital, and consumption tax rates from the estimated model. For each tax change, we compute impulse responses from two different starting positions of the state. The responses of output have been scaled to have the units as a change in output for a one dollar change in revenue. The solid line shows the response in a typical "expansion" and the dashed line in a "recession." To generate these starting positions of the state, we take an average of the simulated state vector when output is in its upper decline (expansion) and lower decile (recession). The basic shapes of the impulse responses are the same in expansion and recession for all three kinds of tax rates, but the responses are larger at all forecast horizons during a downturn. The larger responses in a recession are consistent with the countercylicality of the multipliers in the simulation. The difference between the responses is largest for capital taxes and smallest for the consumption tax, which is consistent with the results in Table 2 about the volatilities of the three different output multipliers.

The bottom row of each panel of Table 2 shows summary statistics on the welfare multipliers for each type of tax cut. The welfare multipliers for each kind of tax cut are positive. The steady state of the economy is already distorted because of monopolistic competition and positive steady state tax rates, so any cut in distortionary taxes financed via future lump sum taxes must be welfare improving. The units of these multipliers have the following interpretation – the extra dollars of consumption in one period that would generate an equivalent welfare increase as occurs in response to a tax change triggering a one dollar change in total tax revenue. The average welfare multiplier is largest for the consumption tax and smallest for the labor tax. These numbers are somewhat misleading because the autoregressive parameters are different for each kind of tax cut. The reason that the consumption tax welfare multiplier is significantly larger than either the capital or labor multipliers is driven entirely by the higher autoregressive parameter: when all three tax processes have the same autoregressive parameter, the capital tax cut has the largest average effect on welfare and a consumption tax cut the smallest.

For each kind of tax, the welfare multipliers move significantly across states and are substantially more volatile than the output multipliers. The welfare multipliers for all three kinds of taxes are significantly countercyclical – the correlations with the simulated level of output are -0.4, -0.6, and -0.8 for the consumption, labor, and capital taxes. Given that the output multipliers are also estimated to be countercyclical, it follows naturally that, for each kind of tax, the output and welfare multipliers are positively correlated. The correlations between the output and welfare multipliers are 0.7, 0.5, and 0.7 for consumption, labor, and capital tax cuts, respectively. This positive correlation between output and welfare multipliers means that, in times when it is relatively advantageous to cut taxes from the perspective of stimulating output, it is also advantageous from the perspective of increasing welfare. This result differs from the results in Sims and Wolff (2014) for government spending multipliers, where it was found that the output and welfare multipliers tend to move opposite from one another over the business cycle.

The basic intuition for the movements of the output and welfare multipliers across states of the business cycle relates to time-varying inefficiency in the economy. In the model, periods when output is low are, on average, relatively inefficient, as summarized by the magnitude of the "labor wedge," or gap between the marginal rate of substitution between consumption and leisure and the marginal product of labor (see, e.g. Chari, Kehoe, and McGrattan, 2007). A tax cut will result in a larger improvement in welfare, other factors held constant, the more inefficient is the state of the economy. Similarly, in states in which the economy is heavily distorted, resources are relatively underutilized, and output can expand more following a tax cut than when overall inefficiency is relatively small. It is therefore natural that both output and welfare increase by more after a tax cut when output is low.

4.4 Historical Simulation

Rather than artificially generating data from the model using random shocks, we also construct an historical simulation. The historical simulation takes the observable variables from our estimation and uses the Kalman filter to construct retrospective "smoothed" estimates of the state vector. Given a time series of the state vector, we can simulate impulse responses to tax shocks at each point in the observed sample. Summary statistics detailing the behavior of these historical multipliers are presented in Table 3. Historical simulations are plotted in Figures 2-4.

Both output and welfare multipliers vary considerably over the period. Summary statistics concerning the output multiplier use the maximum response of the tax change. Consumption multipliers range from 0.48 to 0.58, while labor and capital multipliers range from 0.44 to 0.64 and 0.91 to 1.27, respectively. These are broadly in line with the results from the conventional simulation, but the ranges are naturally somewhat smaller given the shorter sample period. Like our baseline simulation, our historical simulation also finds capital multipliers to be almost twice as volatile as labor multipliers, and nearly three times more volatile than consumption multipliers. Welfare multipliers are between 1.5 to 7 times as volatile as their respective output multipliers. This large volatility found in the historical simulation underscores our key findings from the baseline results that the effectiveness of tax cuts is highly state dependent.

In Figures 2 through 4, we plot the historical output and welfare multipliers for consumption, labor, and capital. The gray shaded regions are recessions as defined by the NBER. Both output and welfare multipliers tend to be elevated during periods of economic contraction. Consumption, labor, and capital output multipliers generated by the simulation have correlations of -0.1272, -0.3465, and -0.3844 respectively with the HP detrended level of real GDP. From visual inspection, it is also quite apparent that each output multiplier strongly co-moves with its respective welfare multiplier. The correlations are 0.9585, 0.4713, and 0.5242 for consumption, labor and capital multipliers respectively. These correlations are in line with our baseline simulation, and again suggest that periods when tax cuts are most effective at stimulating output are also periods in which tax cuts lead to the largest welfare improvements.

5 Robustness

In this section we consider several extensions and robustness checks on our baseline analysis. These extensions include: (1) alternative values of the estimated parameters, (2) anticipation lags in tax rate changes, and (3) different assumptions about how the fiscal authority finances its expenditures. With one exception which we discuss in more depth below, the basic conclusion that tax cut output multipliers are positively correlated with their respective welfare multipliers is robust.

5.1 Alternative Parameterizations

We consider now the sensitivity of our baseline findings to alternative values of estimated parameters. Several key parameters estimated in Section 3 are considered. Among these are σ, the parameter governing the degree of complementarity between consumption and labor; θ_p, the parameter governing the degree of price stickiness in the model; θ_w, which governs the amount of wage rigidity; γ, which controls the labor supply elasticity; ϕ_π, the Taylor rule parameter on inflation; and the autoregressive parameters in the tax processes. Summary statistics for simulations using alternative parameterizations are found in Table 4. The table contains seven main panels, each corresponding to a different simulation with a particular alternative parameterization. Unless otherwise noted, all other parameters are set at their baseline estimated values.

Our preference specification permits non-separability between consumption and leisure. Many medium scale DSGE models assume that consumption and leisure are separable, which amounts to imposing that $\sigma = 1$. The first panel of Table 4 imposes this restriction. This change ends up having very little noticeable effect on our results – the mean values of the multipliers are roughly the same as in our baseline case, and their co-movements with the level of output over the business cycle are also similar.

The next two panels of the table consider different amounts of nominal wage and price rigidity, respectively. The amount of wage rigidity has little effect on the average magnitudes of the multipliers over the business cycle, though more rigid wages does result in a smaller positive correlation between the output and welfare multipliers for labor tax cuts. More price flexibility results in larger values of the average output multipliers for all three kinds of tax rates. This makes sense to the extent to which tax cuts are "supply shocks," which ought to have larger effects on output the more flexible are prices. With more flexible prices the correlations of the output multiplier with the level of simulated output are less positive, but the co-movement between the output and welfare multipliers remains significantly positive for all three kinds of taxes.

The next two panels of the table consider parameters which govern important amplification mechanisms in the model. The parameter ψ_1 governs the cost of capital utilization. By setting $\psi_1 = 1000$, we effectively fix utilization. This results in significantly smaller average output and welfare multipliers, but has little discernible effect on the co-movement properties of the multipliers. The parameter γ governs the elasticity of labor supply: higher values of γ correspond to less elastic labor supply. It is therefore natural that the output multipliers are smaller on average when γ is larger. The output multipliers for all three kinds of taxes remain countercyclical and positively correlated with the welfare multipliers. The second to last panel of the Table considers a stronger reaction to inflation in the monetary policy rule. This results in larger output and welfare multipliers for each kind of tax, but the co-movements of the multipliers across states are qualitatively the same. The intuition for these effects is similar to the role of the Calvo price rigidity term. A stronger response to inflation in the policy rule results in supply shocks have larger effects on output.

The final panel of Table 4 sets the autoregressive parameters in the tax processes to a common value of $\rho_c = \rho_n = \rho_k = 0.95$. In our baseline estimation, the estimated persistence parameters differ: ρ_c is 0.97, while ρ_n and ρ_k are about 0.90. These different persistence parameters complicate a comparison of the magnitudes of multipliers across different kinds of tax cuts, because we are effectively running different experiments due to the difference in the persistence of the tax changes. When the autoregressive parameters are all 0.95, the output (and welfare) multipliers for labor and capital taxes are almost twice as large as in our benchmark exercises, whereas the consumption multipliers are smaller. Roughly speaking, for equal persistence, the capital tax output multiplier is about twice as large as the labor tax multiplier, which is in turn about twice as big as the consumption multiplier. The differences in the average welfare multipliers across the three types of tax cuts are of a similar magnitude. The output multipliers for each type of tax change remain strongly countercyclical and positively correlated with the welfare multipliers.

5.2 Anticipation Lags

Given the delay inherent in the implementation of new legislation, several authors have recently considered the impact that anticipation lags may have in the transmission of fiscal shocks. Early contributions to the anticipated tax literature include Friedman (1948), Ando and Brown (1963), Hall (1971), and Auerback (1989). More recently, contributions by Steigerwald and Stuart (1997), Chun and Yang (2005), House and Shapiro (2006), Leeper Walker and Yang (2011), Mertens and Raven (2011), Mertens and Raven (2012), and Elgin and Solis-Garcia (2013) have examined the impact of anticipation in tax change implementation. We consider this alternative modeling assumption in a full information environment in which households and firms correctly anticipate a defined decrease in taxes H periods in advance where we consider $H = 2, 3, 4, 5, 6$. Given this new modeling assumption, distortionary tax rules appear as follows:

$$\tau_t^c = (1-\rho_c)\tau^c + \rho_c \tau_{t-1}^c + (1-\rho_c)\gamma_c(B_{g,t-1} - B_g^*) + s_C \varepsilon_{c,t-H} \tag{54}$$

$$\tau_t^n = (1-\rho_n)\tau^n + \rho_n \tau_{t-1}^n + (1-\rho_n)\gamma_n(B_{g,t-1} - B_g^*) + s_n \varepsilon_{n,t-H} \tag{55}$$

$$\tau_t^k = (1-\rho_k)\tau^k + \rho_k \tau_{t-1}^k + (1-\rho_k)\gamma_k(B_{g,t-1} - B_g^*) + s_k \varepsilon_{k,t-H} \tag{56}$$

We amend this specification into our baseline model without changing any of the other parameters. Calculation of multipliers is somewhat complicated by the anticipation lag – while output and its components will rise in the period in which the shock is observed, tax revenue will react only indirectly. Since our multiplier scale output responses by the tax revenue response on impact, this could make a comparison with our earlier results difficult. We therefore adopt the following strategy. To calculate output and welfare multipliers, we use the output and welfare responses to the anticipated tax change, but scale them by the impact revenue response that would happen if there were no anticipation. An alternative assumption which would generate similar results would be to scale the output and welfare responses by the tax revenue change in the period the tax change takes effect (e.g. period $t + H$).

Table 5 displays the results of this alternative modeling assumption. The table contains three different panels, separated according to the type of tax cut that was implemented. Each panel contains output and welfare multipliers generated from five different anticipation horizons. Reported results present summary statistics from our baseline 10,000 period simulation. We find that our baseline results, in terms of both magnitude, volatility, and co-movement, are quite robust to all the presence of anticipation in tax processes. Both output and welfare multipliers remain strongly counter-cyclical and positively correlated across the state space. While the change is small, both output and welfare multipliers for all types of tax changes are monotonically increasing in the length of the anticipation horizon. While this may seem odd, it is important to note that we report results for the maximum output response, not the impact response (which is indeed smaller for longer anticipation lags). The reason that the maximum output responses are bigger with longer anticipation horizons is that the anticipation lag gives agents time to adjust in expectation of the tax change, which has the effect that there is functionally less nominal rigidity at play in the period of the tax change, so output can expand by more.

5.3 No Lump Sum Taxes

In our baseline model, we assume that distortionary tax cuts are financed via lump sum tax increases. This assumption offers an especially "clean" exercise in that we are not trading off smaller current distortions for higher distortions in the future, but it may not be particularly realistic. As noted by Christ (1968), Chun and Yang (2005), Mountford and Uhlig (2009), and others, the means by which the government finances their spending increases or tax decreases will impact the effectiveness of the fiscal policy as a means of stimulating growth.

We consider three alternative modeling assumptions which use distortionary tax rate increases in the future to finance tax stimuli in the present. The first employs a consumption tax response to government debt, the second employs a labor tax response to government debt, and the third employs both a labor and capital response to government debt. In these exercises, lump sum taxes are removed from consideration leaving only distortionary taxes to assure the fiscal authority does not violate their no-Ponzi condition. In each exercise, we pursue the lowest possible debt response which offers a unique stable equilibrium in the model across all states. This response value is approximately $\gamma^b = 0.075$ for both the consumption and labor tax rates in their respective exercises. For that reason, we choose to keep the response value of financing tax rates set to 0.075 across each of the exercises allowing us to focus solely on the impact of different financing methods on our baseline results. Table 6 contains the results to these alternative modeling assumptions.

Table 6 presents three main panels, each corresponding to one of the three alternative financing regimes. We find that the mean magnitudes, standard deviations, and co-movements with simulated output vary considerably based upon the tax process used to finance the tax cut. These results largely support the findings of Christ (1968) and Mountford and Uhlig (2009) who suggest that the effectiveness of fiscal stimulus depends critically on the means by which the stimulus is financed. We naturally find that the magnitudes of the welfare multipliers are uniformly smaller in these exercises than in our baseline. This makes sense, as the welfare benefit of a tax cut will be smaller if that tax cut is financed with future distortionary tax increases. In contrast, the mean values of the output multipliers are typically larger for all kinds of tax cuts under the different financing regimes. This results because there is an even greater incentive to intertemporally reallocate productive activity when tax rates decline in avoidance of higher subsequent tax rates. Though there are some differences relative to our baseline in terms of the cyclicality of output and welfare multipliers, the output and welfare multipliers for each type of tax cut remain strongly positively correlated with one exception – when a labor tax cut is financed with future consumption tax increases, the correlation between the output and welfare multiplier is mildly negative.

6 Conclusion

In this paper, we study the output and welfare effects of shocks to distortionary tax rates in a medium-scale DSGE model. We solve the model using a higher order approximation, which allows us to calculate state-dependent effects of tax shocks. Ours is the only paper of which we are aware which computes state-dependent tax multipliers in a DSGE context. We find that there is considerable variation in the magnitudes of tax multipliers across states of the business cycle. For the most part, the output effects of all kinds of tax shocks are strongest when output is low. Put differently, tax cut output multipliers are countercyclical. We also find that the output multipliers for tax cuts tend to be positively correlated with the respective welfare multipliers. This conclusion is qualitatively robust to several alternative modeling assumptions.

Our results suggest that in states of the world where tax cuts are most effective at stimulating output, tax cuts also have their largest effects on household welfare. This result contrasts with results in our earlier paper on government spending shocks (Sims and Wolff, 2014), where we found that the output and welfare multiplier for spending shocks tend to be strongly negatively correlated.

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Table 1: Estimated Parameters
Medium Scale Model

		Prior		Posterior		
Parameter	Dist.	Mean	SE	Mode	Mean	Std Dev
b	Beta	0.7000	0.1000	0.9180	0.9072	0.0208
θ_w	Beta	0.5000	0.1000	0.4610	0.4597	0.0685
θ_p	Beta	0.5000	0.1000	0.8580	0.8516	0.0139
ζ_w	Beta	0.5000	0.2000	0.5479	0.4887	0.2726
ζ_p	Beta	0.5000	0.2000	0.0375	0.0526	0.0287
ϕ_y	Normal	0.1250	0.0500	0.1150	0.1350	0.0507
ϕ_π	Normal	1.5000	0.1000	1.5478	1.5364	0.1096
κ	Normal	4.0000	0.5000	3.5799	3.5990	0.4153
σ	Normal	2.0000	0.2500	1.7445	1.8288	0.2680
γ	Beta	0.5000	0.0100	0.3028	0.2936	0.0494
ρ_i	Beta	0.5000	0.1000	0.9395	0.9285	0.0341
ρ_a	Beta	0.5000	0.1000	0.9483	0.9336	0.0185
ρ_z	Beta	0.5000	0.1000	0.8488	0.8470	0.0243
ρ_ν	Beta	0.5000	0.1000	0.6411	0.6328	0.0613
ρ_g	Beta	0.5000	0.1000	0.9093	0.9053	0.0211
ρ_c	Beta	0.8000	0.1000	0.9755	0.9712	0.0127
ρ_n	Beta	0.8000	0.1000	0.8892	0.8797	0.0345
ρ_k	Beta	0.8000	0.1000	0.8878	0.8832	0.0305
s_i	Inv. Gamma	0.0020	0.0020	0.0017	0.0021	0.0341
s_a	Inv. Gamma	0.0050	0.0020	0.0043	0.0044	0.0003
s_z	Inv. Gamma	0.0050	0.0020	0.0207	0.0219	0.0023
s_ν	Inv. Gamma	0.0050	0.0020	0.0732	0.0748	0.0145
s_g	Inv. Gamma	0.0050	0.0020	0.0080	0.0080	0.0006
s_c	Inv. Gamma	0.0020	0.0020	0.0006	0.0006	0.0127
s_n	Inv. Gamma	0.0020	0.0020	0.0079	0.0048	0.0345
s_k	Inv. Gamma	0.0020	0.0020	0.0048	0.0078	0.0305

Note: The log-likelihood is 2013.3909 and the log-posterior density at the mode is 1857.0451. The posterior is generated with 20,000 random walk Metropolis Hastings draws with an acceptance rate of approximately 21 percent. Series include GDP growth, Inflation, Investment Growth, Labor Growth, and Government Spending Growth. All data is quarterly, detrended, and real when applicable. Data covers the period 1985q1 through 2010q2.

Table 2: Output and Welfare Multipliers
Baseline Estimated Model

	Multiplier					
	Min	Max	Mean	Std Dev	corr($\ln \mathrm{Y}_t^{\mathrm{sim}}$)	corr(V Mult)
Consumption						
Impact Output	0.0459	0.0843	0.0667	0.0053	-0.4820	0.4941
Max Output	0.4586	0.5934	0.5175	0.0184	-0.3113	0.7044
Welfare	6.2393	7.8521	7.0091	0.2507	-0.4421	1
Labor						
Impact Output	-0.1251	0.0730	-0.0226	0.0268	-0.3116	0.4397
Max Output	0.2745	0.8067	0.5224	0.0705	-0.4496	0.4738
Welfare	1.6655	2.8834	2.2244	0.1655	-0.6019	1
Capital						
Impact Output	0.6571	1.1911	0.8659	0.0693	-0.7579	0.7812
Max Output	0.6777	1.4293	1.0196	0.1028	-0.5240	0.6944
Welfare	3.2370	5.2965	4.1166	0.2802	-0.8192	1

Note: This table shows output and welfare multipliers generated by our baseline model. Multiplier summary statistics are constructed through model simulation. We first simulate the model 10,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3. All numbers are multiplied by negative one for ease of analysis.

Table 3: Output and Welfare Multipliers, Tax Shocks
Historical Simulation Summary Statistics

	Multiplier						
	Min	Max	Mean	Std Dev	corr($\ln Y_t^{hp}$)	corr($\Delta \ln Y_t$)	(V Mult)
Consumption							
Max Output	0.4839	0.5759	0.5286	0.0278	-0.1272	-0.1739	0.9585
	(1997Q4)	(2010Q2)					
Welfare	6.7655	7.5003	7.0971	0.2160	-0.0829	-0.1005	1
	(1997Q1)	(2005Q2)					
Labor							
Max Output	0.4406	0.6397	0.5146	0.0356	-0.3465	-0.1193	0.4713
	(1990Q1)	(2009Q2)					
Welfare	1.8145	2.5808	2.0825	0.1537	-0.5651	-0.0728	1
	(1998Q1)	(2009Q3)					
Capital							
Max Output	0.9116	1.2737	1.0283	0.0655	-0.3844	-0.2271	0.5242
	(1991Q1)	(2009Q2)					
Welfare	3.9837	4.4638	4.2370	0.0948	-0.0919	0.0870	1
	(1990Q1)	(2009Q2)					

Note: This table presents summary statistics for the series of tax multipliers generated via the historical simulation. All information is with regards to the maximum output and welfare response to the tax change over the horizon of the tax change. States are inferred via Kalman smoother using the parameterized summarized in Section 2 of the present study. Correlation columns represent the correlation of the tax series in the respective row with the correlation variable in consideration. $\ln Y_t^{hp}$ defines the cyclical component of HP Filtered real gross domestic product extracted with $\lambda = 1600$. $\Delta \ln Y_t$ represents the quarterly growth rate of real gross domestic product.

Table 4: Output and Welfare Multipliers, Tax Shocks

Alternate Paramerization

			Multiplier					
			Min	Max	Mean	Std Dev	corr(ln Y_t)	corr(V Mult)
$\sigma = 1$	Output Mult.	τ_c	0.4384	0.5892	0.4937	0.0232	-0.2080	0.8446
		τ_n	0.3443	0.8535	0.5518	0.0850	-0.4242	0.5786
		τ_k	0.7737	1.4688	1.0640	0.1176	-0.5429	0.7677
	Welfare Mult.	τ_c	6.4626	8.2721	7.2056	0.3225	-0.3464	1
		τ_n	1.7221	3.1759	2.3127	0.2292	-0.5843	1
		τ_k	3.2402	5.5556	4.1270	0.3140	-0.8493	1
$\theta_w = 0.70$	Output Mult.	τ_c	0.4509	0.5732	0.4999	0.0198	-0.0466	0.6731
		τ_n	0.3705	0.7310	0.5248	0.0683	-0.3291	0.0824
		τ_k	0.7749	1.3573	1.0455	0.1025	-0.5291	0.8681
	Welfare Mult.	τ_c	6.4480	8.0530	7.1355	0.3174	-0.3580	1
		τ_n	1.8819	3.0849	2.4205	0.2011	-0.3808	1
		τ_k	3.3415	5.1420	4.0959	0.2783	-0.6154	1
$\theta_p = 0.5$	Output Mult.	τ_c	0.4860	0.6108	0.5316	0.0205	0.0156	0.6986
		τ_n	0.6971	1.0984	0.8649	0.0612	0.1113	0.2288
		τ_k	1.3116	1.9210	1.5736	0.1001	-0.1548	0.3335
	Welfare Mult.	τ_c	6.5205	8.0093	7.1807	0.2799	-0.1655	1
		τ_n	2.9046	3.6414	3.2262	0.1162	-0.6091	1
		τ_k	4.7296	6.0725	5.2316	0.2032	-0.7223	1
$\psi_1 = 1000$	Output Mult.	τ_c	0.3982	0.5284	0.4605	0.0216	-0.4809	0.9185
		τ_n	0.2568	0.5449	0.3853	0.0445	-0.5180	0.3416
		τ_k	0.2889	0.4849	0.3656	0.0315	-0.6605	0.4906
	Welfare Mult.	τ_c	5.9150	7.3263	6.5671	0.2824	-0.6607	1
		τ_n	2.0651	3.5293	2.6822	0.2341	-0.7144	1
		τ_k	0.7633	2.4835	1.6537	0.2526	-0.7435	1
$\gamma = 0.75$	Output Mult.	τ_c	0.3608	0.4583	0.4023	0.0152	-0.0996	0.7370
		τ_n	0.2608	0.5597	0.4002	0.0515	-0.4817	0.1517
		τ_k	0.6732	1.2511	0.9559	0.0928	-0.6004	0.6905
	Welfare Mult.	τ_c	4.8620	6.0273	5.3831	0.2276	-0.3596	1
		τ_n	1.4879	2.3510	1.8743	0.1354	-0.4288	1
		τ_k	3.1419	4.9957	3.9260	0.2816	-0.8776	1
$\phi_\pi = 5$	Output Mult.	τ_c	0.4558	0.5783	0.5010	0.0195	-0.1651	0.7337
		τ_n	0.5089	0.8460	0.6459	0.0513	-0.2102	0.6161
		τ_k	0.9973	1.4476	1.1810	0.0700	-0.3588	0.4586
	Welfare Mult.	τ_c	6.3593	7.8390	7.0034	0.2868	-0.3501	1
		τ_n	2.2416	3.2223	2.6509	0.1516	-0.6771	1
		τ_k	3.9023	5.2149	4.4401	0.1984	-0.8340	1
$\rho_\tau = 0.95$	Output Mult.	τ_c	0.3043	0.3873	0.3358	0.0131	-0.2138	0.7712
		τ_n	0.5687	1.2822	0.8760	0.1227	-0.5357	0.7006
		τ_k	1.3324	2.5240	1.8048	0.1748	-0.7183	0.8252
	Welfare Mult.	τ_c	2.9424	3.6674	3.2556	0.1431	-0.3630	1
		τ_n	4.7222	8.8483	6.1466	0.6089	-0.8894	1
		τ_k	7.7944	15.1802	10.7609	1.0391	-0.8945	1

Note: This table shows output and welfare multipliers generated by our standard model using separable preferences over consumption and leisure. Multipliers summary statistics are constructed through model simulation. We first simulate the model 100 times and then calculate multipliers for each tax shock individually at every point. We then capture summary statistics over these 100 periods. This process is repeated 100 times so as to remove any bias resulting from the original simulation. Summary statistics reported in this table represent averages across these summary statistics. For a full description of the process, see Section 3.

Table 5: Output and Welfare Multipliers, Tax Shocks

Anticipated Tax Shocks

			Multiplier					
			Min	Max	Mean	Std Dev	corr($\ln Y_t$)	corr(V Mult)
Consumption Tax Shock	Output Mult.	2 Quarters	0.4854	0.6191	0.5382	0.0216	-0.2013	0.7529
		3 Quarters	0.5010	0.6367	0.5547	0.0222	-0.2213	0.7619
		4 Quarters	0.5142	0.6536	0.5676	0.0226	-0.2391	0.7766
		5 Quarters	0.5217	0.6670	0.5773	0.0227	-0.2568	0.7863
		6 Quarters	0.5272	0.6690	0.5843	0.0229	-0.2679	0.7928
	Welfare Mult.	2 Quarters	6.5384	8.1534	7.2265	0.3191	-0.3942	1
		3 Quarters	6.6437	8.2904	7.3492	0.3251	-0.3934	1
		4 Quarters	6.7417	8.4347	7.4668	0.3304	-0.3919	1
		5 Quarters	6.8389	8.5490	7.5684	0.3349	-0.3882	1
		6 Quarters	6.8949	8.6590	7.6564	0.3397	-0.3866	1
Labor Tax Shock	Output Mult.	2 Quarters	0.3901	0.8545	0.5845	0.0810	-0.4851	0.6269
		3 Quarters	0.4124	0.9038	0.6191	0.0849	-0.4935	0.6908
		4 Quarters	0.4445	0.9375	0.6516	0.0882	-0.5087	0.7234
		5 Quarters	0.4671	0.9709	0.6748	0.0884	-0.5330	0.7416
		6 Quarters	0.4770	0.9881	0.6909	0.0880	-0.5540	0.7531
	Welfare Mult.	2 Quarters	2.0067	3.3465	2.4954	0.2066	-0.6790	1
		3 Quarters	2.1970	3.8044	2.7276	0.2373	-0.7320	1
		4 Quarters	2.3444	4.2045	2.9340	0.2697	-0.7755	1
		5 Quarters	2.3946	4.5476	3.1185	0.3022	-0.8139	1
		6 Quarters	2.4384	4.8149	3.2781	0.3358	-0.8443	1
Capital Tax Shock	Output Mult.	2 Quarters	0.8330	1.5388	1.1487	0.1158	-0.5692	0.7217
		3 Quarters	0.9173	1.6564	1.2402	0.1199	-0.5809	0.7259
		4 Quarters	0.9960	1.7848	1.3351	0.1232	-0.6167	0.7476
		5 Quarters	1.0852	1.8883	1.4212	0.1251	-0.6616	0.7768
		6 Quarters	1.1394	2.0339	1.4974	0.1300	-0.7005	0.8035
	Welfare Mult.	2 Quarters	3.4451	5.8496	4.3818	0.3364	-0.8673	1
		3 Quarters	3.5980	6.1983	4.6159	0.3656	-0.8689	1
		4 Quarters	3.6972	6.6509	4.8528	0.4058	-0.8743	1
		5 Quarters	3.7703	7.0170	5.0615	0.4478	-0.8793	1
		6 Quarters	3.8616	7.4869	5.2462	0.4940	-0.8839	1

This table shows output and welfare multipliers generated by our standard model augmented with a rule-of-thumb household type. The length of the anticipation horizon is found in the left-most column. Multipliers summary statistics are constructed through model simulation. We first simulate the model 100 times and then calculate multipliers for each tax shock individually at every point. We then capture summary statistics over these 100 periods. This process is repeated 100 times so as to remove any bias resulting from the original simulation. Summary statistics reported in this table represent averages across these summary statistics. For a full description of the process, see Section 3.

Table 6: Output and Welfare Multipliers, Tax Shocks

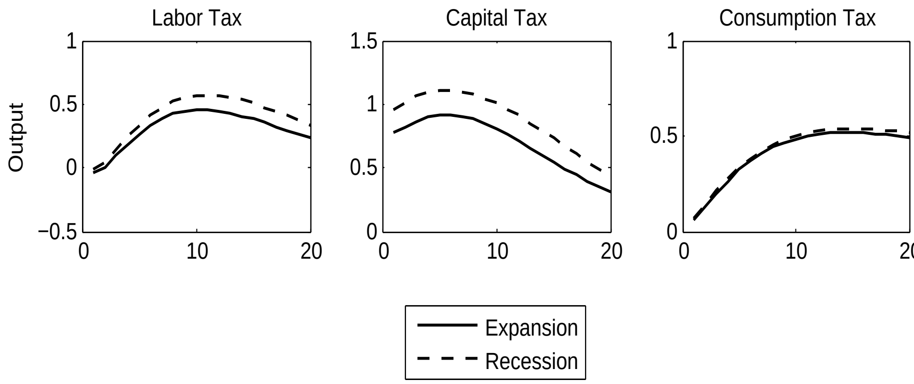
No Lump Sum Taxes

			Multiplier					
			Min	Max	Mean	Std Dev	corr(ln Y_t)	corr(V Mult)
Mechanism: τ_c	Output Mult.	τ_c	0.3400	0.4671	0.3894	0.0201	-0.3015	0.1248
		τ_n	0.2939	0.7297	0.4765	0.0743	-0.4633	0.4506
		τ_k	0.7167	1.4651	1.0148	0.1088	-0.5980	0.9553
	Welfare Mult.	τ_c	-4.7499	-3.0788	-4.0232	0.3342	0.3008	1
		τ_n	-1.1452	0.0762	-0.5889	0.1769	0.1323	1
		τ_k	1.0052	2.6453	1.6265	0.2277	-0.7205	1
Mechanism: τ_n	Output Mult.	τ_c	0.4276	0.7562	0.5645	0.0535	-0.0419	-0.1459
		τ_n	0.2626	0.7591	0.4649	0.0856	-0.2858	0.0956
		τ_k	0.6786	1.4243	0.9917	0.1171	-0.4329	0.5700
	Welfare Mult.	τ_c	-11.2175	-6.9825	-8.4266	0.9112	0.7635	1
		τ_n	-3.4963	-1.5575	-2.2615	0.3737	0.7915	1
		τ_k	-0.5737	0.7322	0.1406	0.2459	0.2798	1
Mechanism: τ_n, τ_k	Output Mult.	τ_c	0.1160	0.5902	0.3350	0.0739	0.1559	0.1725
		τ_n	0.0458	0.6613	0.3069	0.1026	0.0237	0.2915
		τ_k	0.5867	1.3739	0.9109	0.1230	-0.3883	0.5953
	Welfare Mult.	τ_c	-21.6159	-12.0756	-15.1501	1.8848	0.8691	1
		τ_n	-8.0742	-2.9469	-4.2608	0.8670	0.8848	1
		τ_k	-1.9774	-0.7750	-1.3977	0.2173	0.3801	1

Note: This table shows output and welfare multipliers in the DSGE model described in Section 2. All numbers are multiplied by negative one for ease of analysis. Three main panels are presented according to the financing mechanism employed. The first mechanism used only consumption taxes to finance government debt setting the debt response of consumption taxes to $\gamma_b^c = 0.075$. The second mechanism uses only labor taxes to finance government debt setting the debt response of the labor tax process to $\gamma_b^n = 0.075$. The third mechanism uses both labor and capital taxes to finance government debt setting the debt response of the labor and capital tax processes to $\gamma_b^n = 0.075$ & $\gamma_b^k = 0.075$, respectively. Multipliers summary statistics are constructed through model simulation. We first simulate the model 100 times and then calculate multipliers for each tax shock individually at every point. We then capture summary statistics over these 100 periods. This process is repeated 100 times so as to remove any bias resulting from the original simulation. Summary statistics reported in this table represent averages across these summary statistics. For a full description of the process, see Section 3.

Figure 1: Impulse Response Functions

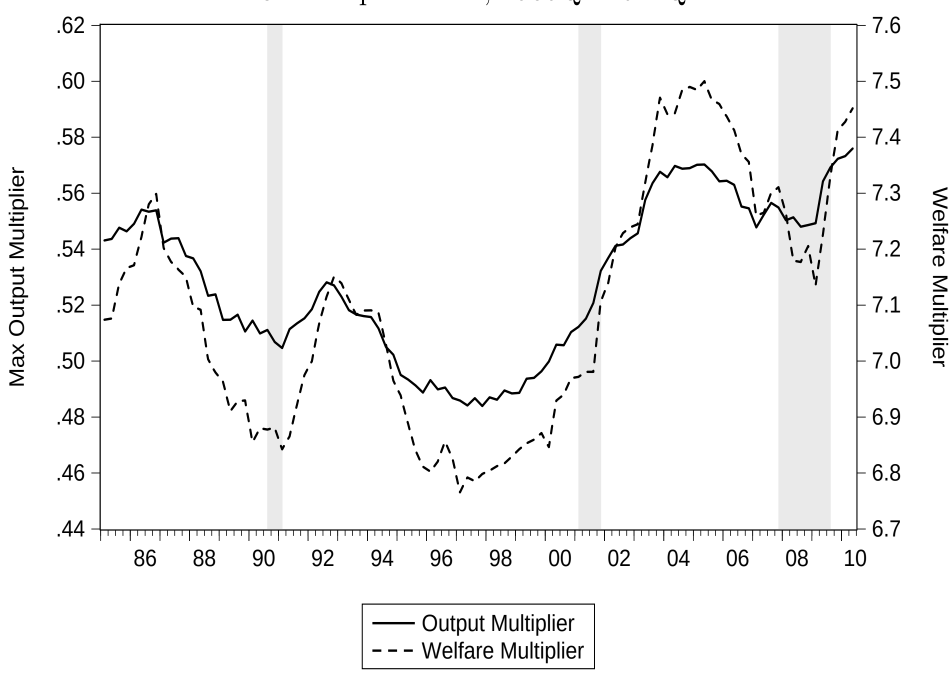
Baseline Model



Note: This figure plots the impulse response functions of output, tax revenue, welfare, consumption, labor hours, and capital to changes in distortionary tax rates. Impulse response functions are generated as described in Section 3. All tax shocks represent one standard deviation declines in tax rates.

Figure 2: Historical Output and Welfare Multipliers

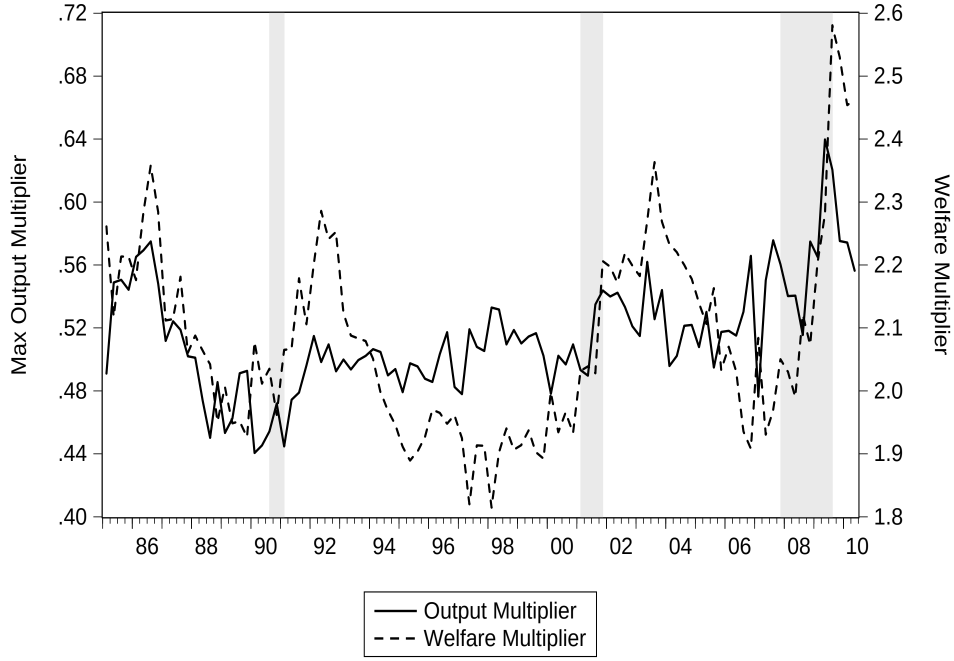
Consumption Tax, 1985Q1-2012Q4



Note: This figure plots the estimated historical output and welfare multipliers to consumption tax shocks in the Great Moderation period. The shaded gray region corresponds to NBER defined recessions. These simulations are founded on the model presented in Section 2 using the Kalman smoother from the estimated model to back out a history of states. Then at each point in the state space, we compute the output and welfare multipliers.

Figure 3: Historical Output and Welfare Multipliers

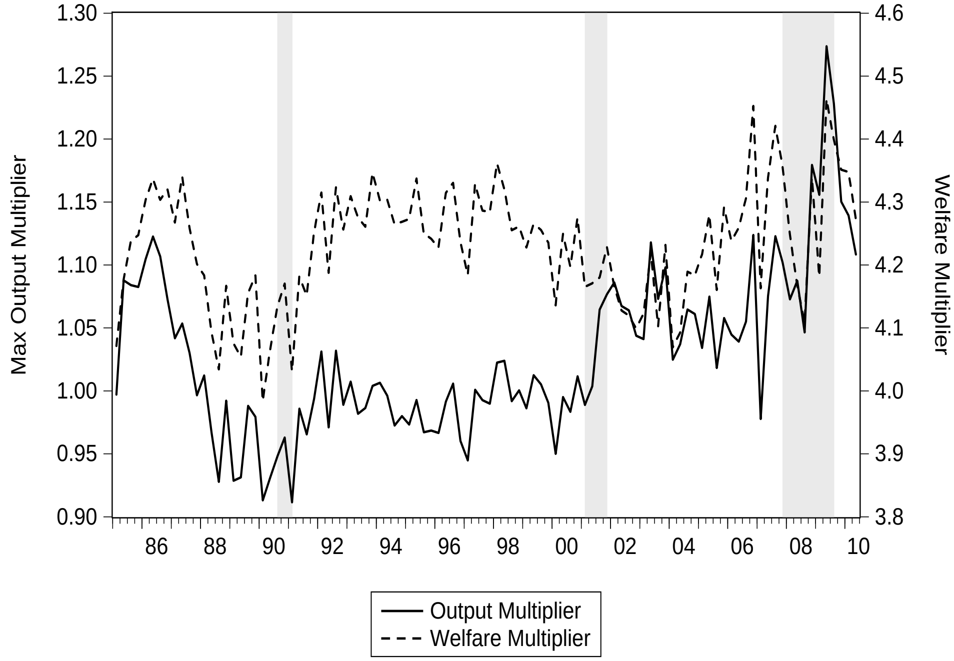
Labor Tax, 1985Q1-2012Q4



Note: This figure plots the estimated historical output and welfare multipliers to labor tax shocks in the Great Moderation period. The shaded gray region corresponds to NBER defined recessions. These simulations are founded on the model presented in Section 2 using the Kalman smoother from the estimated model to back out a history of states. Then at each point in the state space, we compute the output and welfare multipliers.

Figure 4: Historical Output and Welfare Multipliers

Capital Tax, 1985Q1-2012Q4



Note: This figure plots the estimated historical output and welfare multipliers to capital tax shocks in the Great Moderation period. The shaded gray region corresponds to NBER defined recessions. These simulations are founded on the model presented in Section 2 using the Kalman smoother from the estimated model to back out a history of states. Then at each point in the state space, we compute the output and welfare multipliers.