The State-Dependent Effects of Tax Shocks*

Eric Sims
University of Notre Dame
& NBER

Jonathan Wolff
Miami University

May 28, 2016

Abstract

This paper studies the state-dependent effects of shocks to distortionary tax rates in a dynamic stochastic general equilibrium (DSGE) model augmented with a number of real and nominal frictions. The tax output multiplier is defined as the change in output for a one dollar change in tax revenue caused by a shock to distortionary tax rates on consumption, labor income, or capital income. We find that magnitudes of each tax multiplier vary considerably across the state of the business cycle. Tax cuts are typically least effective at stimulating output in states where output is low. To evaluate the desirability of tax cuts as a tool to combat recessions, we also consider the state-dependence of what we define as the tax welfare multiplier. Welfare multipliers for each tax are highest in states where output is low, in contrast to the cyclicality of the output multipliers. We consider the robustness of these baseline results to several alternative modeling specifications which have been shown to impact the magnitude of tax multipliers. These include alternative fiscal adjustment methods, rule-of-thumb households, and anticipation.

JEL Codes: E30, E60, E62

Keywords: fiscal policy, tax policy, business cycle, welfare

*We are particularly grateful to Tim Fuerst, Robert Lester, Michael Pries, Nam Vu, participants at the Fall 2014 Midwest Macro Conferences, and seminar participants at Miami University, University of Notre Dame, and Bowling Green State University for several comments which have substantially improved the paper.

1 Introduction

In recent years there has been renewed interest in the macroeconomic effects of fiscal policy. This revival has been fueled by the confluence of sluggish labor markets, large public debts, and inadequately accommodative monetary policy in many developed countries in the aftermath of the Great Recession. This paper focuses on the macroeconomic effects of shocks to distortionary tax rates. We seek to provide answers to the following questions. How stimulative are tax cuts? Are tax cuts more or less effective at stimulating output during times of recession? From a normative perspective, is it desirable to cut taxes during periods where output is low?

The framework in which we address these questions is a medium-scale dynamic stochastic general equilibrium (DSGE) model similar to Christiano, Eichenbaum, and Evans (2005); Schmitt-Grohe and Uribe (2006); Smets and Wouters (2007); and Justiniano, Primiceri, and Tambalotti (2010). The model features price and wage rigidity as well as several real frictions, including habit formation in consumption, variable capital utilization, and investment adjustment costs. Monetary policy is governed by a Taylor rule. A government consumes some output, and finances this expenditure with a mix of debt, lump sum taxes, and distortionary taxes on consumption, labor, and capital. We fit the model to U.S. data by estimating a subset of the model parameters via Bayesian maximum likelihood and use conventional calibration methods for those parameters which remain. We solve the model via a higher order perturbation.

We define the tax output multiplier to be equal to the change in output for a one dollar change in total tax revenue following an exogenous shock to one of the distortionary tax rates. We focus on multipliers at two horizons: on "impact" (the period of the change in the tax rate) and the "maximum" response (the maximum change in output in the horizons subsequent to a change in a tax rate). These definitions follow Barro and Redlick (2011) and Mertens and Ravn (2012, 2014). Because we solve the model via a higher order approximation, the multiplier for each tax rate may differ across states of the business cycle. In addition, this higher order approximation allows us to compare the welfare implications of tax shocks with recent work studying the welfare implications of fiscal policy over the business cycle.

Our baseline simulation exercise consists of simulating many periods of data from the estimated model. We then construct impulse responses to shocks to each of the three distortionary tax rates at each point in the simulated state space. Because the model is solved via a higher order approximation, the impulse responses depend on the realization of the state. These impulse responses are then used to construct multipliers. We find that the average values of the consumption, labor, and capital tax multipliers are 0.62, 1.39, and 2.74, respectively.[1] That is, a one dollar decline in tax revenue from a cut in the tax rate on capital income stimulates output by approximately two dollars and seventy four cents on average. For each of the three kinds of tax rates, we find

[1]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, tax multipliers in our model are always negative, since any tax change that stimulates output results in less tax revenue (i.e. we are always to the left of the peak of the "Laffer Curve").

that there is significant variation in the magnitudes of the multipliers across states. The capital tax multiplier ranges from a low of 2.54 to a maximum value of 3.08. The range for the labor tax multiplier is 1.27 to 1.56. The consumption tax multiplier varies least across states, with a range of 0.60 to 0.65. These tax multipliers vary considerably more across states than does the government spending multiplier in a similar model, as documented in Sims and Wolff (2015). The tax multipliers for labor and capital are weakly positively correlated with simulated output. The consumption tax multiplier, in contrast, is weakly negatively correlated with output.

The positive co-movement of the multipliers for capital and labor taxes with output means that tax cuts are ineffective at stimulating output in a recession relative to normal times. Does this mean that it is not optimal for governments to cut taxes during recessions? To address this question, we adopt terminology from Sims and Wolff (2015) and define what we call the tax "welfare multiplier." The welfare multiplier is defined as the consumption equivalent change in welfare (the present discounted value of flow utility of the representative household in the model) after a shock to a distortionary tax rate which raises total tax revenue by one dollar. Relative to the output multipliers, we find significantly more state-dependence in the welfare multiplier for each tax rate. Furthermore, and in contrast to the output multipliers, we find that the welfare multipliers for each type of tax are strongly countercyclical, with correlations with simulated output of -0.68 to -0.98. From a normative perspective, these results suggest that tax cuts are particularly desirable during periods where output is low.

There is an extensive literature on the economic effects of tax shocks. Early contributions include Friedman (1948), Ando and Brown (1963), Hall (1971), Barro (1979), Baxter and King (1993), Braun (1994), and McGrattan (1994). More recent contributions include Blanchard and Perotti (2002), Romer and Romer (2010), and Mertens and Ravn (2011, 2012, 2014). Reduced form empirical approaches yield wide ranges of tax cut multipliers. For example, Blanchard and Perotti (2002) find tax cut multipliers of about one, while Romer and Romer (2010) estimate maximum tax cut multipliers around three.[2] Our analysis based on a fully-specified DSGE model is closest to Chahrour, Schmitt-Grohe, and Uribe (2012), Leeper, Walker, and Yang (2013), and Mertens and Ravn (2011). We extend the DSGE-based literature in examining state-dependence of tax multipliers as well as looking at the normative implications of tax rate changes. While there exists an empirical literature studying the state-dependence of the government spending multiplier (e.g. Auerbach and Gorodnichenko, 2012, and Ramey and Zubairy, 2014), we are aware of no similar work with respect to tax shocks.

More recently, studies have given significant consideration to the impact of different policy features, such as anticipation in policy changes, financing method, and the presence of credit constrained consumers, on the magnitude of tax multipliers. Steigerwald and Stuart (1997), Yang (2005), House and Shapiro (2008), Perotti (2012), Mertens and Ravn (2012), and Leeper, Walker, and Yang (2013) study the implications of anticipation lags for the transmission of tax shocks and generally find that anticipation in tax processes can have a significant impact on the size

[2]A drawback of the purely empirical approach taken by these authors is that it does not distinguish between different kinds of tax rates when thinking about the effects of a tax cut.

of multipliers. In an extension of our baseline model, we consider the presence of anticipation lags of 2-6 quarters between when a tax change is announced and when it takes effect. We find that anticipation serves to increase the magnitude of multipliers, while having little impact on the state-dependence of output and welfare multipliers over the business cycle.

In addition to anticipation, several studies have noted the importance of the financing regime as being critical to the effectiveness of changes in tax rates. Christ (1968), Baxter and King (1993), Yang (2005), Mountford and Uhlig (2009), and Leeper, Plante, and Traum (2010) note that, in the presence of forward looking agents, the tool with which the fiscal authority finances present policy changes has a significant impact on the effectiveness of the policy. We consider alternative debt financing methods where lump sum taxes are unavailable and a cut in a tax rate in the present must be financed with future tax increases. We find that the financing tool employed is of central importance for both the magnitude, and the state-dependence, of tax multipliers.

Recent work by Agarwal, Liu, and Souleles (2007), Gali et al. (2007), McKay and Reis (2016), and others suggests that the presence of credit constrained consumers might also impact the magnitude of fiscal multipliers. We therefore consider an extension of the baseline model which incorporates a fist-to-mouth consumer population in the spirit of Campbell and Mankiw (1990). We find the magnitude for each type of tax multiplier to be significantly impacted by the presence of this population while the co-movements and cyclicalities of the multipliers are relatively unchanged. Increasing the rule-of-thumb consumer population from 10 to 50 percent results in 37 percent increase in the average consumption output multiplier and 33 percent increase in the average labor tax multiplier. The average capital tax multiplier, however, is smaller when a larger fraction of the population is credit constrained.

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 considers 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), Schmitt-Grohe and Uribe (2006), Smets and Wouters (2007), and Justiniano, Primiceri, and Tambalotti (2010). The model features a representative household, 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 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 Firms

A single, perfectly competitive final good firm bundles the output of each of the $j \in [0,1]$ intermediate good firms into a single product for consumption and investment by the household. The technology used in transforming these intermediate goods into a final good is given by the following CES aggregator:

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

The output of this final good firm is denoted by Y_t while the output of intermediate good producer j is denote by $Y_t(j)$. The elasticity of substitution between intermediates is measured by $\epsilon_p > 1$ and the prices of each intermediate good j, $P_t(j)$, are taken as given by the final good producer. The final good firm's profit maximization problem results in the following demand schedule for each intermediate good firm j:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon_p} Y_t \quad \forall\, j \tag{2}$$

Using (1) and (2), as well as the firm's zero profit condition, the aggregate price index is given by:

$$P_t = \left(\int_0^1 P_t(j)^{1-\epsilon_p} dj \right)^{\frac{1}{1-\epsilon_p}} \tag{3}$$

Intermediate goods firms produce output using labor, $N_{d,t}(j)$, and capital services, $\widetilde{K}_t(j)$, according to the production function:

$$Y_t(j) = A_t \widetilde{K}_t(j)^{\alpha} N_{d,t}(j)^{1-\alpha} \tag{4}$$

The exogenous variable A_t is a neutral productivity shock common to all intermediate good firms. Capital services (the product of physical capital and utilization) are rented on a period-by-period basis from households at the real rental rate r_t^k. Labor employed by firm j, $N_{d,t}(j)$, is paid a real wage W_t. Cost minimization by intermediate good firm j results in the following optimality conditions:

$$mc_t = \frac{W_t^{1-\alpha} (r_t^k)^{\alpha}}{A_t} (1-\alpha)^{\alpha-1} \alpha^{-\alpha} \tag{5}$$

$$\frac{\widetilde{K}_t(j)}{N_{d,t}(j)} = \frac{\alpha}{1-\alpha} \frac{W_t}{r_t^k} \quad \forall\, j \tag{6}$$

Real marginal cost is defined as mc_t and is given by (5). All intermediate firms face common factor prices. This, coupled with the assumption that all firms face a common productivity shock, implies that intermediate good firms will choose capital services and labor in the same ratio.

Each period, a fraction, $(1-\theta_p)$, of randomly chosen firms have the opportunity to update their price, where $\theta_p \in [0,1)$. The opportunity to update price is independent of pricing history. Non-updating firms have the opportunity to index their price 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 via the household's stochastic discount factor as well as the likelihood of the chosen price remaining in place multiple periods. Given a common real marginal cost, all updating firms select a common reset price which we denote by $P_t^{\#}$. To stationarize the model, we define inflation as $\pi_t = P_t/P_{t-1} - 1$ and reset price inflation as $\pi_t^{\#} \equiv P_t^{\#}/P_{t-1} - 1$. Employing these new variables, the optimal reset price for each firm can be written recursively as:

$$1+\pi_t^{\#} = \frac{\epsilon_p}{\epsilon_p - 1}(1+\pi_t)\frac{X_{1,t}}{X_{2,t}} \tag{7}$$

$$X_{1,t} = mc_t \mu_t Y_t + \theta_p \beta (1+\pi_t)^{-\zeta_p \epsilon_p} E_t (1+\pi_{t+1})^{\epsilon_p} X_{1,t+1} \tag{8}$$

$$X_{2,t} = \mu_t Y_t + \theta_p \beta (1+\pi_t)^{\zeta_p (1-\epsilon_p)} E_t (1+\pi_{t+1})^{\epsilon_p - 1} X_{2,t+1} \tag{9}$$

The variable μ_t is the household's marginal utility of income. Equations (5)-(9) characterize the optimal behavior of the production side of the economy.

2.2 Households

We follow Schmitt-Grohe and Uribe (2006) in populating the economy with a single representative household. The household supplies labor to a continuum of labor markets of measure one, indexed by $h \in [0,1]$. The demand for labor in each market is given by:

$$N_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\epsilon_w} N_{d,t}, \quad \forall\, h \tag{10}$$

The wage charged in a market is given by $W_t(h)$, W_t is a measure of the aggregate wage, $N_{d,t}$ is aggregate labor demand from intermediate good firms, and $\epsilon_w > 1$ is the elasticity of substitution among labor in different labor markets. Wage stickiness is introduced à la Calvo (1983) – each period, the household can adjust the wage in a randomly chosen fraction θ_w of labor markets, where $\theta_w \in [0,1)$. Nominal wages in non-updated markets can be indexed to lagged inflation at rate $\zeta_w \in [0,1]$. Total labor supplied by the household is N_t, which must satisfy $N_t = \int_0^1 N_t(h)dh$. Combining this with (10), we get:

$$N_t = N_{d,t} \int_0^1 \left(\frac{W_t(h)}{W_t}\right)^{-\epsilon_w} dh \tag{11}$$

Household welfare is defined as the present discounted value of flow utility from consumption, C_t, and leisure, $L_t = 1 - N_t$:

$$V_0 = E_0 \sum_{t=0}^{\infty} \beta^t \nu_t U\left(C_t - bC_{t-1}, 1 - N_t\right) \tag{12}$$

The period utility function is increasing and concave in each argument and allows for non-separability between consumption and leisure. The parameter $0 \leq b < 1$ measures the degree of internal habit formation in consumption and $0 < \beta < 1$ is a discount factor. The exogenous variable ν_t is an intertemporal preference shock.

Physical capital, K_t, accumulates according to:

$$K_{t+1} = Z_t \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t + (1-\delta)K_t \tag{13}$$

Investment in new physical capital is denoted by I_t and $0 < \delta < 1$ is the depreciation rate. As in Christiano, Eichenbaum, and Evans (2005), $S(\cdot)$ measures an investment adjustment cost and satisfies $S(1) = S'(1) = 0$, and $S''(1) = \kappa \geq 0$. The exogenous variable Z_t is a shock to the marginal efficiency of investment as in Justiniano, Primiceri, and Tambalotti (2010).

The flow budget constraint faced by the representative household is:

$$\begin{gathered}(1+\tau_t^c)\, C_t + I_t + \Gamma(u_t)K_t + \frac{B_t}{P_t} \leq \\ (1-\tau_t^n)\int_0^1 W_t(h)N_t(h)dh + (1-\tau_t^k)r_t^k u_t K_t + (1+i_{t-1})\frac{B_{t-1}}{P_t} + \Pi_t - T_t\end{gathered} \tag{14}$$

The nominal price of goods is denoted by P_t. Distortionary tax rates on consumption, labor income, and capital income are denoted by τ_t^c, τ_t^n, and τ_t^k, respectively. The stock of nominal bonds with which the household enters the period is denoted by B_{t-1}. The nominal interest rate on bonds taken into period $t+1$ is i_t. The household pays a lump sum tax to the government, T_t. Distributed profit from firms is given by Π_t. Utilization of physical capital is given by u_t. Utilization incurs a resource cost measured in units of physical capital given by the function $\Gamma(\cdot)$. It has the following properties: $\Gamma(1) = 0$, $\Gamma'(1) = \psi_0 > 0$ and $\Gamma''(1) = \psi_1 \geq 0$.

The following conditions characterize optimal behavior by the household:

$$(1+\tau_t^c)\mu_t = \nu_t U_C(C_t - bC_{t-1}, 1 - N_t) - \beta b E_t \nu_{t+1} U_C(C_{t+1} - bC_t, 1 - N_{t+1}) \tag{15}$$

$$\mu_t = \beta E_t \mu_{t+1}(1+i_t)(1+\pi_{t+1})^{-1} \tag{16}$$

$$(1-\tau_t^k)r_t^k = \Gamma^{'}(u_t) \tag{17}$$

$$1 = q_t Z_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \beta E_t \frac{\mu_{t+1}}{\mu_t} q_{t+1} Z_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{18}$$

$$q_t = \beta E_t \frac{\mu_{t+1}}{\mu_t} \left[(1 - \tau_{t+1}^k) r_{t+1}^k u_{t+1} - \Gamma(u_{t+1}) + (1 - \delta) q_{t+1} \right] \tag{19}$$

$$W_t^{\#} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{F_{1,t}}{F_{2,t}} \tag{20}$$

$$F_{1,t} = \nu_t U_L(C_t - bC_{t-1}, 1 - N_t) W_t^{\epsilon_w} N_{d,t} + \theta_w \beta E_t (1 + \pi_t)^{-\epsilon_w \zeta_w} (1 + \pi_{t+1})^{\epsilon_w} F_{1,t+1} \tag{21}$$

$$F_{2,t} = \mu_t (1 - \tau_t^n) W_t^{\epsilon_w} N_{d,t} + \theta_w \beta E_t (1 + \pi_t)^{\zeta_w (1 - \epsilon_w)} (1 + \pi_{t+1})^{\epsilon_w - 1} F_{2,t+1} \tag{22}$$

In these conditions μ_t is the Lagrange multiplier on the flow budget constraint; q_t is the ratio of the multiplier on the accumulation equation and the flow budget constraint. The optimal real reset wage, $W_t^{\#}$, can be written recursively and is the same across all markets. If wages are flexible (i.e. $\theta_w = 0$), then optimality conditions related to the labor market reduce to setting the real wage equal to a markup over the marginal rate of substitution between consumption and leisure.

2.3 Government

Fiscal policy in our model is governed by a system of spending, tax, and budget rules. The fiscal authority has the opportunity to raise revenue via distortionary and lump sum taxes. Any discrepancy between revenue and cost can be settled by the issuance of one period non-state contingent bonds. These bonds are denoted by B_t^g. The real flow budget constraint for the government is given by:

$$G_t + i_{t-1} \frac{B_{t-1}^g}{P_t} = \tau_t^c C_t + \tau_t^n W_t N_t + \tau_t^k r_t^k \widetilde{K}_t + T_t + \frac{B_t^g - B_{t-1}^g}{P_t} \tag{23}$$

We assume that government spending obeys an exogenous AR(1) process in the log, where G is the non-stochastic mean of government spending:

$$\ln G_t = (1 - \rho_g) \ln G + \rho_g \ln G_{t-1} + s_g \varepsilon_{g,t} \tag{24}$$

The innovation, $\varepsilon_{g,t}$, is drawn from a standard normal distribution and s_g is the standard deviation of the shock. We do not explicitly model the usefulness of government spending. As is standard, we could assume that households receive flow utility from government purchases as a way to model the desirability of public expenditure. As long as utility from government spending is additively separable from utility over consumption and leisure, the nature of this utility flow is irrelevant for equilibrium dynamics.

Given an exogenous time path for government spending, a long run debt target, B^g, and an exogenous stock of initial debt, B_{t-1}^g, taxes must react to debt sufficiently so as to support a non-explosive equilibrium. We assume that the tax instruments obey stationary AR(1) processes which feature a built-in reaction to deviations of existing debt from the long run target. These processes are:

$$T_t = (1-\rho_T)\tau^T + \rho_T \tau^T_{t-1} + (1-\rho_T)\left(\gamma^b_T (B^g_{t-1} - B^g) + \gamma^y_T (\ln Y_t - \ln Y_{t-1})\right) \tag{25}$$

$$\tau^c_t = (1-\rho_c)\tau^c + \rho_c \tau^c_{t-1} + (1-\rho_c)\left(\gamma^b_c (B^g_{t-1} - B^g) + \gamma^y_c (\ln Y_t - \ln Y_{t-1})\right) + s_c \varepsilon_{c,t} \tag{26}$$

$$\tau^n_t = (1-\rho_n)\tau^n + \rho_n \tau^n_{t-1} + (1-\rho_n)\left(\gamma^b_n (B^g_{t-1} - B^g) + \gamma^y_n (\ln Y_t - \ln Y_{t-1})\right) + s_n \varepsilon_{n,t} \tag{27}$$

$$\tau^k_t = (1-\rho_k)\tau^k + \rho_k \tau^k_{t-1} + (1-\rho_k)\left(\gamma^b_k (B^g_{t-1} - B^g) + \gamma^y_k (\ln Y_t - \ln Y_{t-1})\right) + s_k \varepsilon_{k,t} \tag{28}$$

Each of these processes features a non-stochastic steady state value of the tax, a persistence parameter, and a reaction coefficient to deviations of debt from target. The coefficients on the deviation of debt from its long run target are given by γ^b_T, γ^b_c, γ^b_n, and γ^b_k. We require the value of these coefficients to be such that the equilibrium feature a non-explosive path of government debt. We also include an automatic stabilizer mechanism wherein the tax rates react to output growth. The automatic stabilizer mechanism is governed by the parameters γ^y_T, γ^y_c, γ^y_n, and γ^y_k. We also consider exogenous shocks to the distortionary tax rates, the effects of which are the principal source of inquiry in the paper. These shocks are drawn from standard normal distributions with standard deviations of s_c, s_n, and s_k. We do not consider shocks to the lump sum tax.

Monetary policy is governed by a Taylor interest rate feedback rule which responds to deviations of inflation from target as well as to output growth:

$$i_t = (1-\rho_i)i + \rho_i i_{t-1} + (1-\rho_i)\left(\phi_\pi(\pi_t - \pi) + \phi_y(\ln Y_t - \ln Y_{t-1})\right) + s_i \varepsilon_{i,t} \tag{29}$$

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

2.4 Exogenous Processes and Market-Clearing

In addition to the processes for the distortionary tax rates, monetary policy rule, and government spending process, the model features three other exogenous processes: a productivity variable, A_t, a variable governing the marginal efficiency of investment, Z_t, and a variable which affects the intertemporal valuation of flow utility, ν_t. Each of these follow mean zero AR(1) processes in the log, with shocks drawn from standard normal distributions, with time invariant standard deviations of s_a, s_z, and s_ν, respectively.

$$\ln A_t = \rho_a \ln A_{t-1} + s_a \varepsilon_{a,t} \tag{30}$$

$$\ln Z_t = \rho_z \ln Z_{t-1} + s_z \varepsilon_{z,t} \tag{31}$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + s_\nu \varepsilon_{\nu,t} \tag{32}$$

Integrating across demand functions for intermediate goods, making use of the fact that all firms hire capital services and labor in the same ratio, and imposing market-clearing for labor yields the following aggregate production function:

$$Y_t = \frac{A_t \widetilde{K}_t^{\alpha} N_{d,t}^{1-\alpha}}{v_t^p} \tag{33}$$

The term v_t^p is a measure of price dispersion arising from staggered price-setting. It can be expressed as:

$$v_t^p = (1+\pi_t)^{\epsilon_p} \left[(1-\theta_p)(1+\pi_t^{\#})^{-\epsilon_p} + \theta_p (1+\pi_{t-1})^{-\epsilon_p \zeta_p} v_{t-1}^p \right] \tag{34}$$

Setting aggregate labor supply from the household to demand from firms yields:

$$N_t = N_{d,t} v_t^w \tag{35}$$

The variable $v_t^w = \int_0^1 \left(\frac{W_t(h)}{W_t} \right)^{-\epsilon_w} dh$ is a measure of wage dispersion and drives a wedge between aggregate labor demand and labor supply. Similarly to price dispersion, it can be written as:

$$v_t^w = (1-\theta_w) \left(\frac{W_t^{\#}}{W_t} \right)^{-\epsilon_w} + \theta_w \left(\frac{W_{t-1}}{W_t} \right)^{-\epsilon_w} \left(\frac{(1+\pi_{t-1})^{\zeta_w}}{(1+\pi_t)} \right)^{-\epsilon_w} v_{t-1}^w \tag{36}$$

Aggregate inflation evolves according to:

$$(1+\pi_t)^{1-\epsilon_p} = (1-\theta_p)(1+\pi_t^{\#})^{1-\epsilon_p} + \theta_p (1+\pi_{t-1})^{\zeta_p (1-\epsilon_p)} \tag{37}$$

Similarly, the aggregate real wage obeys:

$$W_t^{1-\epsilon_w} = (1-\theta_w) \left(W_t^{\#} \right)^{1-\epsilon_w} + \theta_w W_{t-1}^{1-\epsilon_w} (1+\pi_{t-1})^{\zeta_w (1-\epsilon_w)} (1+\pi_t)^{\epsilon_w - 1} \tag{38}$$

Imposing that the household holds any government debt at all times and that flow budget constraints for the household and government both hold with equality yields the aggregate resource constraint:

$$Y_t = C_t + I_t + G_t + \Gamma(u_t) K_t \tag{39}$$

Finally, we include a recursive representation of the value function as an equilibrium condition of the model, which allows us to examine how welfare responds to shocks to tax rates:

$$V_t = \nu_t U(C_t - bC_{t-1}, 1 - N_{d,t} v_t^w) + \beta E_t V_{t+1} \tag{40}$$

3 Functional Forms, Calibration, and Estimation

In this section, we discuss the functional form assumptions as well as the methodology we use to parameterize the model.

3.1 Functional Forms

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

$$U(C_t - bC_{t-1}, 1 - N_t) = \frac{((C_t - bC_{t-1})^\gamma (1 - N_t)^{1-\gamma})^{1-\sigma} - 1}{1 - \sigma}, \qquad \sigma > 0, \;\; 0 < \gamma < 1 \tag{41}$$

This functional form is consistent with balanced growth while also allowing for non-separability in consumption and leisure. For the special case in which $\sigma = 1$, the utility function assumes the 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 capital utilization and investment adjustment cost functions, respectively, take the following forms:

$$\Gamma(u_t) = \left(\psi_0(u_t - 1) + \frac{\psi_1}{2}(u_t - 1)^2\right) \tag{42}$$

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{43}$$

3.2 Parameterization

In total, the model contains forty-five parameters, twenty-five of which relate directly to the fiscal and monetary rules. In our baseline parameterization, we calibrate approximately half of the parameters and estimate the remaining twenty parameters via Bayesian maximum likelihood. The remainder of this section describes the methods used to derive values for each parameter as well as a brief discussion of the sensitivity of the model to some key parameters of interest.

3.2.1 Calibration

The calibrated parameters are $\{\alpha, \beta, \pi, i, \delta, \epsilon_p, \epsilon_w, \psi_0, G, B^g\}$ as well as each of the parameters governing our tax processes. 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 inflation, $\pi = 0$. Together, these parameters imply a steady state risk free interest rate of approximately four percent annualized. The price and wage elasticity parameters ϵ_p and ϵ_w are both set to 10, implying steady state price and wage markups of approximately ten percent. These are broadly consistent with the empirical evidence.[3] We set steady state government spending, G, such that the steady state government

[3] See, for instance, Basu and Fernald (1997).

spending share of output is 20 percent. Steady state government debt, B^g, is chosen such that the steady state debt-GDP ratio is 50 percent. The depreciation rate on physical capital is set to $\delta = 0.025$, implying annual depreciation of approximately 10 percent. For the cost of utilization, the value of ψ_0 is pinned down via the normalization of steady state utilization to unity. This requires that $\psi_0 = \frac{1}{\beta} - (1 - \delta)$. Estimation of models such as the one in this paper typically drive ψ_1 to a very small number; following Christiano, Eichenbaum, and Evans (2005), we set $\psi_1 = 0.01$, implying that the costs of capital utilization are close to linear.

To calibrate the steady state values of τ^c, τ^n, and τ^k, we construct historical tax rate series using data from the national income and product accounts (NIPA). This approach follows Leeper, Plante, and Traum (2010). As our model is very similar to theirs, the constructed series have a relatively clean mapping to our model. Our sample covers the period 1985q1-2008q4. This results in steady state values of $\tau^c = 0.0164$, $\tau^n = 0.2090$, and $\tau^k = 0.1946$. These values are similar to House and Shapiro (2006), Leeper and Yang (2008), Uhlig (2010), and Leeper, Plante, and Traum (2010), though small differences result from different sample periods. The steady state value of lump sum taxes, T, is then chosen to assure that the government's flow budget constraint holds in steady state, given our assumption of a steady state debt-gdp ratio of 50 percent and a steady state government spending share of output of 20 percent.

As a baseline, we assume that the distortionary tax rates do not react to debt and that no taxes respond to output. That is, we set $\gamma_c^b = \gamma_n^b = \gamma_k^b = 0$ and $\gamma_T^y = \gamma_c^y = \gamma_n^y = \gamma_k^y = 0$. We set γ_b^T sufficiently high so that government debt is non-explosive.[4] While perhaps unrealistic, these assumptions are meant to facilitate comparisons with the existing literature. In particular, this specification gives rise to a "clean" interpretation of the thought experiment of changing a distortionary tax rate – if tax rates reacted to debt deviations from target, changes in one tax rate would endogenously induce changes in other tax rates. Also, when estimating the model, we assume that the distortionary tax rates are held fixed at their means, which means that the persistence parameters and standard deviations of the shocks are irrelevant. This is done so that our estimated model aligns closely with other estimated medium-scale DSGE models, which typically do not feature distortionary taxation.

3.2.2 Bayesian Maximum Likelihood

The remaining parameters of our model are estimated via Bayesian maximum likelihood. These parameters include $\{b,\ \theta_w,\ \theta_p,\ \phi_y,\ \phi_\pi,\ \kappa,\ \zeta_w,\ \zeta_p,\ \sigma,\ \gamma\}$, as well as the parameters governing the persistence and volatility of the exogenous processes for A_t, Z_t, i_t, ν_t, and G_t.

Our estimation strategy employs U.S. data covering the period 1985q1 through 2008q4. The beginning date is chosen because of the structural break in aggregate output volatility in the mid-1980s, while the end date of the sample is chosen so as to exclude the zero lower bound period. We use five observable aggregate series in the estimation, corresponding to the number of shocks

[4] 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 baseline results would be identical with higher values of γ_b^T, or if we assumed that lump sum taxes adjusted to balance the government's budget period-by-period.

in the model to be estimated (note that, as discussed above, for the purposes of estimation the distortionary tax rates are held fixed). These series include the growth rates of output, consumption, and investment as well as the levels of inflation and the interest rate. Output growth is constructed using the headline numbers of the main NIPA tables. Investment is defined as new expenditures on durable consumption goods plus private fixed investment. Consumption is defined as the sum of personal consumption expenditures on nondurable goods and services. These series are deflated by the GDP price deflator and divided by the civilian non-institutionalized population before taking the natural log and first differencing. Inflation is the log difference of the GDP price deflator and our measure of the interest rate is the effective Federal Funds Rate. Table 1 shows the prior and posterior distributions of the estimated parameters.

The estimated parameters are largely in-line with existing parameter estimates in the literature.[5] The estimated price rigidity parameter is $\theta_p = 0.62$ and the estimated Calvo parameter for wages is $\theta_w = 0.83$. These imply mean durations between price and wage changes of about three and five quarters, respectively. We find modest amounts of price and wage indexation. The estimated habit persistence parameter is $b = 0.7$, which is quite standard. Our estimated values for the parameters governing curvature in preferences are $\gamma = 0.18$ and $\sigma = 2.47$. These are similar to the assumed values in Christiano, Eichenbaum, and Rebelo (2011). Our baseline estimate of the investment adjustment cost parameter is $\kappa = 4.32$, also a standard value in the literature. The estimated Taylor rule features a strong interest rate smoothing component ($\rho_i = 0.83$), a strong reaction to inflation ($\phi_\pi = 1.55$), and a modest reaction to output growth ($\phi_y = 0.14$). The standard deviation of the Taylor rule shock is $s_i = 0.002$. Estimated autoregressive coefficients for the productivity, marginal efficiency of investment, preference, and government spending processes are 0.94, 0.83, 0.65, and 0.80, respectively. The standard deviations of the correspond shocks are 0.0055, 0.0245, 0.0186, and 0.0104, respectively.

Overall, the estimated model with these parameters fits the data well. The estimated volatility of output growth is about 0.5 percent (close to its value in the data), consumption growth is about 60% as volatile as output, and investment growth is about 4 times more volatile than output. The growth rates of output, consumption, and investment are all significantly autocorrelated, as in the data. Productivity and marginal efficiency of investment shocks each account for approximately 40 percent of the unconditional variance of output growth. The next most important sources of output volatility are preference shocks, which account for 14 percent of the unconditional variance of output growth, followed by interest rate and government spending shocks, which explain 5 and 3 percent, respectively, of the variance of output growth.

4 Baseline Results

In this section, we simulate the model outlined and parameterized in previous sections to quantify the effects of tax cuts on output and welfare over the state space. We begin by briefly outlining the

[5] We henceforth take the mode of the posterior distribution of parameters to represent "the" estimated parameter values.

solution and simulation methodology which permits an investigation of the state-dependent effects of tax shocks. We then provide a definition of our tax output and welfare multipliers in this state dependent environment before concluding the section with a brief summary of the results and some basic intuition.

4.1 Solution Methodology and Multiplier Definitions

We solve our model using the calibrated and estimated parameters via a third order approximation.[6] Solving the model via a peturbation of order higher than one is necessary to examine state-dependence. We generate multipliers by constructing impulse response functions to different shocks. The impulse response function of the vector of endogenous variables, $\mathbf{X}_t$, is defined as follows:

$$\mathbf{IRF}(h) = \{E_t\mathbf{X}_{t+h} - E_{t-1}\mathbf{X}_{t+h} \mid \varepsilon_{j,t} = \varepsilon_{j,t} + s_j, \mathbf{s}_{t-1}\} \tag{44}$$

The impulse response function at forecast horizon h is the difference between forecasts of the endogenous variables at time t (the period of the shock) and $t-1$ (the period immediately before the shock), conditional on the realization of a shock of some value in period t. In a higher order perturbation, the impulse response function in principle depends upon the initial realization of the state, $\mathbf{s}_{t-1}$, in which a shock hits. It may also depend on the size and sign of the shock, though we do not focus on that here.

Given the non-linear solution methodology, these impulse responses are computed via simulation. First, we start with an initial realization of the state, $\mathbf{s}_{t-1}$ (e.g. the non-stochastic steady state). Then we draw shocks from standard normal distributions and simulate data out to horizon H, where we take $H = 20$. This process is repeated $N = 150$ times. Averaging across the N different simulations at horizons up to H yields $E_{t-1}\mathbf{X}_{t+h}$, for $h = 0, \ldots, H$. Then we repeat this process, but add s_j to the realization of the jth shock in the first period of each simulation. Averaging across the N simulations with the extra shock in the first period yields $E_t\mathbf{X}_{t+h} \mid \varepsilon_{j,t} = \varepsilon_{j,t} + s_j$. The difference between these two constructs is the impulse response function. Computing these impulse response functions for different initial values of the state, $\mathbf{s}_{t-1}$, is the means by which we examine state-dependence.

Our definition for the tax output multiplier adapts to a state dependent environment the defintions of Barro and Redlick (2011), and Mertens and Ravn (2012, 2014). We define the "output multiplier" for a shock to a distortionary tax rate as the ratio of the change in output to a change in tax revenue following a tax shock. This definition gives the extra (real) output generated from a change in a tax rate for every extra (real) dollar of tax revenue. We allow the multiplier to vary by forecast horizon. Formally, the output multiplier to shock j at forecast horizon h is defined as:

$$YM_j(h) = \frac{dY_{t+h}}{dTR_t}\bigg|\varepsilon_{j,t} = \varepsilon_{j,t} + s_j, s_{t-1} \quad \text{for } j = c,\, n, \text{ or } k \tag{45}$$

[6] Our results are quite similar if we instead use a second order approximation.

As written, the multiplier is defined for many different forecast horizons. We will focus on two horizons in particular: the "impact" multiplier, which sets $h = 0$, and the "max" multiplier, which is defined as the ratio of the maximum output response to the impact revenue response.[7] As it is based on the impulse response function, the multiplier explicitly depends upon the state in which a shock occurs.

4.2 Baseline Simulation Results

For our benchmark exercise, we draw shocks and simulate the estimated model for 1,000 periods (starting from the non-stochastic steady state). For each simulated state, we then compute impulse responses to the three distortionary tax shocks. In simulating data from the model, we set the standard deviations of the tax rate shocks to zero. This ensures that any state-dependence of the tax multipliers arises for reasons other than tax rates being abnormally high or low. Furthermore, so as to facilitate a comparison of the magnitude of multipliers across different types of taxes, we set the autoregressive parameters for each tax process to 0.95. We consider one percent shocks to each tax rate when computing impulse responses and constructing multipliers.

Table 2 presents some summary statistics from these simulations. For each of the three types of distortionary tax shocks, we present statistics on two different multipliers – the impact output multiplier and the maximum output multiplier. In our model, these multipliers are both negative – i.e. decreases in tax rates stimulate output, but result in lower tax revenue on impact. For ease of exposition we multiply each multiplier by negative one so that they appear as positive numbers. We present statistics on the mean, minimum, and maximum values of each type of multiplier for each type of tax across the 1,000 simulated periods. We also show the standard deviations of each multiplier over the 1,000 different states to get a measure of how much volatility there is in each multiplier. Finally, we show the correlation of each type of multiplier with the simulated level of log output. These statistics are meant to give a sense of the cyclicality of the multipliers.

In terms of average values, the relative magnitudes of tax output multipliers are as follows: the capital tax multiplier is larger than the labor tax multiplier which is larger than the consumption tax multiplier. In particular, the average value of the max multiplier for the consumption tax is 0.62, the average multiplier is 1.39 for labor taxes, and 2.74 for the capital tax rate. To take the capital tax as an example, these numbers mean that a change in the tax rate which generates a one dollar change in total tax revenue generates a maximum output response of more than two-and-a-half dollars. These magnitudes are comparable to recent theoretical studies with a common debt financing exercise by Leeper and Yang (2008) and Uhlig (2010), as well as recent empirical studies by Mertens and Ravn (2012, 2014), who finds multipliers of up to 2 on impact and up to 3 after six quarters. For all three types of taxes, the average impact multiplier is smaller than the max multiplier. This trend is also common in tax studies and is most noticeable for the capital tax rate

[7] We compute impulse responses out to a horizon $H = 20$. The maximum output response to any of the three tax shocks typically occurs at horizons between $h = 5$ and $h = 10$. The maximum tax revenue response is generally on impact.

and least apparent for the consumption tax rate.[8] As we discuss in more detail below, this feature arises because of the numerous real frictions in the model which generate hump-shaped impulse responses to tax changes.

We next turn to the state-dependence of the output multipliers for each type of tax rate. The rank order of volatilities of multipliers across types of tax is the same as the ranking of average multipliers. The standard deviation of the max capital tax multiplier is 0.1, with a min-max range of close to 0.6. The standard deviation of the labor tax multiplier is 0.06 with a min-max range of roughly 0.3. The consumption tax multiplier is least volatile, with a standard deviation of 0.007 and a min-max range of roughly 0.04. For all three types of tax rates, the volatilities of the max multipliers are larger than the volatilities of the impact multipliers. It is interesting to note that there is significantly more state-dependence in these tax multipliers than there is for the government spending multiplier. Sims and Wolff (2015) find that the standard deviation of the spending multiplier across states (outside of the zero lower bound) is roughly 0.01, significantly below the volatility in the labor and capital tax multipliers.

Figure 1 plots impulse responses of output to each of the three different tax shocks. For each kind of tax rate, the solid line shows the median impulse response of output across all the simulated states. To get a sense of state-dependence, the dashed line shows the upper 1 percentile of the output responses and the dashed-dotted line shows the bottom 99 percentile of the output responses. For each of the three kinds of taxes, there are significant differences in the magnitudes at all forecast horizons, though the shapes are similar.

One might be concerned that some of the state-dependence in the multipliers documented in Table 2 is driven not by different output responses to tax rate changes across states but rather different tax revenue responses. For example, it is straightforward to see that tax revenue will respond less to a change in a tax rate in states when the tax base is low.[9] The impulse responses plotted in Figure 1 suggest that there are significant differences in how output reacts to tax changes across states and that state-dependence in the multipliers is not solely-driven by differential tax revenue responses across states. The results in Table 3 also make this clear. This table is the same as Table 2 with the exception that, in the construction of the multipliers, we divide the state dependent output response not by the tax revenue response in a particular state, but rather by the tax revenue response when the economy is in the non-stochastic steady state. This ensures that all state-dependence in the multiplier statistics is driven by state-dependence in the output response to a tax rate change. We find an increase in the state-dependence of output multipliers for each type of tax at each horizon, suggesting that the tax revenue response actually works to mute the state-dependence of the multipliers according to our baseline definition. To further visualize the dispersion in output responses, Figure 2 plots a histogram of multipliers for each type of tax shock and fits a normal distribution to each histogram. These histograms provide a visual representation

[8] See, for example, Mountford and Uhlig (2009), Leeper, Plante, and Traum (2010), or Mertens and Ravn (2014).

[9] To see this clearly, suppose that $TR_t = \tau_t TB_t$, where TR_t is tax revenue, τ_t is a tax rate, and TB_t is the tax base. Totally differentiating about a point holding TB_t fixed, one gets $dTR_t = d\tau_t TB$. This will be smaller when TB is small.

of the data summarized in Table 3.

We next turn to a discussion of the cyclicality of multipliers for each type of tax rate. The multipliers are generally weakly correlated with output in an absolute sense. Most of the multipliers are procyclical (i.e. positively correlated with simulated output); the lone exception is the max consumption multiplier, which is weakly negatively correlated with output. This feature is apparent in Figures 3-5, which plot the times series of max multipliers for the consumption, labor, and capital tax series, respectively. In each Figure, gray shaded regions are periods of recession, which we identify to be periods in which simulated output is in its lower 10th percentile. For the labor and capital tax rates, the max multiplier tends to be low during periods identified as recessions. When compared with the cyclicalities of our multipliers using the steady state tax revenue response in Table 3, we find that the output response to a tax shock is strongly pro-cyclical for each type of tax shock. Each tax at both the impact and maximum horizons display correlation coefficients with simulated output in excess of 0.64 suggesting that the output response to a tax shock is strongly procyclical while the revenue response to a tax shock is countercyclical. The opposing cyclicalities of these variable responses therefore mutes the cyclicalities of the multipliers according to our baseline definition of the multipliers reported in Table 2.

Our results suggest that while there is significant state-dependence in the output effects of changes in distortionary tax rates, these multipliers tend to be mildly procyclical. Does this result imply that tax cuts are relatively undesirable in a recession if the output effects are smaller than average? Not necessarily. To investigate further, we adopt terminology from Sims and Wolff (2015) and define the tax welfare multiplier as the consumption equivalent change in welfare, V_t, for a one dollar change in tax revenues. Formally:

$$VM_j(h) = \frac{dV_t}{dTR_t}\frac{1}{\mu}\bigg|\varepsilon_{j,t} = \varepsilon_{j,t} + s_j, s_{t-1} \quad \text{for } j = c,\, n, \text{ or } k \tag{46}$$

This expression evaluates the change in household welfare, V_t, per one (real) dollar change in tax revenue. As units of welfare are utils, division by the steady state marginal utility of consumption, μ, puts the multiplier into consumption equivalent terms. One can think about this multiplier as measuring what percentage of steady state consumption a household would be willing to give up to avoid a shock to a tax rate.

Table 4 is structured similarly to Table 2 but instead shows results for the welfare multiplier. The welfare multipliers are large and positive for each type of tax. The sign of these multipliers reflects the fact that the economy is on average distorted – this distortion arises both from monopolistic competition as well as from positive steady state tax rates. Lowering tax rates eases distortions and is naturally welfare-improving. The rank ordering of the size of average welfare multipliers is the same as the rank ordering of average output multipliers – the average welfare multiplier for the capital tax rate is larger than the average welfare multiplier for the labor tax rate, which is in turn larger than the average multiplier for the consumption tax rate. The interpretation of the magnitudes of the welfare multipliers is as follows. Taking the labor tax rate as an example, a welfare multiplier of 7.9 means that a cut in the labor tax rate resulting in a one dollar decline in tax revenue leads to an increase in welfare equivalent to a one period increase in consumption of about 8. While this number might seem high, note that it is a one period consumption equivalent corresponding to a persistent change in a tax rate. Were we to compute the amount of consumption a household would need to be given in every period going forward to generate an equivalent change in welfare, the welfare multipliers would be about one one-hundredth of the values presented in the Table.

The welfare multipliers tend to be much more volatile than the output multipliers. This can be clearly seen in Table 4 in comparison to Table 2. It is also visibly apparent in Figures 3-5, which plot the welfare multipliers (dashed lines) along with the output multipliers (solid lines) across time. One also observes that the welfare multipliers, in contrast to the output multipliers, are strongly countercyclical. This holds for each type of tax rate, though the countercyclicality is strongest for the labor and capital tax rates. One can also see this in the time series plots, where the welfare multiplier tends to peak during periods identified as recessions. These results suggest that even though tax changes have relatively smaller effects on output during recessions, these tax cuts are nevertheless relatively more valuable to the household during times of low output than when the economy is in an expansionary phase. Note that this countercyclical desirability of tax changes is not an artifact of the marginal utility of consumption being high on average during recessions, as in our construction of the welfare multipliers we convert to consumption equivalent units by dividing by the steady state marginal utility of consumption. The countercyclicality of tax cut multipliers also stands in contrast with recent work by Sims and Wolff (2015) which found that the welfare multiplier for government spending shocks is procyclical.

The intuition for the strong countercyclicality of the welfare multipliers is straightforward. Viewed through the lens of a prototypical real business cycle model, the economy appears to be highly distorted during downturns. In particular, using the terminology of Chari, Kehoe, and McGrattan (2007), the labor wedge, which is isomorphic to a time-varying tax on labor income, is strongly countercyclical. The same features emerge in our estimated medium scale DSGE model. Because of monopolistic competition and positive average values of the tax rates, the economy is distorted (relative to the first best) on average. Because of price and wage rigidity, this distortion is relatively high in downturns and low in expansions. A tax cut mechanically eases the overall level of distortion in an economy, and is most valuable in highly distorted states. Hence, it is natural that the welfare multipliers for tax cuts are strongly countercyclical.

5 Extensions

In this section we consider the robustness of our baseline results. The extensions we consider include: (i) alternative values for our baseline parameters, (ii) anticipation in tax processes, (iii) alternative fiscal adjustment methods, and (iv) the addition of a rule-of-thumb consumer population to the model economy. Summary statistics similar to our baseline exercises are constructed for each extension via 1,000 period simulations using a third order perturbation method of the modified model. That all multipliers demonstrate strong state-dependence and that welfare multipliers demonstrate far more state-dependence than output multipliers both hold up in each extension considered. We do, however, find that the magnitude and in some instances the cyclicality of multipliers can be sensitive to the modeling assumptions.

5.1 Alternative Parameterizations

We consider alternative values for six key parameters. Table 5 summarizes the results. This table contains six 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.

In our baseline model, we employ a preference specification in which consumption and leisure are non-separable, but which also allows us to consider a more general log-separable specification. We now consider this more standard assumption of log-separable utility which amounts to assuming $\sigma = 1$. With this assumption, our utility function appears as follows:

$$U(C_t - bC_{t-1}, 1 - N_t) = \gamma \ln(C_t - bC_{t-1}) + (1-\gamma)\ln(1 - N_t) \tag{47}$$

The first panel of Table 5 displays some summary statistics with this new preference specification. We find that the new preference specification puts slight upward pressure on the magnitudes of the tax output multiplier for both labor and capital taxes, and slight downward pressure on the consumption tax output multiplier. We find that the state-dependence of each multiplier increases slightly, but that the consumption tax output multiplier becomes even more strongly counter-cyclical while the cyclicality of labor and capital multipliers are left relatively unchanged. The properties of the welfare multipliers for each type of tax are also qualitatively similar to our baseline model.

The next two panels of the table consider different amounts of nominal wage and price rigidity, respectively. In each exercise, we re-parameterize the Calvo stickiness parameter in such a way that the expected duration between price or wage changes is half of what it is in our baseline estimation. Decreasing wage stickiness results in a 6 percent larger average consumption and 9 percent larger average labor tax output multiplier. The capital tax multiplier is 11 percent smaller on average. However, we find that wage stickiness has little impact on the state-dependent properties of each multiplier – the standard deviations of our simulated series are nearly identical to their baseline values and multiplier cyclicalities are relatively unchanged. The welfare multipliers for each type of tax are large, highly volatile, and strongly countercyclical even with less wage rigidity.

Considering now the parameter governing price stickiness, we re-parameterize the Calvo parameter in such a way that the average duration between price changes is 1.3 quarters instead of the baseline 2.6 quarters. The only significant change relative to our baseline results concerns the magnitude and volatility of the capital tax output and welfare multipliers. The average capital tax output multiplier increases 19 percent over the baseline while the corresponding welfare multiplier increases 18 percent. In addition, the range of values the capital tax multiplier takes on over the state space increases from 0.55 to 0.73; an increase of over 30 percent. There is little impact of more flexibility in prices on the co-movements of the output multipliers with simulated output. The welfare multipliers for each type of tax remain strongly countercyclical.

We next consider an alternative value of ψ_1, the parameter governing the cost associated with altering the level of capital utilization. By setting ψ_1=1,000, we effectively fix utilization. Summary statistics for simulations using this alternative parameterization are shown in the fourth panel of Table 5. There is a reduction in the magnitude of consumption, labor, and capital tax output multipliers, as well as significant declines in the relative state-dependence of labor and capital tax multipliers. The consumption and labor tax output multipliers are approximately two-thirds of their baseline value while the capital tax output multiplier is only 20 percent of its baseline value. The standard deviation of simulated labor tax output multipliers in the baseline model is over four times larger than under this parameterization; for the capital tax output multiplier, it is over six times more volatile in the baseline parameterization than here. It is unsurprising that fixing capital utilization makes the multipliers smaller on average, as doing so removes an important amplification mechanism. With fixed utilization, the consumption and capital tax output multipliers flip signs of correlations with output (the consumption tax multiplier becomes procyclical, while the capital tax multiplier is now countercyclical). The labor tax multiplier remains mildly procyclical. With no utilization, the welfare multipliers are smaller on average and somewhat less volatile. They remain strongly countercyclical for each type of tax.

The parameter γ governs the elasticity of labor supply: higher values of γ correspond to less elastic labor supply. The fifth column of Table 5 presents multiplier statistics when we double the estimated value of γ from 0.18 to 0.36. The average value of each output multiplier is smaller when labor supply is less elastic, as one might expect. It is also the case that the output multipliers for each type of tax rate are less volatile. There is little impact of a higher value of γ on the cyclicalities of the output multipliers. The welfare multipliers for each type of tax are a bit smaller than in our baseline analysis, but remain strongly countercyclical.

The sixth panel of Table 5 considers increasing the monetary policy response to inflation from 1.55 to 2.50. This results in larger average values of the labor and capital tax multipliers and a slightly smaller average value of the consumption tax multiplier. The intuition for these effects is similar to the intuition for why the multipliers are larger on average when prices are relatively more flexible. The labor and capital tax multipliers are supply shocks, and price rigidity (or weak monetary policy responses) mutes the output response to such shocks. The output multipliers for capital taxes are slightly more volatile across states, while the labor and consumption tax multiplier relatively unchanged. The welfare multipliers are on average larger for the capital and labor taxes relative to the baseline and smaller for the consumption tax. The welfare multipliers for each type of tax remain strongly countercyclical.

5.2 Anticipation Lags

Given the delay inherent in the implementation of new legislation, several authors have recently considered the impact of anticipation in the transmission of fiscal shocks. Yang (2005), Yang (2005), House and Shapiro (2006), Uhlig (2010), and Mertens and Ravn (2011) find that anticipation in the tax process can have a significant impact on the effectiveness of tax cuts. Leeper, Walker, and Yang (2013) estimate a DSGE model similar to ours which explicitly accounts for both policy lags and phase in periods for a tax rate change and find that anticipation in both the intensive and extensive margins can have a significant impact on the response of key aggregate variables.

In this extension, we consider the impact of a policy announcement of $\Lambda = 2, 3, 4, 5$, or 6 periods in advance of implementation. This means that agents learn of a tax change Λ periods before the tax change takes effect. Given this new modeling assumption, distortionary tax rules appear as follows:

$$\tau_t^c = (1-\rho_c)\tau^c + \rho_c \tau_{t-1}^c + (1-\rho_c)\Big(\gamma_c^b (B_{t-1}^g - B^g) + \gamma_c^y (\ln Y_t - \ln Y_{t-1})\Big) + s_c \varepsilon_{c,t-\Lambda} \tag{48}$$

$$\tau_t^n = (1-\rho_n)\tau^n + \rho_n \tau_{t-1}^n + (1-\rho_n)\Big(\gamma_n^b (B_{t-1}^g - B^g) + \gamma_n^y (\ln Y_t - \ln Y_{t-1})\Big) + s_n \varepsilon_{n,t-\Lambda} \tag{49}$$

$$\tau_t^k = (1-\rho_k)\tau^k + \rho_k \tau_{t-1}^k + (1-\rho_k)\Big(\gamma_k^b (B_{t-1}^g - B^g) + \gamma_k^y (\ln Y_t - \ln Y_{t-1})\Big) + s_k \varepsilon_{k,t-\Lambda} \tag{50}$$

We amend our baseline model to this specification without altering any other parameters. Calculation of multipliers is somewhat complicated by the presence of anticipation – while output and its components will respond in the period in which the future tax change is announced, tax revenue will react only indirectly via the tax base. Since our baseline multipliers scale output responses by the tax revenue response on impact, comparison with our earlier results would be muddied. We therefore adopt the following strategy: we scale the output (or welfare) response to an anticipated tax shock at horizon $t+h$ by the tax revenue response to an unanticipated tax shock of the same magnitude.[10]

Table 6 displays the results of this alternative modeling assumption. The table contains three distinct panels, separated according to the type of tax cut implemented. For each type of tax, we show statistics for different anticipation horizons. For each type of tax, the average output multipliers tend to be larger the longer is the anticipation horizon. We should be clear that here we are presenting statistics on the maximum output multipliers. The impact output multipliers are monotonically decreasing in the anticipation length. Given more time to adjust in anticipation of a tax change, it is the maximum output response that is larger the longer is the anticipation horizon. This follows as agents facing convex costs to adjustment and sticky price and wage contracts are able to more optimally respond to tax cuts when given more notice. The tax multipliers are significantly more volatile across states under anticipation – for example, the standard deviation of the consumption tax multiplier with anticipation is more than double its size without anticipation, while the volatility of the labor tax multiplier is about fifty percent bigger with anticipation. The labor and capital tax multipliers are significantly more positively correlated with simulated output

[10] 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 (i.e. period $t + H$). This strategy is also not without complications as agents begin to adjust behavior H periods prior to the realization of the tax change, thus rendering the single period tax revenue change in period $t + H$ an understatement of the true tax revenue response.

than without anticipation. The consumption tax multiplier is now also procyclical, whereas it is mildly countercyclical in the absence of anticipation. The welfare multipliers for each kind of tax also tend to be larger with longer anticipation horizons. Interestingly, the welfare multipliers are still countercyclical, but are much more weakly correlated with simulated output than in the baseline case. This follows as the welfare multiplier measures the consumption equivalent change in welfare at the time of the announcement while simulated output will not realize its full effect until after the anticipated tax change.

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; however, this common assumption is not particularly realistic. As noted by Christ (1968), Baxter and King (1993), Yang (2005), Leeper and Yang (2008), Mountford and Uhlig (2009), Leeper, Plante, and Traum (2010), and others, the means by which the government finances a current tax cut may be important in how stimulative that tax cut is.

Our assumed tax processes, given in (25)-(28), embed different possibilities for fiscal finance. For the following exercises, we assume that lump sum taxes are fixed (i.e. $\gamma_T^b = \gamma_T^y = 0$). We consider three different alternative financing regimes. In the first, the consumption tax rate responds to debt deviations from steady state, in the second the labor tax responds so as to stabilize debt, while in the third there is a mix of responses between both the labor and capital tax rates. We continue to assume that the autoregressive parameters in the tax processes are each 0.95. For the first exercise, we set $\gamma_c^b = 0.075$ and other parameters in the fiscal rules equal to 0. For the second exercise, we set $\gamma_n^b = 0.075$, and for the third exercise we set $\gamma_n^b = \gamma_k^b = 0.075$.

Table 7 contains the results for these alternative financing exercises. For each exercise and each type of tax shock, the properties of the output multipliers are for the most part fairly similar to our baseline exercises. The average multipliers for each type of tax are slightly smaller when the consumption tax reacts to debt deviations from steady state. In contrast, the average multipliers for each type of tax are slightly larger when labor and/or capital taxes react to stabilize debt, the intuition for which is that the present is a comparatively better time to work relative to the future when taxes will have to rise to stabilize debt. For each financing regime, there is still considerable state-dependence in each tax multiplier, though the volatilities of the labor and capital tax multipliers across states are smaller than in our baseline exercise, whereas the reverse is true for consumption tax shocks. For each different financing regime, and for each different kind of tax shock, the output multipliers are positively correlated with simulated output. The only exception is the labor tax multiplier in the labor tax financing regime which is weakly countercyclical.

The most notable differences relative to our baseline exercise are the properties of the welfare multipliers. When debt deviations from steady state are financed solely by lump sum taxes, the welfare multipliers from tax cuts are unambiguously positive, as the only effect of a tax cut is to temporarily lower distortions. This is not necessarily the case when distortionary taxes must adjust so as to stabilize debt. In Table 7 we see that the welfare multiplier for the consumption tax is negative for each different financing regime, and the welfare multiplier for the labor tax cut is also negative in the third financing regime we consider. We naturally observe that the average welfare multipliers, whether positive or negative, for each kind of tax under each different financing regime are lower than the corresponding values in the baseline lump sum tax finance case. It is also the case that the welfare multipliers are less volatile than in our baseline case. Regardless of financing regime, the capital and labor tax multipliers are strongly countercyclical. The welfare multiplier for the consumption tax cut, in contrast, is strongly procyclical, instead of countercyclical as in our baseline analysis.

5.4 Rule-of-Thumb Households

In our baseline model, the household is assumed to have unrestricted access to both credit and capital as a means of transferring wealth. In this section, we consider an extension of the model in which a portion of the household population is assumed to be removed from both capital and credit markets. For this consumer population, the income effect of tax cuts cannot be smoothed through delayed consumption. Households of this type supply labor at the market wage and consume all of their period income. Such household types have been called "fist-to-mouth" by Campbell and Mankiw (1990) or "rule-of-thumb" by Gali et al. (2007) and McKay and Reis (2016) for their modeled inability to optimally choose consumption across time.

It is assumed that a household of this type supplies labor considering only current period wages, labor income, and current period tax rates, each of which are assumed to be identical to those faced by the optimizing household. The problem of the rule-of-thumb household type appears as follows:

$$\max_{C_t^r N_t^r} \quad \nu_t U(C_t^r, 1 - N_t^r)$$

subject to the budget constraint:

$$(1 + \tau_t^c) C_t^r = (1 - \tau_t^n) W_t N_t^r - T_t \tag{51}$$

Super-scripts are used to distinguish the rule-of-thumb household type from households with access to credit and capital markets. We note that the functional form used for the rule-of-thumb household utility is identical to the optimizing household, except for the absence of habit in the rule-of-thumb consumer population's utility from consumption. Households of this type are assumed to comprise of $\lambda \in (0, 1)$ of the population, where λ is fixed across time. As rule-of-thumb household types make their labor supply decision independent of optimizing households, it is not necessarily the case that they supply λ of a given labor market. In addition, rule-of-thumb households are assumed to supply labor taking aggregate wages as given. Equation (51), in conjunction with the following labor-leisure condition, characterize the rule-of-thumb population's behavior:

$$\frac{U_L(C_t^r, 1 - N_t^r)}{\mu_t^r} = (1 - \tau_t^n)W_t \quad (52)$$

$$(1 + \tau_t^c)\mu_t^r = U_C(C_t^r, 1 - N_t^r) \quad (53)$$

Here, μ_t^r is the multiplier associated with relaxing the rule-of-thumb household's budget constraint.

The population of households able to acquire capital will choose a common level of utilization and investment. This implies that $(1-\lambda)$ households in the economy rent capital of $\widetilde{K}_t$. As a result of this population shift, we define $\hat{K}_t$ to be the total capital available for rent in period t:

$$\hat{K}_t = (1 - \lambda)\widetilde{K}_t \quad (54)$$

Hence, increasing the rule-of-thumb population reduces the supply of productive capital. As previously noted, the rule-of-thumb household chooses their labor supply taking as given current wages and tax rates. Intermediate good firms employ the labor bundle including both rule-of-thumb and optimizing households to produce their monopolistically competitive intermediate good. Aggregate labor is thus defined as follows:

$$\hat{N}_t = (1 - \lambda)N_t + \lambda N_t^r \quad (55)$$

Similarly, we can define aggregate consumption in this context as:

$$\hat{C}_t = (1 - \lambda)C_t + \lambda C_t^r \quad (56)$$

Lastly, government revenue from taxes will also change with the addition of a second household type as will our definition of aggregate welfare. Assuming identical tax rates for both household types, the government's nominal budget constraint appears as follows:

$$G_t + i_{t-1}\frac{B_{t-1}^g}{P_t} = \tau_t^c\hat{C}_t + \tau_t^n W_t\hat{N}_t + \tau_t^k r_t^k\hat{K}_t + T_t + \frac{B_t^g - B_{t-1}^g}{P_t} \quad (57)$$

We define welfare to be a population weighted average of present discounted flow utility to both household types:

$$V_t = (1 - \lambda)U(C_t - bC_{t-1}, 1 - N_t) + \lambda U(C_t^r, 1 - N_t^r) + \beta V_{t+1} \quad (58)$$

Having fully described the alterations made to our baseline model, Table 8 presents the results to this alternative specification. The table presents three distinct panels, each containing a unique population distribution; those population distributions include 10%, 25%, and 50% rule-of-thumb populations. Each of the three distinct panels contain both output and welfare multipliers for consumption, labor, and capital tax shocks.

Considering the mean output multipliers shown in Table 8, we find that consumption and labor tax output multipliers are monotonically increasing in the size of the rule-of-thumb population.

The intuition for such a result is straight forward: rather than smoothing the additional income over several periods, rule-of-thumb households spend all additional income today. Optimizing households, however, will seek to spread their additional income across time through bond and capital holdings. With an increasing share of rule-of-thumb households, therefore, consumption and labor taxes become increasingly effective means of stimulating output growth. Concerning the magnitude of capital tax cuts across various population distributions, we find that capital tax multipliers are monotonically decreasing in the size of the rule-of-thumb population. As rule-of-thumb consumers are unable to accumulate capital, the output response to a capital tax shock will impact a smaller portion of the population and thus, be less effective at stimulating output.

Also important to note is the change in welfare multipliers with the increasing population of rule-of-thumb households. As the rule-of-thumb population increases, welfare multipliers associated with identical consumption and labor taxes cuts monotonically increase as well. In response to capital tax cuts however, welfare is shown to monotonically decrease as the rule-of-thumb household population increases. Once again noting that only optimizing households have access to capital markets, capital tax cuts will affect a smaller portion of the population as the number of optimizing households decreases, thus resulting in smaller welfare effects.

The relative state-dependence of tax output multipliers depends largely upon the tax in question and the size of the rule-of-thumb population. Labor tax output multipliers are slighlty more volatile across states with a higher rule-of-thumb population. The capital tax output multiplier is significantly less volatile across sates, with the standard deviation of this multiplier about one-half as big as in our baseline case when 50 percent of the population is rule-of-thumb. The consumption tax multiplier is about as volatile over states as in our baseline exercises, regardless of the fraction of the population which is rule-of-thumb. Output multipliers remain mildly pro-cyclical for labor and capital tax cuts and counter-cyclical for consumption tax cuts. The welfare welfare multipliers remain strongly counter-cyclical for all types of tax cuts.

The intuition for these results applies to both the output and the total revenue change in tax multipliers. Increasing the rule-of-thumb population results in larger impact and maximum output responses for both consumption and labor tax cuts. In addition, the tax revenue loss for each tax cut is decreasing in the size of the rule-of-thumb population. The net effect is a larger multiplier for either type of tax cut. In contrast, we see a relatively unchanged output response to capital tax cuts as altering the population distribution does very little to the investment behavior of the optimizing households. However, the tax revenue loss following a capital tax cut is increasing in the size of the rule-of-thumb population, which results in smaller average capital tax cut multipliers.

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 perturbation 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. Capital tax multipliers are both the largest in magnitude, and in volatility over the state space. The consumption tax multipliers are smallest on average and least volatile, with the labor tax multiplier somewhere in between.

The output multipliers are tpyically procyclical, meaning that tax cuts are relatively ineffective at stimulating output in periods when output is low. This does not imply that tax cuts during recession are undesirable, however, as we find that welfare multipliers for each type of tax cut are strongly countercyclical.

References

[1] Adam, Klaus and Roberto B. Billi. 2007. “Discretionary Monetary Policy and the Zero Lower Bound on Nominal Interest Rates.” *Journal of Monetary Economics* 54, 728-752.

[2] Agarwal, Sumit, Chunlin Liu, and Nicholas S. Souleles. 2007. “The Reaction of Consumer Spending and Debt to Tax Rebates - Evidence from Consumer Credit Data.” *Journal of Political Economy* 115(6), 986-1019.

[3] Ando, Albert, and E. Cary Brown. 1963. ”Lags in Fiscal Policy.” *Stabilization Policies*, 97-163.

[4] Auerbach, Alan and Yuriy Gorodnichenko. 2012. “Measuring the Output Responses to Fiscal Policy.” *American Economic Journal: Economic Policy* 4(2), 1-27.

[5] Bachmann, Rüdiger, and Eric R. Sims. 2012. “Confidence and the transmission of government spending shocks.” *Journal of Monetary Economics* 59(3), 235-249.

[6] Barro, Robert J. 1979. ”On the determination of the public debt.” *The Journal of Political Economy*, 940-971.

[7] Barro, Robert J. 1981. “Output effects of government purchases.” *Journal of Political Economy* 89(6), 1086-1121.

[8] Barro, Robert J. and Charles J. Redlick. 2011. “Macroeconomic effects from government purchases and taxes.” *The Quarterly Journal of Economics* 126(1), 51-102.

[9] Basu, Susanto and John Fernald. 1997. “Returns to Scale in U.S. Production: Estimates and Implications.” *Journal of Political Economy* 105(2), 249-283.

[10] Baxter, Marianne and Robert G. King. 1993. “Fiscal Policy in General Equilibrium.” *American Economic Review* 83(3), 315-334.

[11] Bernanke, Benjamin and Mark Gertler. 1989. “Agency Costs, Net Worth, and Business Fluctuations.” *American Economic Review* 79(1), 14-31.

[12] Braun, Anton R. 1994. “Tax disturbances and real economic activity in the postwar United States.” *Journal of Monetary Economics* 33, 441-462.

[13] Blanchard, Oliver, and Roberto Perotti. 2002. “An empirical characterization of the dynamic effects of changes in government spending and taxes on output.” *The Quarterly Journal of Economics* 117(4), 1329-1368.

[14] Calvo, Guillermo A. 1983. “Staggered Prices in a Utility-Maximizing Framework.” *Journal of Monetary Economics* 12, 383-98.

[15] Carlstrom, Charles and Timothy Fuerst. 1997. “Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis.” *American Economic Review* 87(5), 893-910.

[16] Campbell, John Y. and Mankiw, N. Gregory. 1990. “Permanent income, current income, and consumption.” *Journal of Business & Economic Statistics* 8(3), 265-279.

[17] Chahrour, R., Schmitt-Groh, S. and Uribe, M., 2012. "A Model-Based Evaluation of the Debate on the Size of the Tax Multiplier." *American Economic Journal: Economic Policy* 4(2), 28.

[18] Chari, VV, Patrick J. Kehoe, and Ellen R. McGrattan. 2007. "Business Cycle Accounting." *Econometrica* 75(3), 781-836.

[19] Christ, Carl F. 1968. "A Simple Macroeconomic Model with a Government Budget Restraint." *Journal of Polictical Economy* 76(1), 53-67.

[20] Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113(1), 1-45.

[21] Christiano, Lawrence J., Martin Eichenbaum, and Sergio Rebelo. 2011. "When is the Government Spending Multiplier Large?" *Journal of Political Economy* 119(1), 78-121.

[22] Coenen, Günter, Christopher Erceg, Charles Freedman, Davide Furceri, Michael Kumhof, René Lalonde, Douglas Laxton, Jesper Lendé, Annabelle Mourougane, Dirk Muir, Susanna Mursula, Carlos de Resende, John Roberts, Werner Roeger, Stephen Snudden, Mathias Trabandt, and Jan in 't Veld. 2012. "Effects of Fiscal Stimulus in Structural Models" *American Economic Journal: Macroeconomics* 4(1), 22-68.

[23] Cogan, John F., Tobias Cwik, John B. Taylor, and Volker Wieland. 2010. "New Keynesian Versus Old Keynesian Government Spending Multipliers." *Journal of Economic Dynamics and Control* 34(3), 281-295.

[24] Drautzburg, Thorsten and Harald Uhlig. 2011. "Fiscal Stimulus and Distortionary Taxation." *ZEW-Centre for European Economic Research Discussion Paper No. 11-037.*

[25] Eichenbaum, Martin and Jonas Fisher. 2005. "Fiscal Policy in the Aftermath of 9/11." *Journal of Money, Credit, and Banking* 37(1), 1-22.

[26] Eggertsson, Gauti B. and Michael Woodford. 2003. " The Zero Bound on Interest Rates and Optimal Monetary Policy." *Brookings Papers on Economic Activity* 1:2003, 212-219.

[27] Eggertsson, Gauti B. 2011. "What fiscal policy is effective at zero interest rates?" *NBER Macroeconomic Annual 2010,* University of Chicago Press, 2011.

[28] Friedman, M. 1948. "A monetary and fiscal framework for economic stability." *American Economic Review* 38, 245264.

[29] Galí, Jorda, López-Salido, J.D., and Vallés, J.. 2007. "Understanding the effects of government spending on consumption." *Journal of the European Economic Association* 5(1), 227-270.

[30] Hall, Robert E. 1971. "The dynamic effects of fiscal policy in an economy with foresight." *The Review of Economic Studies* 38(2), 229-244.

[31] House, Christopher and Matthew Shapiro. 2008. "Temporary Tax Incentives: Theory with Evidence from Bonus Depreciation" *American Economic Review* 98, 737-768.

[32] Jorda, Oscar. 2005. "Estimation and inference of impulse responses by local projections." *American Economic Review* 95(1), 161-182.

[33] Jorgenson, Dale W. and Kun-Young Yun. 1990. "Tax Reform and U.S. Economic Growth." *Journal of Political Economy* 98(5), 151-193.

[34] Justiniano, Alejandro, Giorgio Primiceri, and Andrea Tambalotti. 2010. "Investment Shocks and Business Cycles." *Journal of Monetary Economics* 57(2), 132-145.

[35] Justiniano, Alejandro, Giorgio Primiceri, and Andrea Tambalotti. 2011. "Investment Shocks and the Relative Price of Investment." *Review of Economic Dynamics* 14(1), 101-121.

[36] Leeper, Eric M., and Shu-Chun Yang. 2008. "Dynamic scoring: Alternative financing schemes." *Journal of Public Economics* 92, 159-182.

[37] Leeper, Eric M., Nora Traum, and Todd B. Walker. 2015. "Clearing up the Fiscal Multiplier Morass." Working Paper.

[38] Leeper, Eric M., Michael Plante, and Nora Traum. 2010. "Dynamics of fiscal financing in the United States." *Journal of Econometrics* 156, 304-321.

[39] Leeper, Eric M., Walker, Todd B. and Shu-Chun Susan Yang. 2013. "Fiscal foresight and information flows." *Econometrica* 81(3), 1115-1145.

[40] McGrattan, Ellen R. 1994. "The macroeconomic effects of distortionary taxation." *Journal of Monetary Economics* 33, 573-601.

[41] McKay, Alisdair and Ricardo Reis. 2016. "The Role of Automatic Stabilizers in the U.S. Business Cycle." *Econometrica* 84(1), 141-194.

[42] Mertens, Karel and Morten O. Ravn. 2011. "Understanding the Aggregate Effects of Anticipated and Unanticipated Tax Shocks." *Review of Economic Dynamics* 14, 27-54.

[43] Mertens, Karel and Morten O. Ravn. 2012. "Empirical Evidence on the Aggregate Effects of Anticipated and Unanticipated US Tax Policy Shocks." *American Economic Journal: Economic Policy* 4(2), 145-181.

[44] Mertens, Karel and Morten O. Ravn. 2014. "A Reconciliation of SVAR and Narrative Estimates of Tax Multipliers." *Journal of Monetary Economics* 68, S1-S19.

[45] Mitnik, Stefan and Willi Semmler. 2012. "Regime Dependence of the Fiscal Multiplier." *Journal of Economic Behavior and Organization* 83, 502-522.

[46] Monacelli, Tommaso, and Roberto Perotti. 2008. "Fiscal policy, wealth effects, and markups." *National Bureau of Economic Research* No. w14584.

[47] Mounford, Andrew, and Harald Uhlig. 2009. "What are the effects of fiscal policy shocks?" *Journal of Applied Econometrics* 24(6), 960-992.

[48] Nakata, Taisuke. 2013. "Optimal fiscal and monetary policy with occasionally binding zero bound constraints." Finance and Economics Discussion Series 2013-40. Board of Governors of the Federal Reserve System.

[49] Owyang, Michael T., Valerie A. Ramey, and Sarah Zubairy. "Are Government Spending Multipliers Greater during Periods of Slack? Evidence from Twentieth-Century Historical Data." *American Economic Review* 103(3), 129-34.

[50] Parker, Jonathan. 2011. "On Measuring the Effects of Fiscal Policy in Recessions." *Journal of Economic Literature* 49(3), 703-718.

[51] Perotti, Roberto. 2012. "The Effects of Tax Shocks on Output: Not So Large, But Not Small Either". emphAmerican Economic Journal: Economic Policy 4(2), 214237.

[52] Ramey, Valerie A., and Matthew D. Shapiro. 1998. "Costly capital reallocation and the effects of government spending." *Carnegie-Rochester Conference Series on Public Policy* 48.

[53] Ramey, Valerie A. 2011. "Identifying Government Spending Shocks: It's all in the Timing." *The Quarterly Journal of Economics* 126(1), 1-50.

[54] Romer, Christina and David Romer. 2010. "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks" *American Economic Review* 100(3), 763-801.

[55] Schmitt-Grohe, Stephanie and Martin Uribe. 2006. "Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model." *NBER Macroeconomics Annual 2005* Mark Gertler and Kenneth Rogoff, eds. Cambridge, MA: 383-425.

[56] Sims, Eric and Jonathan Wolff. 2015. "The Output and Welfare Effects of Government Spending Shocks over the Business Cycle." Working Paper.

[57] Steigerwald, Douglas and Charles Stuart. 1997. "Econometric Estimation of Foresight: Tax Policy and Investment in the United States." *The Review of Economics and Statistics* 79(1), 32-40.

[58] Smets, Frank, and Raf Wouters. 2003. "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association* 1(5), 1123-1175.

[59] Smets, Frank and Raf Wouters. 2007. "Shocks and Frictions in U.S. Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97(3), 586-606.

[60] Traum, Nora and Shu-Chun Yang. 2013. "When Does Government Debt Crowd Out Investment?" Forthcoming, *Journal of Applied Econometrics.*

[61] Uhlig, Harald. 2010. "Some fiscal calculus." *The American Economic Review* 100(2), 30-34.

[62] Woodford, Michael. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton, NJ: Princeton University Press.

[63] Woodford, Michael. 2011. "Simple Analytics of the Government Expenditure Multiplier." *American Economics Journal: Macroeconomics* 3(1), 1-35.

[64] Yang, Shu-Chun Susan. 2005. "Quantifying tax effects under policy foresight." *Journal of Monetary Economics* 52, 1557-1568.

[65] Zubairy, Sarah. 2014. "On Fiscal Multipliers: Estimates from a Medium Scale DSGE Model." *International Economic Review* 55(1), 169-195.

Table 1: Estimated Parameters
Medium Scale Model

		Prior		Posterior		
Parameter	Dist.	Mean	SE	Mode	Mean	Std Dev
b	Beta	0.7000	0.1000	0.6976	0.6698	0.0640
θ_w	Beta	0.7000	0.0500	0.8267	0.8011	0.0405
θ_p	Beta	0.7000	0.0500	0.6216	0.6271	0.0381
ϕ_y	Normal	0.1250	0.0250	0.1384	0.1410	0.0247
ϕ_π	Normal	1.5000	0.1000	1.5538	1.5459	0.0979
κ	Normal	4.0000	0.5000	4.3198	4.3207	0.4572
ζ_w	Beta	0.5000	0.0500	0.4918	0.5173	0.0507
ζ_p	Beta	0.5000	0.0500	0.4116	0.4126	0.0487
σ	Normal	2.0000	0.2500	2.4713	2.4957	0.2124
γ	Beta	0.3000	0.0500	0.1786	0.1926	0.0311
ρ_i	Beta	0.7000	0.1000	0.8334	0.8284	0.0188
ρ_a	Beta	0.7000	0.1000	0.9413	0.9407	0.0253
ρ_z	Beta	0.7000	0.1000	0.8298	0.8094	0.0483
ρ_ν	Beta	0.7000	0.1000	0.6537	0.6622	0.0773
ρ_g	Beta	0.7000	0.1000	0.8041	0.8197	0.0537
s_i	Inv. Gamma	0.0050	0.0025	0.0017	0.0017	0.0001
s_a	Inv. Gamma	0.0050	0.0025	0.0055	0.0058	0.0008
s_z	Inv. Gamma	0.0050	0.0025	0.0245	0.0260	0.0039
s_ν	Inv. Gamma	0.0050	0.0025	0.0186	0.0183	0.0045
s_g	Inv. Gamma	0.0050	0.0025	0.0104	0.0114	0.0015

Note: The log-posterior density is 1,974.717761. The posterior is generated with 20,000 random walk Metropolis Hastings draws with an acceptance rate of approximately 21 percent. Series include GDP growth, Federal Funds Target Rate, Inflation, Investment Growth, and Consumption Growth. GDP, Investment, and Consumption are detrended and converted to real terms using the quarterly GDP Delfator. All data is quarterly and covers the period 1985q1 through 2008q4.

Table 2: State Dependent Output Multipliers

Baseline Estimated Model

	Multiplier				
	Min	Max	Mean	Std Dev	corr($\ln \mathrm{Y}_t$)
Consumption					
Impact Output	0.2316	0.2419	0.2375	0.0016	0.0601
Max Output	0.6043	0.6478	0.6237	0.0066	-0.2251
Labor					
Impact Output	0.2576	0.3779	0.3059	0.0204	0.1279
Max Output	1.2659	1.5603	1.3918	0.0584	0.1702
Capital					
Impact Output	1.3086	1.6511	1.4314	0.0569	0.2082
Max Output	2.5361	3.0827	2.7417	0.0990	0.3341

Note: This table shows output multiplier summary statistics generated by simulations of the DSGE model described in Section 2. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

Table 3: State Dependent Output Multipliers

Steady State Tax Revenue Response

	Multiplier				
	Min	Max	Mean	Std Dev	corr($\ln \mathrm{Y}_t$)
Consumption					
Impact Output	0.2157	0.2620	0.2362	0.0086	0.6411
Max Output	0.5781	0.6717	0.6202	0.0190	0.6643
Labor					
Impact Output	0.2439	0.3694	0.2982	0.0231	0.6662
Max Output	1.2009	1.5857	1.3574	0.0838	0.8114
Capital					
Impact Output	1.2824	1.7118	1.4187	0.0817	0.8849
Max Output	2.4439	3.2559	2.7185	0.1664	0.8941

Note: This table shows output multiplier summary statistics generated by simulations of the baseline model outlined in Section 2 using the steady state tax revenue response. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

Table 4: State Dependent Welfare Multipliers

Baseline Estimated Model

	Multiplier					
	Min	Max	Mean	Std Dev	corr(ln Y_t)	corr(Y Mult)
Consumption						
Welfare	4.4626	5.3682	5.0184	0.1752	-0.6781	0.3030
Labor						
Welfare	7.8969	9.9059	9.2248	0.3908	-0.9756	-0.2355
Capital						
Welfare	12.2237	15.6061	14.2972	0.6383	-0.9431	-0.3621

Note: This table shows welfare multiplier summary statistics generated by simulations of the DSGE model described in Section 2. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

Table 5: 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	0.5830	0.6376	0.6107	0.0088	-0.7805	0.8122
		τ_n	1.3193	1.6522	1.4592	0.0632	0.2516	-0.1918
		τ_k	2.6337	3.3193	2.9014	0.1191	0.3693	-0.2725
	Welfare Mult.	τ_c	4.5029	5.3443	5.0077	0.1510	-0.6473	1
		τ_n	8.0899	10.1219	9.4184	0.3708	-0.9702	1
		τ_k	12.7025	15.9300	14.6813	0.5960	-0.9373	1
$\theta_w = 0.66$	Output Mult.	τ_c	0.6409	0.6865	0.6618	0.0067	-0.0396	0.3950
		τ_n	1.3988	1.6799	1.5235	0.0572	0.2218	-0.2598
		τ_k	2.2461	2.7108	2.4402	0.0838	0.2482	-0.2384
	Welfare Mult.	τ_c	4.5766	5.4660	5.0703	0.1780	-0.6270	1
		τ_n	8.4621	10.3430	9.6017	0.3714	-0.9763	1
		τ_k	11.7365	14.6085	13.5117	0.5308	-0.9477	1
$\theta_p = 0.25$	Output Mult.	τ_c	0.6076	0.6508	0.6277	0.0064	-0.1296	0.1950
		τ_n	1.2854	1.5992	1.4146	0.0620	0.2246	-0.2631
		τ_k	2.9709	3.7060	3.2675	0.1373	0.4202	-0.2797
	Welfare Mult.	τ_c	4.4563	5.3485	5.0069	0.1703	-0.6766	1
		τ_n	8.0946	10.1288	9.4048	0.3841	-0.9713	1
		τ_k	14.4509	18.3860	16.8326	0.6997	-0.9078	1
$\psi_1 = 1000$	Output Mult.	τ_c	0.4029	0.4328	0.4181	0.0049	0.3663	-0.1698
		τ_n	0.8127	0.8886	0.8528	0.0136	0.1685	-0.1889
		τ_k	0.5184	0.6117	0.5588	0.0162	-0.6712	0.6259
	Welfare Mult.	τ_c	3.2288	3.9005	3.6974	0.1206	-0.8671	1
		τ_n	7.2928	9.0217	8.4274	0.3303	-0.9779	1
		τ_k	4.5692	5.8947	5.4516	0.2221	-0.8709	1
$\gamma = 0.36$	Output Mult.	τ_c	0.4720	0.5018	0.4857	0.0051	-0.2310	0.0587
		τ_n	0.8921	1.0867	0.9829	0.0397	0.0735	-0.2447
		τ_k	2.0494	2.4152	2.2010	0.0690	0.1576	-0.2744
	Welfare Mult.	τ_c	3.3710	4.1103	3.8104	0.1495	-0.7393	1
		τ_n	6.0474	7.6777	7.0390	0.3239	-0.9675	1
		τ_k	10.1229	13.2548	12.0641	0.6029	-0.9305	1
$\phi_\pi = 2.5$	Output Mult.	τ_c	0.6005	0.6425	0.6206	0.0065	-0.2547	0.3929
		τ_n	1.3166	1.5915	1.4358	0.0576	0.2242	-0.2452
		τ_k	2.7064	3.3821	2.9457	0.1163	0.3354	-0.3173
	Welfare Mult.	τ_c	4.4108	5.3489	4.9771	0.1840	-0.6794	1
		τ_n	8.1069	10.1720	9.4943	0.3817	-0.9743	1
		τ_k	12.8596	16.3259	14.9321	0.6121	-0.9366	1

Note: This table shows output and welfare multiplier summary statistics generated by simulations of the DSGE model described in Section 2 using alternative parameterizations as noted by the left-most column. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

Table 6: 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	0.6078	0.7068	0.6518	0.0203	0.6743	-0.5401
		3 Quarters	0.6260	0.7243	0.6693	0.0204	0.6890	-0.5664
		4 Quarters	0.6427	0.7417	0.6855	0.0207	0.7020	-0.5922
		5 Quarters	0.6512	0.7508	0.6943	0.0211	0.7104	-0.6046
		6 Quarters	0.6604	0.7590	0.7036	0.0207	0.7225	-0.6203
	Welfare Mult.	2 Quarters	4.9585	5.1136	5.0600	0.0269	-0.2309	1
		3 Quarters	5.0566	5.2027	5.1540	0.0256	-0.2200	1
		4 Quarters	5.1200	5.2586	5.2113	0.0240	-0.2091	1
		5 Quarters	5.1537	5.2854	5.2387	0.0229	-0.2053	1
		6 Quarters	5.1708	5.2961	5.2503	0.0222	-0.2071	1
Labor Tax Shock	Output Mult.	2 Quarters	1.2620	1.6688	1.4274	0.0890	0.8237	-0.5241
		3 Quarters	1.2928	1.7004	1.4610	0.0882	0.8232	-0.5652
		4 Quarters	1.3232	1.7164	1.4897	0.0856	0.8204	-0.6240
		5 Quarters	1.3252	1.7038	1.4903	0.0827	0.8163	-0.6953
		6 Quarters	1.3305	1.6940	1.4910	0.0785	0.8113	-0.7644
	Welfare Mult.	2 Quarters	9.0014	9.4629	9.2663	0.0928	-0.0361	1
		3 Quarters	9.3294	9.7803	9.5814	0.0952	-0.1043	1
		4 Quarters	9.5908	10.0325	9.8339	0.0980	-0.1945	1
		5 Quarters	9.7532	10.2175	10.0121	0.1019	-0.3000	1
		6 Quarters	9.8290	10.3484	10.1303	0.1067	-0.4049	1
Capital Tax Shock	Output Mult.	2 Quarters	2.5283	3.4085	2.8273	0.1812	0.8945	-0.4088
		3 Quarters	2.5975	3.4532	2.8920	0.1764	0.8917	-0.4464
		4 Quarters	2.6582	3.4685	2.9291	0.1646	0.8866	-0.4928
		5 Quarters	2.6670	3.4398	2.9210	0.1566	0.8816	-0.5502
		6 Quarters	2.6816	3.3948	2.9158	0.1426	0.8766	-0.5966
	Welfare Mult.	2 Quarters	13.5245	14.8460	14.2943	0.2182	-0.1085	1
		3 Quarters	13.8432	15.1603	14.6086	0.2215	-0.1604	1
		4 Quarters	14.1254	15.4394	14.8919	0.2278	-0.2217	1
		5 Quarters	14.2179	15.4994	14.9675	0.2318	-0.2920	1
		6 Quarters	14.2274	15.5099	14.9980	0.2379	-0.3602	1

This table shows output and welfare multiplier summary statistics generated by simulations of the DSGE model described in Section 2 augmented with a delayed tax implementation. The length of the anticipation horizon is found in the left-most column. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

Table 7: Output and Welfare Multipliers, Tax Shocks

No Lump Sum Taxes

			Multiplier					
			Min	Max	Mean	Std Dev	corr($\ln \mathrm{Y}_t$)	corr(V Mult)
Mechanism: τ_c	Output Mult.	τ_c	0.5557	0.6092	0.5845	0.0100	0.0080	0.3185
		τ_n	1.2284	1.5014	1.3475	0.0543	0.2795	-0.3400
		τ_k	2.5163	3.0409	2.7236	0.0938	0.3618	-0.3187
	Welfare Mult.	τ_c	-2.4839	-1.6010	-1.9382	0.1794	0.7309	1
		τ_n	2.9205	5.0552	3.9568	0.5407	-0.6856	1
		τ_k	8.1194	12.1314	10.2282	0.8475	-0.8257	1
Mechanism: τ_n	Output Mult.	τ_c	0.6706	0.7543	0.7078	0.0136	0.3349	-0.0797
		τ_n	1.3664	1.6536	1.4770	0.0551	-0.0807	0.4854
		τ_k	2.5712	3.0729	2.7801	0.0900	0.2877	-0.1648
	Welfare Mult.	τ_c	-5.6849	-3.2256	-4.1154	0.5896	0.6383	1
		τ_n	1.3527	3.9916	2.5006	0.7497	-0.5980	1
		τ_k	7.1604	10.9966	9.0321	0.8767	-0.8037	1
Mechanism: τ_n, τ_k	Output Mult.	τ_c	0.6530	0.7469	0.6967	0.0153	0.6217	0.5075
		τ_n	1.3153	1.5443	1.4355	0.0473	0.3802	-0.4430
		τ_k	2.5573	3.0465	2.7830	0.0858	0.1245	-0.0039
	Welfare Mult.	τ_c	-9.22933	-6.1924	-7.4717	0.7430	0.8023	1
		τ_n	-1.2920	1.0676	-0.2408	0.6335	-0.6784	1
		τ_k	4.6835	11.0661	7.3974	1.7351	-0.7768	1

Note: This table shows output and welfare multiplier summary statistics generated by simulations of the DSGE model described in Section 2 using altnerative fiscal financing mechanisms. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Three main panels are presented according to the financing mechanism employed. The first mechanism uses 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. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

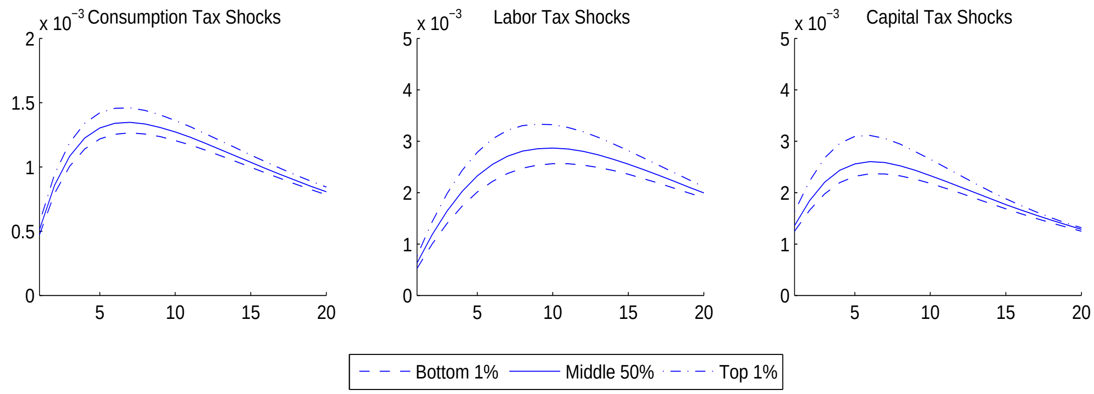
Table 8: Output and Welfare Multipliers, Tax Shocks

Rule-of-Thumb Household

			Multiplier					
			Min	Max	Mean	Std Dev	corr($\Delta \ln \mathrm{Y}_t$)	corr(V Mult)
$\lambda = 0.10$	Output Mult.	τ_c	0.6609	0.7027	0.6784	0.0063	-0.2461	0.2698
		τ_n	1.3506	1.6577	1.4775	0.0617	0.1906	-0.2330
		τ_k	2.2725	2.7986	2.4662	0.0963	0.4042	-0.4511
	Welfare Mult.	τ_c	4.8422	5.8413	5.3766	0.1922	-0.6896	1
		τ_n	8.3496	10.4821	9.7359	0.4166	-0.9796	1
		τ_k	10.8097	13.8129	12.6445	0.5739	-0.9487	1
$\lambda = 0.25$	Output Mult.	τ_c	0.7332	0.7734	0.7508	0.0063	-0.3368	0.2857
		τ_n	1.4764	1.8287	1.6208	0.0701	0.1426	-0.1320
		τ_k	1.8836	2.3216	2.0460	0.0814	0.3985	-0.4611
	Welfare Mult.	τ_c	5.4171	6.5053	5.9951	0.2132	-0.7023	1
		τ_n	9.3440	11.7932	10.9339	0.4774	-0.9810	1
		τ_k	8.9844	11.4841	10.5178	0.4781	-0.9526	1
$\lambda = 0.50$	Output Mult.	τ_c	0.9013	0.9436	0.9265	0.0066	-0.4978	0.2184
		τ_n	1.7768	2.2560	1.9681	0.0944	0.0370	0.0974
		τ_k	1.2346	1.5226	1.3367	0.0551	0.3803	-0.4712
	Welfare Mult.	τ_c	6.5492	7.8546	7.2634	0.2580	-0.7249	1
		τ_n	11.5709	14.9907	13.6912	0.6492	-0.9708	1
		τ_k	5.9017	7.55515	6.9216	0.3178	-0.9572	1

Note: This table shows output and welfare multiplier summary statistics generated by simulations of the baseline model outline in Section 2 augmented with a rule-of-thumb household type. The size of the rule-of-thumb population is declared by λ which is found in the left-most column. The magnitudes of all multipliers are multiplied by negative one for ease of analysis. Multiplier summary statistics are constructed via model simulation. We first simulate the state dependent model 1,000 times and then calculate multipliers for each tax shock at every point. For a detailed description of the simulation process, see Section 3.

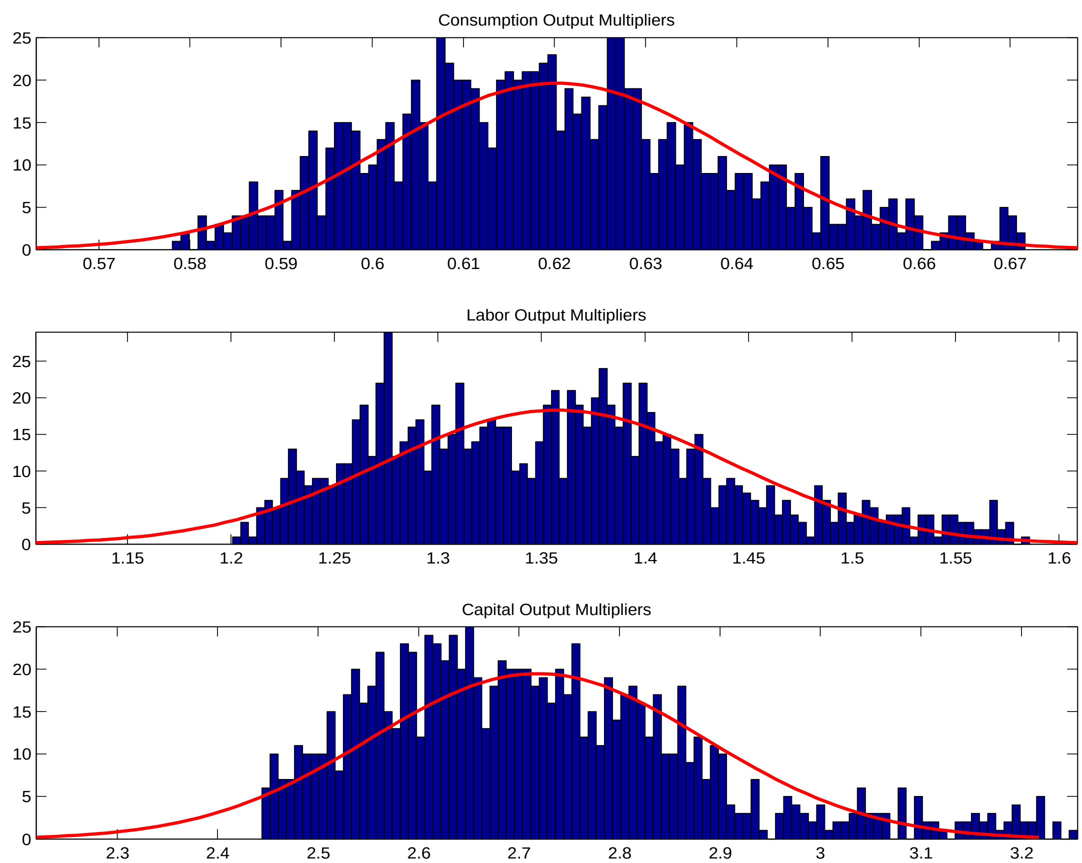
Figure 1: State Dependent Impulse Response Functions



Note: This figure plots state dependent impulse response functions of output to shocks in distortionary consumption, labor, and capital tax rates. In each figure, the dashed line represents the average output response to a one standard deviation shock when output is in the bottom 1% over a 1,000 period simulation. The solid and dash-dotted line represent the corresponding lines when output is in the 50% and 99% response, respectively.

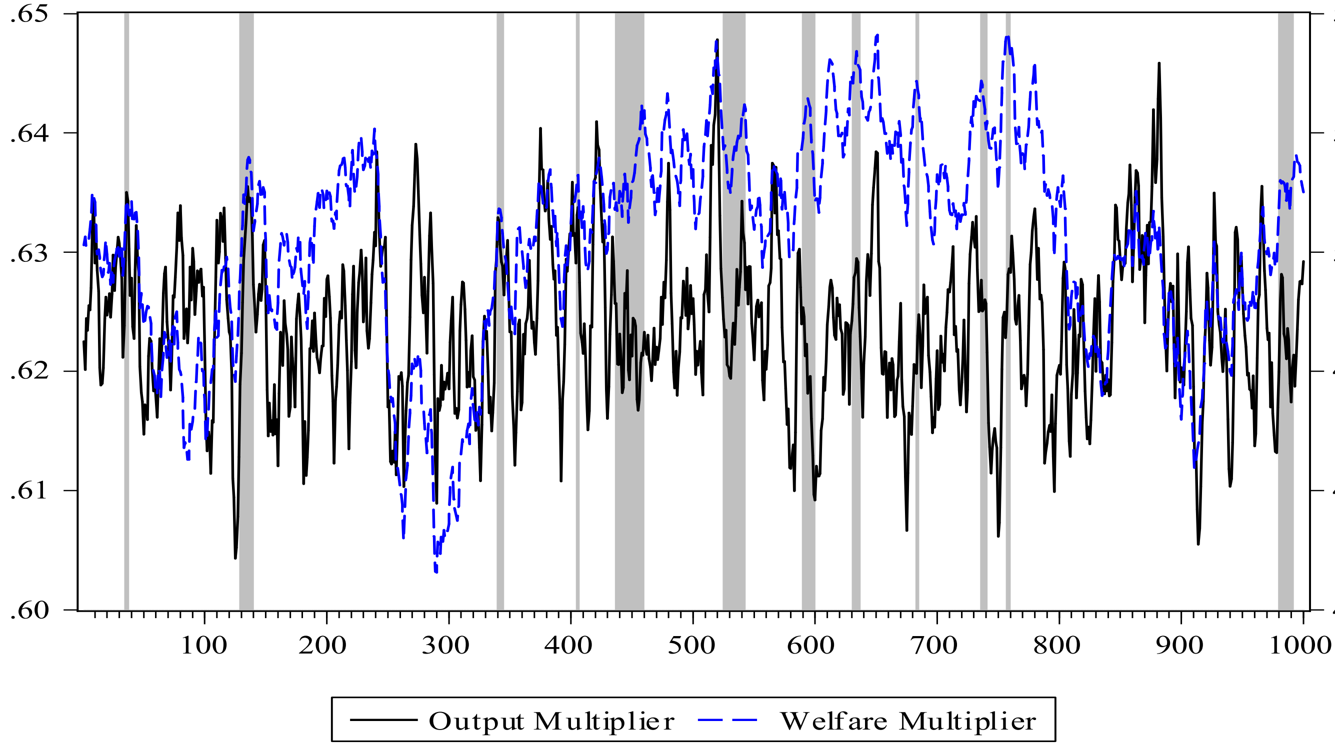
Figure 2: Output Multiplier Distribution

Steady State Tax Revenue Response



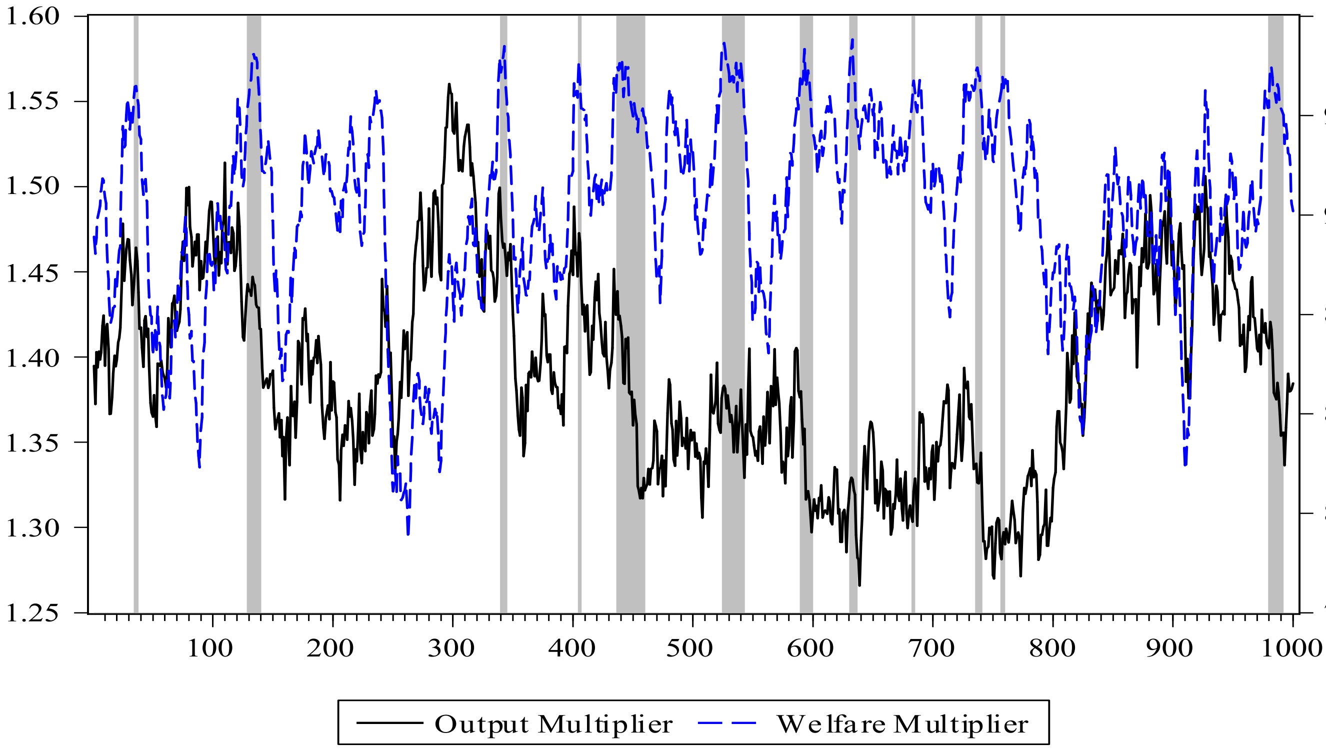
Note: This figure plots three separate histograms displaying the dispersion in consumption, labor, and capital tax output responses over the state space. Multiplier definitions employ the steady state response of tax revenue; as a result, all dispersion shown is directly attributed to variation in the output response over the state space. We fit a normal distribution to each histogram for illustrative purposes.

Figure 3: Simulated Output and Welfare Multipliers
Consumption Tax Shocks



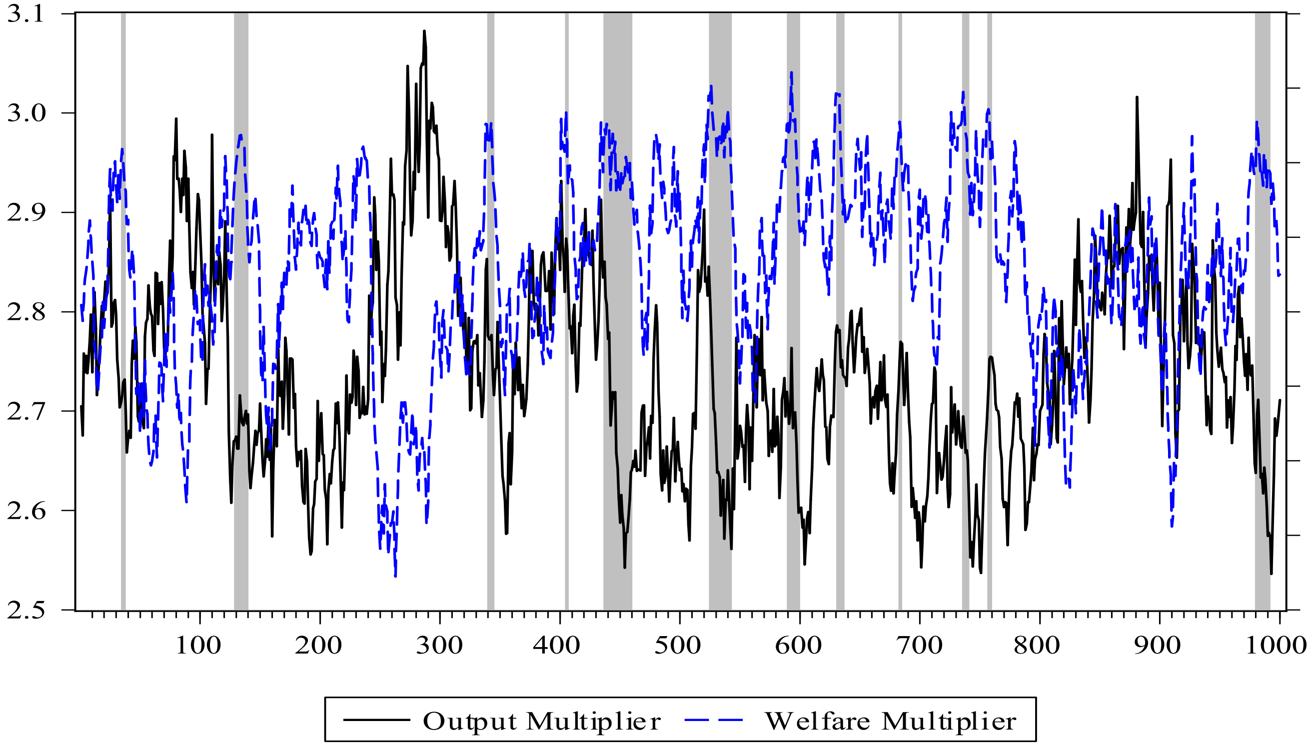
Note: This figure plots simulated time series for the output multiplier and welfare multiplier in response to a consumption tax shock. These simulations are conducted using the estimated parameter values starting from the non-stochastic steady state. Vertical gray-shaded areas denote periods when the level of output is in its lowest 10th percentile, meant to proxy for periods of recession. A third order perturbation method is used to generate the multipliers in this figure.

Figure 4: Simulated Output and Welfare Multipliers
Labor Tax Shocks



Note: This figure plots simulated time series for the output multiplier and welfare multiplier in response to a labor tax shock. These simulations are conducted using the estimated parameter values starting from the non-stochastic steady state. Vertical gray-shaded areas denote periods when the level of output is in its lowest 10th percentile, meant to proxy for periods of recession. A third order perturbation method is used to generate the multipliers in this figure.

Figure 5: Simulated Output and Welfare Multipliers
Capital Tax Shocks



Note: This figure plots simulated time series for the output multiplier and welfare multiplier in response to a capital tax shock. These simulations are conducted using the estimated parameter values starting from the non-stochastic steady state. Vertical gray-shaded areas denote periods when the level of output is in its lowest 10th percentile, meant to proxy for periods of recession. A third order perturbation method is used to generate the multipliers in this figure.