The State-Dependent Effects of Tax Shocks[*]

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Abstract

This paper studies the state-dependent effects of shocks to tax rates. We begin with a stylized model in which clean analytical expressions are available. The model predicts that a tax rate cut is most stimulative for output in periods in which output is relatively high. The model is also used to discuss some conceptual issues related to the construction of tax multipliers. We then consider a medium-scale DSGE model with tax rates on labor and capital income and on consumption. The model is solved via a third order perturbation. Consonant with the intuition from the analytical model, tax multipliers for all three types of tax rates vary significantly across states, and are most stimulative for output in states in which output is high. To evaluate the normative desirability of tax cuts as a tool to combat recessions, we also study the properties of the tax cut welfare multiplier, which measures the change in aggregate welfare conditional on a tax rate change. In contrast to output multipliers, welfare multipliers are found to be countercyclical. A number of extensions and modifications are considered and our conclusions are generally robust.

JEL Classification: E30, E60, E62

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1 Introduction

Recent events have sparked a 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 countries in the wake of the Great Recession. This paper studies the macroeconomic effects of cuts to tax rates. We seek to provide answers to the following questions. How stimulative are tax cuts for output? How much do these effects vary over the business cycle? Are tax cuts more or less effective at stimulating output during periods of recession? From a normative perspective, is it desirable to cut tax rates during periods in which output is low?

We ultimately wish to provide quantitative answers to the questions posed in the paragraph above, but we begin in Section 3 by studying a highly stylized model. The model is static and features a tax rate on labor income. Other than the tax rate, the model is frictionless. The simplified nature of the model allows us to derive analytical expressions for the output effects of a cut in the tax rate. Under some common assumptions about preferences, we show that tax cuts should have large effects on output in periods in which output is relatively high. Put differently, the stimulative nature of tax cuts ought to be procyclical. This is perhaps surprising given widespread belief and some empirical evidence suggesting that the effectiveness of fiscal stimulus (i.e. spending increases or tax cuts) is countercyclical. We also use the stylized model to highlight some conceptual issues involving the measurement of fiscal multipliers. It is common to quantify the output effects of tax rate changes using a "tax multiplier" defined as the change in output for a change in tax revenue, i.e. $\frac{dY_t}{dTR_t}$. We show that defining a multiplier in this way could give misleading results concerning the stimulative nature of tax cuts at different points of the business cycle. In addition, we point out some potential pitfalls involving the construction of tax multipliers in a state-dependent context by first measuring the elasticity of output with respect to tax revenue, i.e. $\frac{d\ln Y_t}{d\ln TR_t}$.

Building off the insights of the stylized model, in Section 4 we incorporate a detailed fiscal block into an otherwise conventional medium-scale dynamic stochastic general equilibrium (DSGE) model along the lines of Christiano, Eichenbaum and Evans (2005) or Smets and Wouters (2007). The model features a number of real and nominal frictions and several shocks. There are three different types of distortionary taxes – tax rates on capital and labor income and a tax rate on consumption. The model is fit to U.S. data by estimating a subset of its parameters using Bayesian methods and conventional calibration methods for those parameters which remain.

In Section 5 we solve the model via a third order perturbation. Our principal quantitative exercise involves first simulating state vectors from the model. We then shock the economy with cuts to each tax rate (one at a time in isolation) starting from each simulated vector of state variables. Because the model is solved via a perturbation higher than order one, how the change in tax rate impacts output and other endogenous variables will in general vary across different realizations of the state vector. We measure tax multipliers as the negative of the ratio of the output response to a tax rate cut divided by the tax revenue response to the same tax rate cut.[1] The output response

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[1]Here and throughout the remainder of the paper, tax multipliers are defined to be positive numbers. In our

is measured at different points in the state space, while the tax revenue response is evaluated in the non-stochastic steady state. This is motivated by our analysis in Section 3, where we show that scaling the output response to a tax rate cut in a particular realization of the state by the tax revenue response in that same state could give a misleading sense of how the stimulative nature of tax rate cuts changes over time. Scaling the output response by the tax revenue response evaluated in the steady state gives our multipliers the same scale as traditionally defined tax multipliers, but correctly captures any state-dependence in the output response to a tax rate change. 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 following a change in a tax rate). These definitions follow Barro and Redlick (2011) and Mertens and Ravn (2012, 2014a). Because the maximum output response to a tax rate changes typically occurs several periods after impact, it is common to focus on the "maximum" multiplier (e.g. Chahrour, Schmitt-Grohé and Uribe 2012), and we follow suit throughout most of the paper.

The average values of consumption, labor, and capital tax cut (maximum) multipliers are 0.58, 0.97, and 1.51, respectively. That is, a change in the capital tax rate which would lower tax revenue by one (real) dollar in the steady state stimulates output by an average of 1.5 (real) dollars. We find that there is significant variation in the magnitudes of the multipliers across states. For example, the capital tax cut multiplier ranges from a low 1.09 to a high of 1.91, with a standard deviation of 0.15. The min-max range for the labor tax cut multiplier is 0.69-1.25 and it is 0.51-0.64 for the consumption tax cut multiplier. Tax cut multipliers for all three types of tax rates are strongly positively correlated with the simulated level of log output. This procyclicality is consistent with the intuition developed in Section 3. We quantitatively show that scaling the output response to a tax rate change by the tax revenue response in that same state can give misleading results. In particular, tax multipliers constructed in this manner are less volatile across states and are mildly countercyclical in comparison to multipliers constructed according to our baseline definition.

In our quantitative model tax cuts are least stimulative for output in periods in which output is low. Does this imply that countercyclical tax cuts are undesirable? To address this question, we construct what we call a "tax cut welfare multiplier." Rather than measuring the output response to a tax rate cut, this multiplier measures the consumption equivalent change in a measure of aggregate welfare in relation to the response of tax revenue. Welfare multipliers are large and positive in an average sense. This is unsurprising given that the equilibrium of the model is on average distorted compared to an efficient allocation. We find that the welfare multipliers for each type of tax rate are countercyclical in spite of the fact that output multipliers are positively correlated with the simulated level of output. The intuition for this result is that the economy is countercyclically distorted on average. Cutting a tax rate, which eases a policy-imposed distortion, is naturally most valuable in periods in which other distortions are relatively high. Nevertheless, there are some important nuances to our normative results. While welfare multipliers are robustly countercyclical

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model, the economy is always to the left of the peak of the "Laffer Curve," meaning that tax rate changes which cause output to rise always cause tax revenue to fall. Multiplying the ratio of these changes by negative one results in positive multipliers.

in an unconditional sense, the cyclicality can flip signs depending on which shocks are driving fluctuations.

Section 6 considers several different extensions to our medium-scale model. These extensions include alternative methods of fiscal finance, anticipation in tax rate changes, a rule-of-thumb household population, and the interaction between tax cuts and the stance of monetary policy. All of these extensions to the baseline model have been shown in other contexts to matter both quantitatively and qualitatively for the magnitudes of tax cut multipliers. They do so in our framework as well. While we find that average values of tax cut multipliers are impacted by these extensions, our basic results concerning volatility across states and co-movement with the business cycle as measured by the level of output are generally unaffected.

2   Related Literature

There is a voluminous and growing literature on the macroeconomic effects of fiscal policy more generally and on the economic consequences of tax changes more specifically. Our objective is not to thoroughly review this literature. Rather, in this section we highlight a few papers which are highly relevant to ours and discuss the dimensions along which our paper builds upon, extends, and in some cases reaches different conclusions from existing work.

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), Braun (1994), and McGrattan (1994). Much of the recent literature is empirical in nature and seeks to measure tax multipliers using reduced form empirical techniques – see, for example, Blanchard and Perotti (2002), Romer and Romer (2010), Barro and Redlick (2011), and Mertens and Ravn (2012, 2014a). These papers produce a wide range of multipliers. Much of this literature centers on conflicting results from identifications based on recursive identifications in VARs (which tend to find relatively low multipliers, e.g. Blanchard and Perotti 2002) and narrative identifications (which tend to find much higher multipliers, e.g. Romer and Romer 2010). Our analysis does not directly speak to this empirical debate, since it is based on a quantitative study of a fully-specified DSGE model. In that sense, our paper is closer to recent work by Mertens and Ravn (2011), Chahrour, Schmitt-Grohé and Uribe (2012), and Leeper, Walker and Yang (2013), all of which are based on similar DSGE models.[2] These papers solve their models using linear approximations, and hence cannot directly speak to state-dependence. Our paper builds off this work by studying variation in magnitudes of multipliers across states in a higher order approximation and also in studying the normative implications of tax rate changes.

There is also a growing literature studying state-dependent effects of fiscal shocks. This literature

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[2]Much of the DSGE-based literature focuses on issues related to anticipation (e.g. Steigerwald and Stuart 1997; Yang 2005; House and Shapiro 2008; Perotti 2012; Mertens and Ravn 2012; Leeper, Richter and Walker 2012; and Leeper, Walker and Yang 2013); the method of fiscal finance (e.g. Christ 1968; Leeper and Yang 2008; and Leeper, Plante and Traum 2010); the role of credit market imperfections (e.g. Agarwal, Liu and Souleles 2007; Galí, López-Salido and Vallés 2007; and McKay and Reis 2016); and the stance of monetary policy (e.g. Eggertsson 2011 and Mertens and Ravn 2014b). We consider all of these issues in Section 6.

is primarily empirical in nature, relying on reduced-form VARs and related time series models. The majority of this literature focuses on measuring state-dependent government spending multipliers – see, for example, Auerbach and Gorodnichenko (2012), Bachmann and Sims (2012), Mittnik and Semmler (2012), and Ramey and Zubairy (2017), among others. There are a few papers which study state-dependent tax multipliers in reduced-form time series models. These include Candelon and Lieb (2013) and Arin, Koray and Spagnolo (2015), the latter of whom report that tax cut multipliers are largest in periods in which output is highest. This is consistent with our quantitative results. Candelon and Lieb (2013) find tax cut multipliers which are either higher or lower in a period of high output depending on the horizon over which the multiplier is measured. Hussain and Malik (2016) study whether increases and decreases in tax rates have differential effects. Dependence on the sign of tax shocks is not something on which we focus in this paper.

Our work expands upon the literature on fiscal multipliers in several ways. We provide the first analysis (of which we are aware) of tax multiplier state-dependence in a fully-specified DSGE framework. Most DSGE models used for fiscal policy analysis are solved using a linear approximation, and those which are not (e.g. Boneva, Braun and Waki 2016) do not focus on how multipliers vary across different states of the business cycle. Most of the rest of the work on state-dependence is based on reduced-form time series models. Our paper provides a natural bridge between these literatures, though we do not try to explicitly write down a model to match any empirical findings from the time series literature.

The definition and construction of tax multipliers are issues which are generally overlooked in the literature but which we highlight in this paper. Tax cut multipliers are typically expressed as ratios of output responses to a tax rate change divided by the total tax revenue response. Dividing by total tax revenue is a normalization meant to facilitate comparison to the literature on government spending multipliers. In a non-linear model in which state-dependence is present, scaling by tax revenue could give a misleading sense of how the output effects of tax rate cuts change across states. This is because tax revenue is endogenous to the business cycle, which is typically not the case for government spending where most models assume an exogenous spending process. An important contribution of our paper is to show how one scales tax cut multipliers can have an important effect on inferences one might draw about how multipliers vary across states. In this respect our paper is similar to Ramey and Zubairy (2017), who argue that the common practice of converting elasticities into multipliers in the government spending literature is potentially problematic in models of state-dependence.

This paper shares some similarities with Sims and Wolff (2018), who study the state-dependence of government spending multipliers in a medium-scale DSGE model. Aside from its focus on tax multipliers instead of spending multipliers, the present paper expands upon our earlier work in a few important ways. First, we provide clean analytical intuition which suggests that tax multipliers might vary more across states than do spending multipliers. The analytical intuition is borne out in our quantitative analysis, where we find that tax cut multipliers vary substantially across states, whereas spending multipliers do not. Second, though we borrow the terminology "welfare multiplier"

to study the normative desirability of tax rate changes across the business cycle, our findings for tax rates are different than for government spending. Whereas Sims and Wolff (2018) argue that welfare multipliers for government spending are procyclical, we find that tax cut welfare multipliers are countercyclical in an unconditional sense. From a policy perspective, tax cuts during a recession are therefore more desirable than countercyclical spending increases, at least viewed through the lens of our model. This normative result concerning tax cut welfare multipliers is all the more interesting because we find the opposite pattern for output multipliers, where tax cuts are generally least stimulative for output during periods of recession.

3   Intuition in a Simple Model

In this section we present a stylized model. The purpose of doing so is to build some intuition for how and why changes in tax rates might impact output differentially over the business cycle. We also use the model to highlight some conceptual difficulties in how tax multipliers are defined and how traditional definitions from the literature might give a misleading sense of how the stimulative nature of tax rate changes might vary across the business cycle. We also use the model to provide some intuition for why tax cut multipliers might vary more across states than does the government spending multiplier. The simple model is not meant to provide any definitive answers, but rather serves as intuition and motivation for the quantitative analysis which follows.

The model features a representative household, a representative firm, and a government. The household receives a utility flow from consumption and disutility from labor. The firm produces output using a linear technology in labor subject to an exogenous productivity variable. The government imposes a distortionary tax rate on labor income and consumes an exogenous fraction of output. Other than the distortionary tax rate on labor income, there are no frictions. The model features no endogenous state variables. As such, the model can be thought of as static.

Flow utility for the household is given by:

$$U = u(C_t) - h(N_t) \tag{1}$$

C_t is consumption and N_t is labor. We assume that $u'(\cdot) > 0$, $u''(\cdot) < 0$, $h'(\cdot) > 0$, and $h''(\cdot) \geq 0$. Let w_t be the real wage and τ_t be the tax rate on labor income. The optimality condition for the household is:

$$h'(N_t) = u'(C_t)(1 - \tau_t)w_t \tag{2}$$

The firm produces output according to a linear technology in labor and an exogenous productivity variable, A_t:

$$Y_t = A_t N_t \tag{3}$$

Optimizing behavior by the firm implies the labor demand condition:

$$w_t = A_t \tag{4}$$

Each period, the government consumes an exogenous fraction of output, $G_t = \phi_t Y_t$, where G_t is government spending and ϕ_t is the exogenous share of government spending in output (and is hence restricted to lie between zero and one). Tax revenue collected in period t is:

$$TR_t = \tau_t w_t N_t \tag{5}$$

Any difference between revenue and spending in period t is met by the issuance of one period government bonds. We implicitly assume that lump sum taxes adjust at some future date so that a no-Ponzi condition for the government holds. Because the model can be thought of as static, it does not matter when this adjustment occurs.

Market-clearing for this economy requires that $(1 - \phi_t)Y_t = C_t$. The market-clearing condition along with the household optimality condition, (2), production technology, (3), and labor demand function, (4), together implicitly determine Y_t as a function of exogenous variables:

$$h'\left(\frac{Y_t}{A_t}\right) = u'\left((1 - \phi_t)Y_t\right)(1 - \tau_t)A_t \tag{6}$$

Totally differentiate (6) about a point, where $dY_t = Y_t - Y$. Variables without time subscripts denote the point of approximation (note the point of approximation is not necessarily the steady state). Holding productivity and the government spending share of output fixed allows one to derive an expression for the "tax rate multiplier":

$$\frac{dY_t}{d\tau_t} = \frac{-u'(\cdot)A^2}{h''(\cdot) - u''(\cdot)(1 - \phi)(1 - \tau)A^2} \tag{7}$$

Given our assumptions on preferences, this tax rate multiplier is negative – i.e. increases in the tax rate on labor income result in output falling. As a signing convention, here and throughout the remainder of the paper we wish to focus on how output reacts to tax rate *cuts*, so we define the tax rate cut multiplier as the negative of this expression (which means that the tax rate cut multiplier is positive):

$$\left(\frac{dY_t}{d\tau_t}\right)^c = \frac{u'(\cdot)A^2}{h''(\cdot) - u''(\cdot)(1 - \phi)(1 - \tau)A^2} \tag{8}$$

Without further assumptions, it is not particularly straightforward to use (8) to build intuition for how the effects of tax cuts on output might vary across states (the state variables are A, ϕ, and τ). Some additional assumptions, however, permit a much cleaner expression. In particular, assume that disutility from labor is linear, so that $h''(\cdot) = 0$. This would be consistent, for example, with a model in which labor is indivisible (Hansen 1985). Furthermore, assume that flow utility over consumption is of the constant relative risk aversion form, so that $\sigma = \frac{-Cu''(C)}{u'(C)}$ is constant. Since $C = (1 - \phi)Y$, under these assumptions (8) reduces to:

$$\left(\frac{dY_t}{d\tau_t}\right)^c = \frac{Y}{(1-\tau)\sigma} \tag{9}$$

The simplified tax rate cut multiplier in (9) reveals three important points. First, the multiplier should not be constant. The multiplier will vary to the extent to which output, Y, and the tax rate, τ, vary.[3] Second, the effectiveness of tax cuts in stimulating output ought to be procyclical – in states where output is relatively high, the tax rate cut multiplier will be relatively high as well. Finally, the household's risk aversion parameter can amplify or mute the volatility of the multiplier across states.

It is most common to define a tax multiplier as a derivative of output with respect to total tax revenue, not a particular tax rate (see e.g. Blanchard and Perotti 2002 or Barro and Redlick 2011). In this simple model, tax revenue is simply proportional to output, $TR_t = \tau_t Y_t$, and hence $d\tau_t = \frac{1}{Y}dTR_t - \frac{\tau}{Y}dY_t$, where again variables without time subscripts denote the point of approximation. We can therefore transform (9) into the traditional definition of a tax multiplier, which yields the following expression:

$$\left(\frac{dY_t}{dTR_t}\right)^c = \frac{1}{(1-\tau)\sigma + \tau} \tag{10}$$

The traditional definition of a tax multiplier might give a misleading impression concerning how the effectiveness of tax cuts varies across states. In (9) we observe that the stimulative effect of a tax cut is positively related to the level of output. In (10), in contrast, the level of output is not directly relevant for the multiplier. The multiplier defined as in (10) only varies to the extent to which the tax rate itself varies across states. How variation in the tax rate across states impacts the multiplier is in turn impacted by the value of σ. For $\sigma = 1$, for example (i.e. log utility), the traditionally defined tax multiplier would be constant at 1. This is an issue which is relevant for existing empirical work. Arin, Koray and Spagnolo (2015), for example, estimate time-varying tax multipliers in a regime-switching VAR model. They find that tax cut are most stimulative for output in periods in which output is high. Because both numerator and denominator (i.e. dY_t and dTR_t, respectively) can be sources of state-dependence, if anything our analysis would suggest that they are understating the procyclical nature of tax cuts on output.

For the quantitative work which follows, we wish to adopt a definition of the tax rate cut multiplier which is as close as possible to the standard definition of a multiplier (i.e. (10)), but which nevertheless captures the state-dependence of the output response to tax cuts embodied in (9). We therefore define a modified definition of the tax rate cut multiplier as the ratio of the output response in a particular state to the response of a tax revenue *evaluated in the non-stochastic steady state*. In particular, we define $dTR^* = d\tau_t Y^* + \tau^* dY^*$ (i.e. we consider the same absolute change in the tax rate as above, but evaluate the change in revenue relative to the non-stochastic steady state). Continuing with our maintained assumptions, our modified tax rate cut multiplier can be written:

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[3]Output, Y, is not a state variable, but depends on the values of the states A, τ, and ϕ. Writing the expression in terms of output rather than the states is cleaner and facilitates building intuition.

$$\left(\frac{dY_t}{dTR^*}\right)^c = \frac{Y}{Y^*}\frac{1}{(1-\tau)\sigma+\tau^*} \tag{11}$$

Evaluated in the non-stochastic steady state, (11) is exactly the same as (10). But unlike the expression in (10), the modified multiplier in (11) will vary with Y in exactly the same way as (9). In other words, our modified multiplier will have the same scale (in an average sense) as the traditional definition of a tax multiplier, which facilitates comparison with other work. But it will capture the state-dependence associated with (9), which the traditionally defined multiplier would potentially miss.

Before concluding this section we wish to make two additional points. The first concerns the construction of multipliers by first measuring elasticities. In the empirical literature, it is common to not directly estimate multipliers but rather to first estimate the elasticity of output with respect to tax revenue, i.e. $\frac{d\ln Y_t}{d\ln TR_t}$, and then transform this by multiplying by the inverse of the average tax revenue share of output (see, for example, Blanchard and Perotti 2002 and Mountford and Uhlig 2009). Let variables with a superscript * denote non-stochastic steady state values. Then the tax cut multiplier so-defined in our model would be:

$$\left(\frac{d\ln Y_t}{d\ln TR_t}\frac{Y^*}{TR^*}\right)^c = \frac{\tau}{\tau^*}\frac{1}{(1-\tau)\sigma+\tau} \tag{12}$$

Evaluated in the non-stochastic steady state (12) would be identical to (10). But away from the steady state, the multiplier measured in this way could give misleading results. To see this clearly, suppose that $\sigma = 1$. Then (12) reduces to $\frac{\tau}{\tau^*}$. This would not be constant across states (unlike (10) with $\sigma = 1$), but would not move across states in the way that (9) or (11) do – in particular, the multiplier constructed by converting an elasticity would not directly vary with Y (whereas (9) and (11) co-vary positively with Y). The point that care must be taken when converting elasticities into multipliers echoes a similar criticism raised by Ramey and Zubairy (2017) applied to the empirical literature on state-dependent government spending multipliers. The conversion of an elasticity into a multiplier is what is done in Candelon and Lieb (2013), who estimate a regime-switching VECM model to empirically study the state-dependent effects of tax shocks. Our analytical results suggest that this approach could significantly bias results concerning how tax multipliers vary across states.

The second point we wish to make before closing this section concerns a comparison between the tax rate cut multiplier and the government spending multiplier. Setting $d\tau_t = 0$ and instead allowing government spending to change (where $dG_t = Y d\phi_t + \phi dY_t$), we get the following expression for the government spending multiplier:

$$\frac{dY_t}{dG_t} = \frac{-u''(\cdot)(1-\tau)A^2}{h''(\cdot)-u''(\cdot)(1-\tau)A^2} \tag{13}$$

This looks similar to (9) with two exceptions: (i) $(1-\tau)$ appears in the numerator here, and (ii) the numerator in (13) depends on the second derivative of the utility function with respect to consumption instead of the first. A similar analytical expression for the government spending

multiplier can be found in Woodford (2011). Given standard assumptions on preferences, the government spending multiplier is positive and must lie between zero and one. If we again assume that utility with respect to leisure is linear, the government spending multiplier reduces to:

$$\frac{dY_t}{dG_t} = 1 \tag{14}$$

In other words, the government spending multiplier is constant across states under exactly the same assumptions under which the tax rate cut multiplier varies across states. One would be tempted to conclude from this exercise that there ought to be more state-dependence in tax cut multipliers than in government spending multipliers. While this is in fact consistent with our quantitative results to follow, we wish to emphasize that we do not have a formal proof of this under more general assumptions; this result obtains in a stylized model and under somewhat restrictive assumptions about preferences. More generally, while we think that the simple model laid out in this section is useful for developing intuition and for pointing out some potential pitfalls in the measurement and construction of multipliers, to conclude much with confidence we need a more detailed theoretical model with a number of frictions parameterized to fit observed data. We turn to this exercise next.

4 A Medium Scale DSGE model

Although the simple framework from Section 3 is useful for building intuition, we wish to study a more detailed theoretical framework in order to produce plausible quantitative conclusions concerning the magnitudes and cyclicalities of tax multipliers. To that end, we consider a reasonably standard medium scale DSGE model along the lines of Christiano, Eichenbaum and Evans (2005), Schmitt-Grohé and Uribe (2005), Smets and Wouters (2007), and Justiniano, Primiceri and Tambalotti (2010, 2011). The model features both nominal frictions (price and wage stickiness) as well as real frictions (investment adjustment costs, habit formation, and variable capital utilization). The model also features a number of exogenous disturbances, including shocks to neutral productivity, the marginal efficiency of investment, preferences, and price and wage markups. In addition there are several distortionary tax rates. Monetary policy is characterized by a Taylor rule. Details of the firm and household blocks of the model can be found in Appendix A. In the text we focus only on the fiscal block of the model.

Fiscal policy in the model is governed by a system of spending, tax, and budget rules. The government chooses an exogenous sequence of spending, G_t. It can finance this spending and interest payments on debt with distortionary taxes on consumption, labor income, and capital income, as well as a lump sum tax. Any flow discrepancy between revenue and expenditure is settled via the issuance of new one period, non-state contingent bonds, $B_{g,t}$. The government's flow budget constraint in real terms is given by:

$$G_t + i_{t-1}\frac{B_{g,t-1}}{P_t} = \tau_{c,t}C_t + \tau_{n,t}w_tN_t + \tau_{k,t}r_t^k\widetilde{K}_t + T_t + \frac{B_{g,t} - B_{g,t-1}}{P_t} \tag{15}$$

In (15), i_t is the nominal interest rate and P_t is the nominal price of the final output good. r_t^k is the rental rate on capital services, $\widehat{K}_t$ (the product of physical capital and utilization). $\tau_{c,t}$, $\tau_{n,t}$, and $\tau_{k,t}$ are tax rates on consumption, labor income, and capital income. T_t is a lump sum tax. Government spending, G_t, is assumed to follow a stationary AR(1) process in the natural log:

$$\ln G_t = (1 - \rho_g) \ln G^* + \rho_g \ln G_{t-1} + s_g \varepsilon_{g,t}, \ \ 0 \le \rho_g < 1 \tag{16}$$

The shock $\varepsilon_{g,t}$ is drawn from a standard normal distribution and s_g is the standard deviation of the shock. Here and going forward variables with * superscripts denote non-stochastic steady state values.

We assume that the distortionary tax rates obey exogenous AR(1) processes. The shocks are drawn from standard normal distributions with standard deviations of s_j for $j = c, n, k$:

$$\tau_{j,t} = (1 - \rho_j)\tau_j^* + \rho_j \tau_{j,t-1} + s_j \varepsilon_{j,t}, \ \ 0 \le \rho_j < 1, \ \text{for} \ j = c, n, k \tag{17}$$

The lump sum tax obeys the following process:

$$T_t = (1 - \rho_T)T^* + \rho_T T_{t-1} + (1 - \rho_T)\gamma_T^b (B_{g,t-1} - B_g^*) + s_T \varepsilon_{T,t}, \ \ 0 \le \rho_T < 1, \ \ \gamma_T^b > 0 \tag{18}$$

The lump sum tax follows an AR(1) process with non-stochastic steady state value of T^* and shock drawn from a standard normal distribution with standard deviation s_T. The lump sum tax reacts to deviations of government debt, $B_{g,t-1}$, from an exogenous steady state target, B_g^*. The reaction is governed by the parameter γ_T^b. Because we assume that the distortionary tax rates follow purely exogenous processes, the exact value of γ_T^b is only important insofar that it renders the path of government debt non-explosive. In Section 6, we will consider alternative specifications in which lump sum taxes are unavailable and distortionary tax rates must adjust so as to produce a non-explosive path of government debt.

The model as laid out in the Appendix A features a number of parameters. Some of these are calibrated to match long run targets or to conventional values in the literature, while the remaining are estimated via Bayesian methods.[4] Values of calibrated parameters are listed in Table 1. These parameters include the discount factor, exponent on capital services in the production function, the depreciation rate, the trend inflation rate, and terms related to the capital utilization cost function. Steady state government spending is chosen so that the steady state share of government spending in output is 20 percent. We also calibrate steady state values of the three distortionary tax rates. We construct historical tax rate series using data from the national income and product accounts (NIPA) following Leeper, Plante and Traum (2010).[5] This results in steady state values of $\tau_c^* = 0.0169$,

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[4]To estimate the model, we employ Bayesian methods using a first order approximation of the model. While estimating the non-linear version of the model is desirable, estimating a non-linear model with the number of state variables specified above is computationally challenging. Parameters estimated using the linear approximation of the model are then used to solve the model via higher order perturbation.

[5]We direct the reader to the Appendix accompanying Leeper, Plante and Traum (2010) for detailed instructions to construct these series.

$\tau_n^* = 0.2104$, and $\tau_k^* = 0.1975$. 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 the lump sum tax, T^*, is chosen to be consistent with a steady state government debt-gdp ratio of 50 percent. The parameter $\gamma_b^T = 0.05$ results in non-explosive debt dynamics.

Other parameters of the model are estimated via Bayesian methods. Estimation results are presented in Table 2. Descriptions and assumed prior distributions for each parameter are listed in the left columns of the table. Means and 95 percent confidence intervals for each estimated parameter appear under the column heading "Baseline." Remaining columns of the table pertain to estimation exercises for different extensions to be considered in Section 6. Parameters not estimated in the baseline analysis are indicated by a "-" marker.

Our estimation strategy employs U.S. data covering the period 1984q1 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 eleven observable aggregate series in the estimation, corresponding to the number of shocks in the model to be estimated. We follow Leeper, Plante and Traum (2010) in the choice of observables. These series include the growth rates of consumption, investment, labor, government spending, and government debt as well as the levels of inflation, the nominal interest rate, and the growth rates of tax revenue from lump sum, consumption, labor, and capital taxes. Where applicable, series are from the BEA's national income and product accounts. Consumption is defined as the sum of personal consumption expenditures on nondurable goods and services. Investment is the sum of personal consumption expenditures on durable goods and gross private fixed investment. Hours worked is constructed as the product of average weekly hours in the non-farm business sector with total civilian employment aged sixteen and over. The nominal interest rate is the three month Treasury Bill rate. Inflation is the growth rate of the price index for personal consumption expenditures. Nominal series are converted to real by deflating by this price index and, where relevant, series are converted to per-capita terms by dividing by the civilian non-institutional population aged sixteen and over.

Table 2 displays the results of our estimation. The estimated parameters are largely in-line with existing parameter estimates in the literature.[6] The estimated price and wage rigidity parameters imply mean durations between price and wage changes of about 3.6 and 2 quarters, respectively. We find modest amounts of price and wage indexation. The estimated habit formation parameter is $b = 0.75$, which is quite standard. Our estimated values for the parameters governing curvature in preferences are $\gamma = 0.24$ and $\sigma = 2.40$. These are similar to the assumed values in Christiano, Eichenbaum and Rebelo (2011). Our baseline estimate of the investment adjustment cost parameter is $\kappa = 4.11$, also a relatively standard value in the literature. The estimated Taylor rule features a smoothing component $\rho_i = 0.75$, a strong reaction to inflation ($\phi_\pi = 1.63$), and a modest reaction to

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[6]We henceforth engage in a minor abuse of terminology and consider the mean of the posterior distribution of parameters as "the" estimated parameter values.

output growth (ϕ_y = 0.13). Remaining persistence parameters and standard deviations of shocks are found in the second section of Table 2.

Overall, the model solved at the mean of the estimated 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 percent as volatile as output, and investment growth is about 3 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 account for approximately 30 percent of the unconditional variance of output growth. Likewise, price markup shocks count for approximately 35 percent of output's variance. The next most important sources of output volatility are preference shocks, monetary policy shocks, and government spending shocks, which explain nearly 30 percent of the output growth's volatility. Wage markup shocks and the different tax shocks account for the remaining 9 percent.

5   Quantitative Results

In this section, we simulate the model outlined and parameterized in the previous section and Appendix A to quantify the effects of tax cuts on output over the state space. We also examine the movements of what we call the "welfare multiplier" for tax cuts over the business cycle. We begin by briefly outlining the solution and simulation methodology. We then provide formal definitions of the tax rate cut multipliers, based on the analysis from Section 3. We then present and discuss results.

5.1   Solution Methodology and Multiplier Definitions

We solve the model at the mean of the posterior distribution of the parameters via third order perturbation.[7] Solving the model via a perturbation of order higher than one is necessary to examine state-dependence. To construct tax multipliers, we first generate impulse response functions to each tax shock. The impulse response function of the vector of endogenous variables, $\mathbf{X}_t$, to a shock to tax rate j, is defined as follows:

$$\mathbf{IRF}(h) = \{\mathbb{E}_t \, \mathbf{X}_{t+h} - \mathbb{E}_{t-1} \, \mathbf{X}_{t+h} \mid \varepsilon_{j,t} = -1, \mathcal{S}_{t-1}\} \tag{19}$$

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 $t-1$, conditional on the realization of a negative shock in period t.[8] In a higher order perturbation, the impulse response function in principle depends upon the initial realization of the state, $\mathcal{S}_{t-1}$, in which a shock hits. It may also depend on the size and sign of the shock, though we do not focus on these elements at this time.

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[7] Our results are quite similar if we instead use a second order perturbation.

[8] Recall that the shocks are drawn from a standard normal distribution and then are scaled by the s_j, so this corresponds to a one standard deviation negative shock to a tax rate.

Given our non-linear solution methodology, these impulse responses are computed via simulation. First, we start with an initial realization of the state, $\mathcal{S}_{t-1}$ (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 out to horizon H yields $\mathbb{E}_{t-1}\mathbf{X}_{t+h}$, for $h = 0, \ldots, H$. We then repeat this process, but subtract 1 from the realization of the jth shock in the first period of each simulation.[9] Averaging across the N simulations with the shock in the first period yields $\mathbb{E}_t\mathbf{X}_{t+h} \mid \varepsilon_{j,t} = -1$. The difference between these two constructs is the impulse response function. Computing these impulse response functions for different initial values of the state, $\mathcal{S}_{t-1}$, is the means by which we examine state-dependence. The states themselves (other than the non-stochastic steady state) are generated via simulation.

We define the "output multiplier" for a cut in a distortionary tax rate as the ratio of the change in output to a change in tax revenue following a tax shock, multiplied by negative one. Multiplying by negative one makes the multipliers positive. As discussed at length in Section 3, we scale the output response (at a particular realization of the state, $\mathcal{S}_{t-1}$), by the tax revenue response to a tax rate cut *evaluated in the non-stochastic steady state*. This ensures that any movements in the multiplier over the state space come from differences in the output response to a tax cut across states, not differences in the tax revenue response to a tax rate cut. We define output multipliers for $h = 0, \ldots, H$ forecast horizons where $H = 20$. Formally, the output multiplier to tax shock j at forecast horizon h is defined as:

$$YM_j(h)^c = -\frac{dY_{t+h}}{dTR^*}\bigg|\varepsilon_{j,t} = -1, \mathcal{S}_{t-1} \quad \text{for } j = c,\, n,\, \text{or } k \tag{20}$$

The presentation of our results focuses on two multiplier horizons: the "impact" multiplier, which sets $h = 0$, and the "max" multiplier, which is defined as the ratio of the maximum output response to the steady state revenue response.[10] As it is based on the impulse response function of output, the multiplier explicitly depends upon the state in which a shock occurs.

For the purposes of quantitatively illustrating some pitfalls involving construction of the multipliers, we also consider an alternative definition of the tax cut multiplier which scales the output response by the tax revenue response evaluated in that same state (instead of the non-stochastic steady state). Formally:

$$\widehat{YM}_j(h)^c = -\frac{dY_{t+h}}{dTR_t}\bigg|\varepsilon_{j,t} = -1, \mathcal{S}_{t-1} \quad \text{for } j = c,\, n,\, \text{or } k \tag{21}$$

For our baseline multiplier, (20), any state-dependence in the multiplier must come from state-dependence in the output response to a tax rate cut, dY_{t+h}. In contrast, when using (21), both the numerator and denominator (dTR_t) can be sources of state-dependence. As we argue on the basis of a stylized model in Section 3, the multiplier constructed as in (21) can give a misleading sense of

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[9]Since we are studying the effects of tax *cuts*, we consider *negative* shocks to tax rates.

[10]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.

how the effectiveness of tax cuts in stimulating output varies across states.

5.2 Baseline Results

For our benchmark exercise, we simulate 1,100 periods of data from the model starting from the non-stochastic steady state and discard the first 100 periods as a burn-in. From each remaining 1,000 simulated state vectors, we compute impulse responses to the three negative distortionary tax shocks. Each shock is considered individually and represents a cut to a single tax rate. In our initial simulation of states, 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. Our results are not sensitive to doing this.

Table 3 presents some summary statistics from these simulations. Multipliers are defined according to (20). For each of the three types of distortionary tax shocks, we present statistics on impact and maximum output multipliers. Recall that the multipliers are multiplied by negative one so that numbers presented are positive. 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 state vectors. We also present the standard deviations of each multiplier over the 1,000 different states to provide a measure of volatility for each multiplier. Finally, we show the correlation of each type of multiplier with the simulated level of log output to get a sense of the cyclicality of the tax rate cut multipliers.

Focusing on the maximum output multipliers, the average consumption tax multiplier across states is 0.58, the average labor tax multiplier is 0.97, and the average capital tax multiplier is 1.51. To take the capital tax as an example, this means that a cut in the capital tax rate which generates a one (real) dollar change in tax revenue at the non-stochastic steady state on average raises output by about 1.5 (real) dollars. The average magnitudes of the tax cut multipliers are comparable to recent quantitative studies (Leeper and Yang 2008 and Uhlig 2010), but considerably lower than recent empirical studies by Mertens and Ravn (2012, 2014a), who find multipliers of up to 2 on impact and up to 3 after six quarters.[11] For all three types of taxes, the average impact multiplier is smaller than the average max multiplier, suggesting that the peak effect of tax changes on output occurs after several periods. To visualize this point, Figure 1 presents impulse responses of output from each of the 1,000 simulated states for each of the tax shocks. The impulse responses are scaled by the impact response of tax revenue evaluated in the non-stochastic steady state, giving the units a multiplier interpretation. The 1,000 unique impulse responses are presented in gray while an average response at each horizon is presented in black. We find that tax shocks generally have their largest effect after approximately 5-7 quarters.[12]

Each tax cut multiplier varies considerably across states. The rank ordering of multiplier volatilities across states is the same as the ranking of average magnitudes across type of tax. The

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[11]Many empirical studies of tax multipliers often group revenue from all taxes together and do not distinguish between changes in different types of tax rates. Comparisons against other specified-DSGE models are therefore cleaner.

[12]This pattern is common across tax studies. See, for example, Mountford and Uhlig (2009), Leeper, Plante and Traum (2010), or Mertens and Ravn (2014a).

standard deviation of the max capital tax multiplier is 0.15, with a min-max range of 0.8. The standard deviations of the max labor and consumption tax multipliers are 0.09 and 0.02, respectively. These volatilities across states are significantly larger than the standard deviation of the government spending multiplier across states. In particular, in a similar quantitative exercise on the basis of a medium scale DSGE model with many of the same features, Sims and Wolff (2018) report that the standard deviation of the government spending multiplier is about 0.02 with a min-max range of only about 0.1. That tax cut multipliers appear to exhibit significantly more state-dependence than do spending multipliers is consistent with the intuition from the stylized model laid out in Section 3.

Figure 2 plots time series of multipliers across the 1,000 simulated states. Solid lines (as measured on the left vertical axes) are the tax rate cut multipliers as defined in (20). Dashed blue lines (as measured on the right vertical axes) are simulated values of log output. Gray shaded regions demarcate periods in which simulated output is in its lowest 20th percentile; one can think of such episodes as being recessions. It is visually apparent that all three types of tax rate cut multipliers strongly co-move with output. Multipliers tend to be low in periods identified as recessions and high in periods of expansion. These visual impressions are confirmed in Table 3, which shows that tax rate cut multipliers for all three types of taxes are strongly procyclical (correlations with simulated output of 0.7-0.9). Although the medium scale DSGE mode is substantially more complicated and features many more frictions compared to the stylized model of Section 3, the strong procyclicality of tax rate cut multipliers is consistent with our analytical results from that model.

We also present summary statistics on multipliers constructed dividing the output response to a tax rate cut by the tax revenue response in that same state (i.e. $\widehat{YM}_j(h)^c$ instead of $YM_j(h)^c$ from (20)-(21)). These results are presented in Table 4. The average multipliers for each kind of tax are similar to what is presented in Table 3. But a couple of important things are apparent in Table 4. First, scaling the output response by the tax revenue response in each state reduces the standard deviations of all of the tax cut multipliers across states. Second, scaling the output responses in this way results in the multipliers being negatively correlated with simulated output, rather than positively correlated as in Table 3. These results are again consistent with our discussion in Section 3, which shows that under certain assumptions scaling the output response to a tax rate cut in a particular state by the tax revenue response in that same state will result in the measured multipliers being less volatile and less procyclical than the output response to a tax rate cut. The intuition for this finding is that the response of tax revenue to a tax rate change depends on the size of the tax base. When the tax base is low (i.e. the economy is in a recession), a tax cut has a comparatively small effect on tax revenue. This comparatively small effect on tax revenue counteracts the comparatively small output response to a tax rate cut in a recession, making the multiplier appear less procyclical (and indeed even countercyclical). This underscores the need to think carefully about how to measure tax rate cut multipliers in a state-dependent context.

Some additional quantitative exercises are considered and results presented and discussed in Appendix C. In particular, we show correlations between multipliers and output over different quantiles of the distribution of output (Table C1) and present summary statistics when states are

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generated conditional on one shock at a time (Table C2).

5.3 Are Tax Cuts in a Recession Desirable?

Our results from the previous section are consistent with the intuition from the frictionless analytical model in Section 3. In particular, tax rate cuts have relatively small effects on output in periods in which output is low (i.e. in recessions). Does this mean that tax rate cuts in recessions are undesirable in a normative sense compared to periods of expansion?

Before presenting some quantitative results, we briefly return to the analytical model from Section 3. We use the model to think not about how a tax cut impacts output, but rather how it impacts flow utility. Totally differentiating (1) about a point and using some of the equilibrium conditions of the static model allows one to derive an expression for the "utility tax rate cut multiplier":

$$\left(\frac{dU}{d\tau_t}\right)^c = u'((1-\phi)Y)(\tau-\phi)\left(\frac{dY_t}{d\tau_t}\right)^c \tag{22}$$

In terms of thinking about how $\left(\frac{dU}{d\tau_t}\right)^c$ varies across states, there are competing influences. On the one hand, when output is low the marginal utility of consumption, $u'(C)$, ought to be comparatively high. This means that the household would particularly value extra resources freed up from a tax cut in a time in which resources are dear. On the other hand, as discussed in Section 3, $\left(\frac{dY_t}{d\tau_t}\right)^c$ might be low in a recession, which would work in the opposite direction. Finally, even though the model in Section 3 is frictionless other than the distortionary labor income tax, one could think of τ as measuring distortions potentially arising from monopolistic competition and staggered price and wage-setting more generally. To the extent to which distortions are high in periods in which output is low, this would work to make $\left(\frac{dU}{d\tau_t}\right)^c$ comparatively big in such periods.

To simplify (22), we make the same assumptions as in Section 3 (namely, that disutility from labor is linear and that utility from consumption is of the constant relative risk aversion form). Then (22) can be written:

$$\left(\frac{dU}{d\tau_t}\right)^c = (\tau-\phi)\left(\frac{1-\phi}{1-\tau}\right)^\sigma Y^{1-\sigma} \tag{23}$$

Even though it is based on admittedly strict assumptions, (23) nevertheless permits some clean inferences. First, consider the case when $\sigma = 1$. Then the term relating to Y drops out. The tax cut utility multiplier would vary positively with τ. This simply means that when distortions are high, the value of reducing distortions is larger than normal. Consider next the case in which $\sigma > 1$. Here the utility tax cut multiplier would vary inversely with Y in spite of the fact that the output tax cut multiplier would co-vary positively with Y. This is because if σ is sufficiently big, the household values extra resources in periods when output is low by more than enough to make up for the fact that tax cuts are relatively ineffective at stimulating output when output is low.

Intuition from the simple analytical model therefore suggests that the utility benefits of tax

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cuts could be higher in a downturn compared to an expansion, which is the opposite pattern of what we find for the output response to tax cuts. Because the model is highly stylized, however, it remains an open quantitative question as to whether tax cuts during a downturn are normatively desirable. To investigate this matter further, we adopt terminology from Sims and Wolff (2018) and introduce what we call the "tax rate cut welfare multiplier." In our medium scale model as laid out in Appendix A there is a representative household. We therefore define aggregate welfare, V_t, as the present discounted value of flow utility of that household, which can be written recursively as follows:[13]

$$V_t = u(C_t - bC_{t-1}, 1 - N_t) + \beta \, \mathbb{E}_t \, V_{t+1} \tag{24}$$

We are interested in the response of welfare, dV_t, to a tax rate cut and how it varies across states. To facilitate comparison with the output multiplier, we scale this by the tax revenue response to a tax rate cut evaluated in the non-stochastic steady state, dTR^*, and we multiply it by negative one so that it is positive on average. To give the multiplier meaningful units, we divide by the steady state marginal utility of consumption, μ^*, which gives the multiplier a consumption-equivalent interpretation. Formally:

$$(VM_j)^c = -\frac{dV_t}{dTR^*} \frac{1}{\mu^*} \bigg|_{\varepsilon_{j,t} = -1, \mathcal{S}_{t-1}} \quad \text{for } j = c, \, n, \, \text{or } k \tag{25}$$

(25) evaluates the change in household welfare, V_t, per one (real) dollar change in tax revenue (evaluated in the steady state). One can think about this multiplier as measuring how many units of consumption a household would need to receive or have taken away in a single period to achieve the same lifetime utility benefit generated by a cut in a distortionary tax rate. Like the output multiplier, the magnitude of the welfare multiplier depends explicitly on the state in which the tax rate change occurs.

Table 5 is constructed similarly to Table 3 but instead shows results for tax welfare multipliers. The welfare multipliers are on average positive and large for all three types of tax rates. The sign of these multipliers reflects the fact that the economy is on average distorted – this distortion arises because of monopolistic competition in goods and labor markets and positive average tax rates. Lowering tax rates eases distortions and is therefore naturally welfare-improving. The interpretation of the magnitude of these welfare multipliers is as follows. Taking the labor tax rate as an example, a welfare multiplier of 9.3 means that the 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

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[13]The specific flow utility function we assume in the paper takes the form $u(C_t - bC_{t-1}, 1 - N_t) = \frac{\left((C_t - bC_{t-1})^\gamma (1 - N_t)^{1-\gamma} \right)^{1-\sigma} - 1}{1 - \sigma}$. The parameter b is a measure of internal habit formation and σ and γ are curvature parameters.

about nine.[14]

Welfare multipliers tend to be much more volatile across states than are the corresponding output multipliers. Importantly, one also observes from Table 5 that welfare multipliers are strongly countercyclical in an unconditional sense. The correlations of the tax rate cut welfare multipliers for the consumption, labor, and capital tax rates with simulated output are -0.75, -0.59, and -0.51, respectively. Consistent with the intuition from the simple analytical model, periods of low output are in fact the most desirable periods in which to cut tax rates (the reverse would hold true for tax rate increases). This is in spite of the fact that output responds relatively less to tax rate cuts in periods in which output is low.

To gain some quantitative intuition for these results, we simulate data from our model and measure the so-called "labor wedge" (Chari, Kehoe and McGrattan 2007). The simulated labor wedge in the model is strongly countercyclical, with a correlation with simulated output of -0.76.[15] This is similar to the correlation between a measured labor wedge and output in actual data.[16] Figure 3 shows scatter plots of tax rate cut welfare multipliers with the simulated labor wedge. Welfare multipliers are strongly positively correlated with the labor wedge. This visually confirms the commonsense intuition laid out above that the welfare value of easing distortions is highest when the economy is most highly distorted. Since periods of high distortion correspond to periods of low output on average, this accounts for the strong negative correlation between welfare multipliers and simulated output.[17]

Appendix C contains some additional quantitative results concerning properties of the welfare multipliers conditional on particular shocks. These results are summarized in Table C3. Though welfare multipliers are strongly countercyclical in an unconditional sense, cyclicalities depend in important ways on the particular shocks driving fluctuations. In some cases (i.e. conditional on

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[14]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-hundredth of the values presented in the Table.

[15]The labor wedge is defined implicitly as: $\frac{u_L(\cdot)}{u_C(\cdot)} = (1-\tau_t^l)(1-\alpha)\frac{Y_t}{N_{d,t}}$. In other words, the labor wedge, τ_t^l, measures the discrepancy between the marginal rate of substitution between leisure and consumption and the marginal product of labor. The variable τ_t^l could be interpreted as a labor tax in a "prototype" economy with no other frictions, but in actuality other frictions (such as time-varying markups) will map into the wedge. We define the labor wedge as the net tax rate in a "prototype" economy, not the gross rate (see also the discussion in the following footnote).

[16]Chari, Kehoe and McGrattan (2007) report that the labor wedge is positively correlated with HP filtered output with a correlation of 0.71. They define the labor wedge as the gross labor tax rate in a "prototype" economy, $1-\tau_t^l$, whereas we define the labor wedge as the net tax rate, τ_t^l. Hence, our negative correlation is consistent with their positive correlation. See also the previous footnote.

[17]It should be noted that output multipliers for each of the three types of tax rates are negatively correlated with simulated labor wedges. This would appear consistent with a conclusion that the overall level of distortion in the economy is a major driving factor of the state-dependence in output multipliers. This result would not square well with the results to follow in Table 6, where we show that the state-dependent properties of output multipliers are largely unaffected by parameters relating to nominal frictions in the model. We find that the partial correlations of the output multipliers with the labor wedge, *conditioning* on the level of simulated output, are all close to zero. In contrast, the partial correlations of the welfare multipliers with the labor wedge are similar to the unconditional correlations. These findings are consistent with our other results, where the level of output itself seems to drive the state-dependent properties of output multipliers, not the level and time-variation in overall distortions, while the opposite is true for the welfare multipliers.

preference or investment shocks, for example), welfare multipliers tend to be procyclical. Overall, while welfare multipliers are quite countercyclical in an unconditional sense, these results suggest that some care needs to be taken in interpreting our normative results, because the type of shock driving fluctuations is potentially important.

5.4 Sources of State-Dependence

Our analytical intuition immediately above and earlier in Section 3 is based on a simple, frictionless model. Our medium scale model, in contrast, features a number of frictions. To investigate the relative importance of different frictions in driving our results, Table 6 shows selected summary statistics from our simulations with key parameters changed so as to neutralize a particular friction. The column labeled "Baseline" simply repeats entries from Tables 3 and 5 and is included to facilitate comparison. In the first inner column, labeled $\theta_p = 0.01$, we make prices effectively perfectly flexible. This results in average output multipliers for each type of tax being slightly higher than in our baseline. The same is true for average welfare multipliers. Price flexibility makes the output multiplier somewhat less volatile across states (i.e. lower standard deviations), but does not have much effect on cyclicalities of the output multipliers. There is, however, an important effect of price stickiness on the cyclicality of the welfare multipliers. In particular, when prices are flexible, welfare multipliers are significantly less countercyclical. In the case of the labor and capital taxes, the welfare multipliers become positively correlated with output when prices are (nearly) flexible. The intuition for this finding is reasonably straightforward. When prices are flexible, in our model the economy is not, on average, countercyclically distorted. This means that there are not unusually large gains from easing distortions when the economy is in a recession, and the cyclicalities of the welfare multipliers consequently looks more in-line with the cyclicality of the output multipliers. In comparison to assuming (near) price flexibility, making wages (nearly) flexible (second inner column, labeled $\theta_w = 0.01$) does not have very discernible effects on the properties of either type of multiplier across states.

The remaining columns of Table 6 consider the role of real frictions in generating our quantitative results. The column labeled $\psi_1 = 1,000$ penalizes variable capital utilization to an extreme degree, resulting in capital utilization in effect being fixed. This results in significant reductions in the mean values of both output and welfare multipliers for all types of tax rates. It also results in significant reductions in standard deviations of multipliers across states. It does not have much noticeable effect on the correlations of output or welfare multipliers with simulated output. The column labeled $\kappa = 1,000$ considers making the investment adjustment cost very large. For all three types of tax cuts, this tends to reduce volatility of the output multipliers across states. It also lowers the average value of each multiplier, albeit not as much as shutting off variable capital utilization. We finally consider the effects of reducing habit formation in consumption (i.e. in setting the parameter b low). Doing so tends to raise average values of output multipliers for all three types of tax cuts and also makes these multipliers more variable across states. Welfare multipliers, in contrast, are slightly lower on average. There is not much effect on cyclicalities of output or welfare multipliers from

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eliminating habit formation.

The following conclusions can be gleaned from the results in Table 6. First, output multipliers for all three tax rates are strongly positively correlated with simulated output regardless of which nominal or real frictions are weakened or strengthened. This suggests that the co-movements of output multipliers across states are to a large extent driven by the frictionless backbone of the model as laid out in a simple form in Section 3. Second, average output multipliers for all three tax rates tend to move in the expected direction with the level of distortions – when prices are flexible or real frictions (e.g. variable capital utilization) are weaker, output multipliers are larger on average. Third, with the exception of the degree of price stickiness, welfare multipliers are robustly countercyclical.

6   Extensions

In this section we consider the robustness of our baseline results to several alternative modeling assumptions. The extensions we consider include: (i) anticipation in tax processes, (ii) alternative fiscal financing rules, (iii) the addition of a rule-of-thumb consumer population, and (iv) a passive monetary policy regime in the spirit of the recent zero lower bound episode.

6.1   Anticipation Lags

Given inherent delays in the legislative process, a number of authors have recently taken seriously the idea that agents become aware of tax rate changes before those changes go into effect. For example, Leeper, Walker and Yang (2013) estimate a DSGE model which explicitly accounts for implementation lags and phase-in periods. We therefore consider a modification in which tax rate shocks are observed by agents Q periods in advance of taking effect. In particular, we assume that:

$$\tau_{j,t} = (1 - \rho_j)\tau_j^* + \rho_j\tau_{j,t-1} + s_j\varepsilon_{j,t-Q}, \ \ Q \ge 0, \ \text{for} \ j = c, n, k \tag{26}$$

To facilitate comparison with our baseline results, we do not re-estimate the model parameters under anticipation. We consider anticipation horizons of $Q = 2, \ldots, 6$. Calculation of multipliers is complicated by the presence of anticipation. Output (and welfare) will react immediately to an announced change in tax rates, but tax revenue will only react indirectly through the tax base. Scaling output responses by the impact revenue response would therefore muddy any comparison with our earlier results. We therefore adopt the following strategy. We scale the output (or welfare) response to an anticipated tax rate change in a particular state by the tax revenue response to an *unanticipated* tax rate change evaluated in the non-stochastic steady state. This ensures that any differences relative to our baseline results are driven by differences in how output (or welfare) react to an anticipated tax rate change, not how tax revenue reacts.

Table 7 displays the results of this alternative modeling assumption. The table contains three distinct panels, separated according to the type of tax cut implemented. We find that given more time to adjust in anticipation of a tax change, the maximum output response increases monotonically

while the impact response decreases monotonically. This pattern is made clear by the impulse response functions shown in Figure 4. This figure shows average responses of each of the three tax rates and output under the five alternative anticipation assumptions. The intuition is straightforward; agents facing real frictions are better able to respond to tax cuts when they have the opportunity to adjust slowly. In comparison with the multipliers presented in Table 3, however, the volatility of each multiplier across states is relatively unchanged and the comovements with output are virtually identical.

Similar to output multipliers, welfare multipliers for each kind of tax also tend to be larger with longer anticipation horizons. Interestingly, the welfare multipliers experience increases in volatility across states and become increasingly countercyclical in the presence of anticipation. For instance, the standard deviation of the labor tax welfare multiplier increases from 0.54 to 0.67 with six quarters of anticipation and the comovement with output decreases from -0.60 to -0.70. The normative case for countercyclical tax stimulus is thus made stronger by the presence of anticipation.

6.2   Alternative Fiscal Financing

In our baseline model, we assume that tax rate cuts are financed via lump sum tax increases. This offers an especially clean interpretation of our exercises in that we avoid trading smaller current distortions for higher future distortions. However this may not be particularly realistic. As noted by Christ (1968), Yang (2005), Leeper and Yang (2008), Mountford and Uhlig (2009), Leeper, Plante and Traum (2010), and others, the means by which the government finances tax rate changes can impact how stimulative tax cuts are when agents are forward looking.

In this section we consider a modification of our assumed processes for tax rates. The process for the lump sum tax is the same as earlier with the exception that we allow for an "automatic stabilizer" component wherein the lump sum tax reacts to deviations of output growth relative to trend:

$$T_t = (1 - \rho_T)T^* + \rho_T T_{t-1} + (1 - \rho_T)\left[\gamma_T^b\left(B_{g,t-1} - B_g^*\right) + \gamma_T^b\left(\ln Y_t - \ln Y_{t-1}\right)\right] + s_T\varepsilon_{T,t}, \ \ \gamma_T^b > 0 \qquad (27)$$

Individual tax rates obey a similar process:

$$\tau_{j,t} = (1 - \rho_j)\tau_j^* + \rho_j\tau_{j,t-1} + (1 - \rho_j)\left[\gamma_j^b\left(B_{g,t-1} - B_g^*\right) + \gamma_j^y\left(\ln Y_t - \ln Y_{t-1}\right)\right] + s_j\varepsilon_{j,t}, \ \ \text{for} \ \ j = c,n,k \qquad (28)$$

In (27) and (28), the parameters γ_j^b govern how individual taxes react to deviations of government debt from target. The parameters γ_j^y measure the strength of the automatic stabilizer mechanism. In our baseline analysis from Section 5, we assume that $\gamma_j^b = 0$ for $j = c,n,k$ and $\gamma_j^y = 0$ for $j = T,c,n,k$.

Similarly to Leeper, Plante and Traum (2010), we re-estimate the model under four different assumptions about how taxes react to debt and output. These four regimes are: (i) all taxes are allowed to respond to both debt and output growth; (ii) only distortionary taxes react to debt and output growth (i.e. the lump sum tax is fixed at its steady state value); (iii) labor and capital

taxes react to debt and output (i.e. lump sum and consumption taxes are fixed); and (iv) only labor income taxes react to debt and output (i.e. lump sum, consumption, and capital taxes are fixed). Columns seven through ten of Table 2 present estimation results for these alternative specifications. We find parameters unrelated to the tax processes are relatively consistent across different specifications. In the specification in which all taxes can react to debt and output, we find that all four kinds of taxes respond positively to debt. We also estimate reasonably strong built-in "automatic stabilizer" features in which taxes react positively to output growth. The results for non-restricted tax policy parameters are reasonably consistent across (i)-(iv).

Multiplier summary statistics for simulations using these alternative parameters are presented in Table 8. For most exercises and most types of tax shocks, the average multipliers are smaller when distortionary taxes are used to stabilize debt. An exception is when future labor tax increases finance present tax cuts. In this scenario, the average labor tax multiplier increases by as much as 50 percent. This is the natural result of intertemporal substitution in labor supply – if future labor taxes are expected to rise, it makes sense to increase labor by more in the present in response to a tax cut than otherwise. For each financing regime, there is still considerable state-dependence in each tax multiplier, with standard deviations across states generally close to what we find in our baseline simulations. The output multipliers tend to be more strongly positively correlated with simulated output in comparison to Table 3.

The most noteworthy differences relative to our baseline exercise concern welfare multipliers. When debt deviations from steady state are financed solely via lump sum taxes (i.e., the baseline exercise), the welfare multipliers from tax cuts are unambiguously positive. This is not necessarily the case when distortionary taxes must adjust so as to stabilize debt. In Table 8, we see that the average welfare multipliers are in some cases negative suggesting that the household would be better off without incurring the fiscal deficit to cut present taxes. Most of the tax welfare multipliers remain negatively correlated with simulated output in the different financing regimes. An exception is the consumption tax welfare multiplier, which turns procyclical when only distortionary taxes are used to finance debt. The capital tax welfare multiplier also turns mildly procyclical (correlation with simulated output of 0.13) when only the labor income tax adjusts to stabilize debt.

6.3   Rule-of-Thumb Households

In our baseline model, the representative household is unrestricted in its ability to transfer resources intertemporally by accumulating capital or bonds. In this section, we consider a modification of the model in which a portion of the population does not have access to capital or credit markets. Households of this type consume all of their flow income in a period and supply labor at the market wage. These households comprise a fraction $\lambda \in (0, 1)$ of the population, where λ is a fixed parameter. Constrained households such as this have been called "fist-to-mouth" by Campbell and Mankiw (1990) or "rule-of-thumb" by Galí, López-Salido and Vallés (2007) and McKay and Reis (2016).

A detailed description of how the model with rule-of-thumb households differs from the baseline

model can be found in Appendix B. We consider different values of the share parameter λ and keep all other parameters at the mean of their estimated posterior distribution from the baseline model. Results are presented in Table 9. The table considers three different values of λ: 0.05, 0.25, and 0.45. These are considered in different rows. For each type of tax, we present properties of both output and welfare multipliers across simulated states.[18]

We find that average output multipliers are monotonically increasing in the rule-of-thumb population. The differences are most noticeable for the consumption tax multiplier, which increases by 18 percent as the rule-of-thumb population share increases from 5 to 45 percent. The average output multiplier for the labor tax increases by 13 percent for the same population share change, while the capital tax output multiplier increases by 6 percent. In addition, we find that output multipliers for all three types of tax rates are more volatile across states the larger is the rule-of-thumb population share. Regardless of the fraction of rule-of-thumb households, we find that output multipliers for all three types of tax rates are strongly procyclical.

We find that the average welfare multipliers are always positive for all three kinds of tax rates regardless of the rule-of-thumb population. The average aggregate welfare multipliers are increasing in the rule-of-thumb population size for the consumption and labor taxes, but the population-weighted average welfare multiplier for the capital tax is decreasing in the rule-of-thumb population. This is to be expected, as rule-of-thumb households do not directly benefit from lower capital taxes. For all three types of tax rates, we find that the welfare multipliers are significantly negatively correlated with simulated output in magnitude similar to what we find in our baseline model.

6.4 Passive Monetary Policy

Much of the renewed interest in fiscal policy is the result of the recent period of passive monetary policy. We therefore consider an alternative specification of the baseline model in which tax shocks occur during periods characterized by unresponsive monetary policy. In particular, we assume that the nominal interest rate is (in expectation) pegged at its most recent value for a known duration, after which time policy reverts to following a Taylor rule. One can think of this approach as a tractable way of approximating the effects of a binding zero lower bound (in which the nominal interest rate is unresponsive to shocks).

Following Laseen and Svensson (2011), we assume that monetary policy is characterized as follows:

$$
E_t i_{t+h} = \begin{cases} i_{t-1} & \text{if } h \leq Q \\ (1-\rho_i)i + \rho_i i_{t+h-1} + (1-\rho_i)\left(\phi_\pi(\pi_{t+h} - \pi) + \phi_y(\ln Y_{t+h} - \ln Y_{t+h-1})\right) & \text{if } h > Q \end{cases} \quad (29)
$$

In (29), it is assumed that the nominal interest rate is (in expectation) pegged at its most recent

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[18]With two different household types, it is not obvious how to measure aggregate welfare. As described in Appendix B, we define aggregate welfare to be the present discounted value of a population-weighted share of flow utilities for each household type.

value for the subsequent $Q \geq 0$ periods, after which time policy is expected to obey the standard Taylor rule as presented in (A.23) of Appendix A. To implement this specification we augment the model's Taylor rule with a series of "forward guidance" shocks in the spirit of Del Negro, Giannoni and Patterson (2012). These shocks are fully observed by agents and have the flavor of "news" shocks. Their magnitudes are chosen so that the nominal interest rate does not react to a shock for the desired number of periods. It is important to note that our model does not explicitly incorporate a zero lower bound constraint and thus faces no endogenous likelihood of exiting or re-entering the passive policy regime. Rather, passive policy in our framework is fully exogenously determined with a duration known to all agents. We consider exactly the same set of simulated state vectors as in our baseline exercises above (in particular, we revert to assuming that only lump sum taxes are used to finance government debt). But the policy functions for endogenous variables are generated with this alternative monetary rule as opposed to the standard Taylor rule. Multipliers are constructed based on the impulse responses to tax rate cuts when the nominal interest rate is pegged.

Table 10 presents multipliers for each tax rate for peg durations $Q = 1, 2, 3$ and 4. We find that for each tax rate, multipliers monotonically decrease in the length of the passive policy regime. Labor and capital tax multipliers experience the largest decrease. This pattern is confirmed in Figure 5, which displays the average nominal interest rate and output responses to a tax rate shock with varying durations of the passive policy regime. As the peg length increases, we find a monotonic decrease in both the impact response of output as well as the maximum response. The same is also true for multiplier state-dependence, with standard deviations across states declining in the length of the period of passive policy. Average welfare multipliers for each type of tax become smaller as the duration of passive monetary policy increases. Output multipliers become more positively correlated with simulated output as the length of the period of passive policy increases, while welfare multipliers generally become less countercyclical as the peg length increases (an exception is the consumption welfare multiplier, whose correlation with simulated output is unaffected by the duration of the passive policy regime).

Intuition for these results follows from the inflation response to tax shocks. As the nominal interest rate is held fixed over the regime, all changes in expected inflation translate into opposite-signed movements in the short term real interest rate. In the model, negative tax shocks push current and expected inflation down. With nominal interest rates fixed, the real interest rate rises, which works to dampen economic activity. As the peg duration increases, so too does the decline in expected inflation, which serves to amplify the increase in the real interest rate and the dampening effect on economic activity. This is exactly the opposite pattern for government spending increases, where passive policy tends to both raise the magnitude of the spending multiplier (Christiano, Eichenbaum and Rebelo 2011) as well as its volatility across states (Sims and Wolff 2017).

7 Conclusion

In this paper we have studied the effects of shocks to tax rates across states of the business cycle. Beginning with a highly stylized model, we produced analytical expressions which suggest that tax cuts should not have constant effects on output over time. Rather, the model suggests that tax cuts ought to be least stimulative for output in periods in which output is low (i.e. in periods of recession). We also used the model to highlight some conceptual issues for the measurement and construction of tax multipliers, findings which may be of particular relevance for researchers interested in studying time-varying multipliers.

We then solved and simulated an otherwise standard medium scale DSGE model with a detailed fiscal block. Tax multipliers vary considerably across states for all three types of tax rates considered. Consonant with the intuition from the stylized model, tax multipliers are generally largest in periods in which output is relatively high. We then studied the properties of a welfare multiplier for tax cuts. In our quantitative simulations the tax cut welfare multiplier is countercyclical for all three kinds of taxes. This suggests that tax cuts are in fact most desirable in a normative sense during periods of recession, in spite of the fact that tax cuts are comparatively less stimulative for output in such periods. We considered a number of extensions to our baseline quantitative framework and our basic conclusions are generally robust.

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Table 1: **Calibrated Parameters**

Parameter	Value or Target	Description
β	0.99	Discount factor
α	1/3	Capital's share
π^*	0	Trend Inflation
ϵ_p	11	Intermediate goods elasticity
ϵ_w	11	Labor elasticity
δ	0.025	Depreciation rate
ψ_0	$u^* = 1$	Linear term utilization cost
ψ_1	0.01	Quadratic term utilization cost
G^*	$\frac{G^*}{Y^*} = 0.2$	Steady state government spending
τ_c^*	0.0169	Consumption tax rate
τ_n^*	0.2104	Labor tax rate
τ_k^*	0.1975	Capital tax rate
T^*	$\frac{B_g^*}{Y^*} = 0.5$	Steady state lump sum tax
γ_b^T	0.05	Lump sum tax response to debt

Note: This table lists the values of calibrated parameters or the target used in the calibration.

Table 2: **Estimated Parameters**

		Prior			Mean (95th Percentile) of Posterior Distribution				
Parameter	Description	Dist.	Mean	SD	Baseline	All Adjust	Distortionary Taxes Adjusts	Labor and Capital Adjust	Labor Adjust
b	Habit formation	B	0.700	0.100	0.7463 (0.70, 0.79)	0.7076 (0.65, 0.77)	0.6955 (0.64, 0.75)	0.6999 (0.64, 0.76)	0.7120 (0.65, 0.77)
ϕ_y	TR output growth	N	0.125	0.025	0.1311 (0.09, 0.17)	0.1346 (0.09, 0.17)	0.1353 (0.10, 0.18)	0.1363 (0.10, 0.18)	0.1340 (0.09, 0.17)
ϕ_π	TR inflation	N	1.500	0.100	1.6258 (1.49, 1.77)	1.6244 (1.48, 1.77)	1.6304 (1.47, 1.76)	1.6186 (1.46, 1.76)	1.6104 (1.46, 1.75)
σ	Utility curvature	N	2.000	0.250	2.4017 (2.05, 2.75)	2.4714 (2.09, 2.81)	2.5077 (2.15, 2.80)	2.4727 (2.12, 2.80)	2.4720 (2.14, 2.80)
γ	Utility curvature	B	0.300	0.050	0.2429 (0.23, 0.25)	0.2484 (0.22, 0.28)	0.2529 (0.24, 0.26)	0.2423 (0.23, 0.25)	0.2540 (0.24, 0.26)
κ	Inv. adj. cost	N	4.000	0.500	4.1141 (3.30, 4.90)	4.0539 (3.32, 4.75)	4.0462 (3.21, 4.83)	4.1259 (3.42, 4.94)	4.2207 (3.51, 4.99)
ζ_w	Wage indexation	B	0.500	0.050	0.4966 (0.42, 0.57)	0.4976 (0.41, 0.58)	0.4951 (0.41, 0.58)	0.4918 (0.40, 0.57)	0.4929 (0.41, 0.58)
ζ_p	Price indexation	B	0.500	0.050	0.4740 (0.39, 0.56)	0.4864 (0.41, 0.57)	0.4782 (0.39, 0.57)	0.4795 (0.40, 0.56)	0.4728 (0.39, 0.55)
θ_w	Wage stickiness	B	0.500	0.050	0.5111 (0.43, 0.59)	0.5061 (0.43, 0.58)	0.5036 (0.41, 0.58)	0.5039 (0.42, 0.58)	0.5023 (0.43, 0.59)
θ_p	Price stickiness	B	0.500	0.050	0.7228 (0.68, 0.77)	0.7294 (0.69, 0.77)	0.7336 (0.70, 0.77)	0.7375 (0.70, 0.78)	0.7359 (0.70, 0.78)
γ_b^c	Consumption tax debt	B	0.500	0.200	- -	0.1479 (0.07, 0.23)	0.1073 (0.05, 0.16)	- -	- -
γ_b^k	Capital tax debt	B	0.500	0.200	- -	0.0993 (0.04, 0.16)	0.0805 (0.02, 0.13)	0.1140 (0.04, 0.18)	- -
γ_b^n	Labor tax debt	B	0.500	0.200	- -	0.1206 (0.05, 0.19)	0.0822 (0.03, 0.13)	0.1112 (0.05, 0.17)	0.1461 (0.06, 0.24)
γ_b^T	Lump sum tax debt	B	0.500	0.200	- -	0.1795 (0.10, 0.27)	- -	- -	- -
γ_y^c	Cons. tax output	B	0.500	0.200	- -	0.2879 (0.10, 0.50)	0.2802 (0.08, 0.47)	- -	- -
γ_y^k	Capital tax output	B	0.500	0.200	- -	0.7600 (0.47, 1.02)	0.8060 (0.51, 1.07)	0.7699 (0.51, 1.03)	- -
γ_y^n	Labor tax output	B	0.500	0.200	- -	0.4404 (0.16, 0.70)	0.4957 (0.17, 0.79)	0.5006 (0.24, 0.80)	0.5503 (0.26, 0.82)
γ_y^T	Lump sum tax output	B	0.500	0.200	- -	0.7770 (0.49, 1.07)	- -	- -	- -

Parameter	Description	Prior			Mean (95th Percentile) of Posterior Distribution				
		Dist.	Mean	SD	Baseline	All Adjust	Distortionary Taxes Adjusts	Labor and Capital Adjust	Labor Adjust
ρ_i	TR AR(1)	B	0.700	0.100	0.7527	0.7886	0.7954	0.7802	0.7662
					(0.70, 0.80)	(0.75, 0.83)	(0.76, 0.83)	(0.74, 0.82)	(0.72, 0.81)
ρ_a	Productivity AR(1)	B	0.700	0.100	0.9429	0.9476	0.9462	0.9453	0.9418
					(0.92, 0.96)	(0.93, 0.97)	(0.92, 0.97)	(0.92, 0.97)	(0.92, 0.96)
ρ_z	MEI AR(1)	B	0.700	0.100	0.8258	0.7894	0.7974	0.7910	0.8084
					(0.74, 0.90)	(0.71, 0.88)	(0.70, 0.88)	(0.72, 0.87)	(0.72, 0.90)
ρ_ν	Preference AR(1)	B	0.700	0.100	0.6241	0.6875	0.6887	0.6807	0.6620
					(0.51, 0.73)	(0.59, 0.79)	(0.60, 0.78)	(0.59, 0.77)	(0.57, 0.75)
ρ_{uw}	Wage markup AR(1)	B	0.700	0.100	0.6926	0.6910	0.6898	0.6748	0.6901
					(0.52, 0.86)	(0.55, 0.87)	(0.53, 0.85)	(0.52, 0.94)	(0.52, 0.85)
ρ_{up}	Price markup AR(1)	B	0.700	0.100	0.9417	0.9417	0.9346	0.9340	0.9401
					(0.92, 0.97)	(0.91, 0.97)	(0.90, 0.97)	(0.90, 0.97)	(0.91, 0.97)
ρ_g	Gov. spending AR(1)	B	0.700	0.100	0.9493	0.9570	0.9545	0.9553	0.9517
					(0.93, 0.97)	(0.94, 0.97)	(0.94, 0.97)	(0.94, 0.97)	(0.94, 0.97)
ρ_T	Lump sum tax AR(1)	B	0.700	0.100	0.9485	0.9379	0.9387	0.9474	0.9515
					(0.92, 0.97)	(0.91, 0.96)	(0.91, 0.97)	(0.92, 0.97)	(0.93, 0.98)
ρ_{τ_c}	Cons. tax AR(1)	B	0.700	0.100	0.9543	0.9542	0.9527	0.9314	0.9426
					(0.93, 0.98)	(0.92, 0.99)	(0.92, 0.98)	(0.90, 0.96)	(0.92, 0.97)
ρ_{τ_k}	Capital tax AR(1)	B	0.700	0.100	0.8985	0.9288	0.9193	0.9241	0.8972
					(0.86, 0.94)	(0.88, 0.97)	(0.88, 0.96)	(0.88, 0.96)	(0.85, 0.94)
ρ_{τ_n}	Labor tax AR(1)	B	0.700	0.100	0.9016	0.9328	0.9396	0.9440	0.9557
					(0.86, 0.95)	(0.89, 0.98)	(0.90, 0.98)	(0.91, 0.98)	(0.92, 0.99)
$100 \times s_a$	SD productivity shock	IG	0.400	0.200	0.7900	0.7100	0.6800	0.7100	0.7500
					(0.70, 0.88)	(0.62, 0.79)	(0.60, 0.76)	(0.63, 0.79)	(0.66, 0.83)
$100 \times s_z$	SD MEI shock	IG	0.400	0.200	3.0200	3.2100	3.1900	3.2600	3.1400
					(2.20, 3.80)	(2.50, 4.10)	(2.30, 4.00)	(2.50, 4.90)	(2.30, 4.00)
$100 \times s_i$	SD TR shock	IG	0.400	0.200	0.2600	0.2200	0.2000	0.2300	0.2500
					(0.23, 0.30)	(0.19, 0.25)	(0.18, 0.23)	(0.19, 0.26)	(0.21, 0.28)
$100 \times s_\nu$	SD preference shock	IG	0.400	0.200	1.7400	1.5700	1.5000	1.5200	1.5600
					(1.20, 2.20)	(1.10, 2.00)	(1.10, 1.90)	(1.10, 1.90)	(1.20, 2.00)
$100 \times s_{uw}$	SD wage markup shock	IG	0.400	0.200	0.3600	0.3900	0.4000	0.5300	0.3800
					(0.19, 0.54)	(0.18, 0.62)	(0.19, 0.61)	(0.02, 1.20)	(0.18, 0.59)
$100 \times s_{up}$	SD price markup shock	IG	0.400	0.200	0.4500	0.4100	0.3900	0.3900	0.4200
					(0.36, 0.54)	(0.33, 0.49)	(0.31, 0.47)	(0.32, 0.46)	(0.33, 0.50)
$100 \times s_g$	SD gov. spending shock	IG	0.400	0.200	2.5900	2.5500	2.5800	2.5800	2.5500
					(2.20, 2.90)	(2.30, 2.90)	(2.30, 2.90)	(2.30, 2.90)	(2.20, 2.80)
$100 \times s_{\tau_c}$	SD cons. tax shock	IG	0.200	0.200	0.1800	0.2600	0.2600	0.4100	0.2800
					(0.14, 0.22)	(0.15, 0.37)	(0.15, 0.37)	(0.32, 0.51)	(0.21, 0.35)
$100 \times s_{\tau_k}$	SD capital tax shock	IG	0.200	0.200	1.0600	0.5800	0.6000	0.5500	1.2200
					(0.90, 1.20)	(0.37, 0.79)	(0.44, 0.79)	(0.37, 0.73)	(1.0, 1.4)
$100 \times s_{\tau_n}$	SD labor tax shock	IG	0.200	0.200	0.5000	0.4600	0.4300	0.4100	0.3700
					(0.44, 0.57)	(0.32, 0.57)	(0.35, 0.52)	(0.31, 0.49)	(0.29, 0.46)
$100 \times s_T$	SD lump sum tax shock	IG	0.200	0.200	0.5200	0.4900	0.5400	0.5000	0.5200
					(0.46, 0.58)	(0.42, 0.57)	(0.47, 0.62)	(0.44, 0.57)	(0.46, 0.58)

Note: B stands for beta distribution, N for normal distribution, and IG stands for inverse gamma. The posterior is generated with 20,000 random walk Metropolis Hastings draws with an acceptance rate of approximately 25 percent. Observable variables used in the estimation are described in the text. Under posterior means, the ranges in parentheses give 95 percent confidence intervals. The column labeled "Baseline" lists posterior estimates in our baseline estimation. Non-estimated parameters are indicated with a "−" marker. Remaining columns consider alternative estimations taken up in Section 6.

Table 3: **Properties of Output Multipliers**

| | Multiplier | | | | |
	Min	Max	Mean	Std Dev	corr($\ln Y_t$)
Consumption					
Impact	0.1540	0.2028	0.1788	0.0085	0.7028
Max	0.5085	0.6447	0.5825	0.0234	0.7901
Labor					
Impact	0.1508	0.2910	0.2052	0.0246	0.5427
Max	0.6880	1.2460	0.9685	0.0921	0.8379
Capital					
Impact	0.7845	1.3373	1.0407	0.1055	0.9336
Max	1.0841	1.9188	1.5061	0.1467	0.8941

Notes: This table provides summary statistics concerning properties of simulated output multipliers for three different types of tax rate cuts (denoted in bold). Both impact and maximum multipliers are presented. Construction of multipliers is as described in the text.

Table 4: **Properties of Output Multipliers**

State Dependent Tax Revenue Response

| | Multiplier | | | | |
	Min	Max	Mean	Std Dev	corr($\ln Y_t$)
Consumption					
Impact	0.1663	0.1908	0.1783	0.0046	-0.0777
Max	0.5416	0.6228	0.5809	0.0137	-0.1599
Labor					
Impact	0.1422	0.2918	0.1987	0.0261	-0.2960
Max	0.7484	1.1691	0.9353	0.0726	-0.3138
Capital					
Impact	0.8892	1.2143	1.0172	0.0553	-0.0454
Max	1.2490	1.7986	1.4734	0.0940	-0.1542

Note: This table is constructed similarly to Table 3, but multipliers are constructed by scaling the output response to a tax rate cut in a particular realization of the state by the tax revenue response in that same realization of the state (as opposed to the tax revenue response evaluated in the non-stochastic steady state).

Table 5: **Properties of Welfare Multipliers**

| | Multiplier | | | | |
	Min	Max	Mean	Std Dev	corr($\ln Y_t$)
Consumption					
Welfare	9.9382	12.2570	11.0794	0.4191	-0.7549
Labor					
Welfare	7.8361	10.5577	9.3551	0.4885	-0.5866
Capital					
Welfare	10.9431	15.0482	13.1810	0.6954	-0.5011

Note: This table is similar to Table 3 but presents properties of simulated welfare multipliers instead of output multipliers.

Table 6: **Sources of Volatility**

	Baseline	$\theta_p = 0.01$	$\theta_w = 0.01$	$\psi_1 = 1{,}000$	$\kappa = 1{,}000$	$b = 0.01$
Consumption						
Mean Output Mult	0.5825	0.6074	0.5698	0.4291	0.5558	1.0323
St. Dev.	0.0234	0.0157	0.0222	0.0165	0.0172	0.0571
Corr w/ Output	0.7901	0.7071	0.7888	0.9333	0.7898	0.8150
Mean Welfare Mult	11.0794	11.4357	10.7587	8.5787	11.0394	9.9201
St. Dev.	0.4191	0.1003	0.4178	0.3278	0.3779	0.4298
Corr w/ Output	-0.7549	-0.2217	-0.7500	-0.7202	-0.7302	-0.7956
Labor						
Mean Output Mult	0.9685	1.1436	0.8591	0.6273	0.4467	1.1631
St. Dev.	0.0921	0.0765	0.0798	0.0338	0.0167	0.1011
Corr w/ Output	0.8379	0.7852	0.8334	0.9196	0.7537	0.8044
Mean Welfare Mult	9.3551	10.8781	8.1704	9.1591	5.8829	7.1019
St. Dev.	0.4885	0.1579	0.4495	0.4135	0.3626	0.4107
Corr w/ Output	-0.5866	0.4775	-0.5794	-0.6159	-0.7684	-0.6968
Capital						
Mean Output Mult	1.5061	2.1468	1.4602	0.2195	0.9638	1.8193
St. Dev.	0.1467	0.1354	0.1404	0.0180	0.0562	0.1599
Corr w/ Output	0.8941	0.8216	0.8967	0.7162	0.8455	0.8677
Mean Welfare Mult	13.1810	17.8018	12.9075	3.6129	9.2959	9.4822
St. Dev.	0.6954	0.3205	0.6570	0.1613	0.6079	0.5352
Corr w/ Output	-0.5011	0.5468	-0.5040	-0.5716	-0.6642	-0.6338

Note: This table shows summary statistics for both output and welfare multipliers under different parameterizations of the baseline model. All but the listed parameter in each column are set to their baseline values.

Table 7: **Properties of Output and Welfare Multipliers**
Anticipated Tax Shocks

			Multiplier				
		Anticipation	Min	Max	Mean	Std Dev	$\mathrm{corr}(\ln Y_t)$
Consumption	Output Mult.	2 Quarters	0.5274	0.6689	0.6038	0.0239	0.7909
		4 Quarters	0.5523	0.6997	0.6318	0.0242	0.7943
		6 Quarters	0.5683	0.7126	0.6467	0.0239	0.7976
	Welfare Mult.	2 Quarters	10.2820	12.6414	11.4445	0.4278	-0.7546
		4 Quarters	10.7110	13.0369	11.8625	0.4259	-0.7547
		6 Quarters	10.9405	13.1681	12.0486	0.4120	-0.7553
Labor	Output Mult.	2 Quarters	0.7423	1.3371	1.0398	0.0970	0.8345
		4 Quarters	0.8149	1.4196	1.1174	0.0948	0.8218
		6 Quarters	0.8548	1.4231	1.1396	0.0877	0.8086
	Welfare Mult.	2 Quarters	8.5624	11.5861	10.2295	0.5370	-0.5968
		4 Quarters	9.6431	13.1626	11.5216	0.6227	-0.6406
		6 Quarters	10.2955	14.0355	12.2316	0.6748	-0.6932
Capital	Output Mult.	2 Quarters	1.1775	2.0701	1.6293	0.1565	0.8967
		4 Quarters	1.3025	2.2464	1.7844	0.1597	0.8979
		6 Quarters	1.3689	2.2850	1.8454	0.1476	0.8905
	Welfare Mult.	2 Quarters	11.7058	15.9555	14.0452	0.7333	-0.5189
		4 Quarters	12.8336	17.2857	15.2595	0.7801	-0.5738
		6 Quarters	13.5112	18.0229	15.9013	0.8024	-0.6334

Note: This table shows output and welfare multiplier summary statistics generated by simulations of the model with anticipation in tax processes presented in Section 6. The length of anticipation is indicated in the third column.

Table 8: **Properties of Output and Welfare Multipliers**
Alternative Estimations

			Multiplier				
			Min	Max	Mean	Std Dev	corr(ln Y_t)
All	Output Mult.	τ_c	0.3221	0.4398	0.3733	0.0233	0.8354
		τ_n	0.6020	0.8710	0.7228	0.0480	0.8183
		τ_k	1.0944	1.7969	1.4057	0.1331	0.9390
	Welfare Mult.	τ_c	3.3693	5.7726	4.6451	0.4952	-0.8783
		τ_n	6.8732	13.7862	10.0885	1.3188	-0.8856
		τ_k	15.2833	20.5106	18.1124	0.8511	-0.4154
Distortionary	Output Mult.	τ_c	0.3326	0.4830	0.3886	0.0347	0.8247
		τ_n	0.6325	0.8894	0.7412	0.0464	0.8628
		τ_k	0.9415	1.4912	1.1596	0.1061	0.9520
	Welfare Mult.	τ_c	-13.6464	-7.2891	-10.3236	1.1022	0.4585
		τ_n	-2.5736	3.9616	0.6883	1.4868	-0.8552
		τ_k	3.7647	6.0523	4.7925	0.4551	-0.1183
Labor/Capital	Output Mult.	τ_c	0.3157	0.4695	0.3607	0.0379	0.9409
		τ_n	0.6860	1.0065	0.7982	0.0651	0.9033
		τ_k	0.9358	1.5651	1.1418	0.1328	0.9680
	Welfare Mult.	τ_c	-24.8026	-8.7817	-17.8810	3.7100	0.8513
		τ_n	-7.3458	4.5418	-1.4411	2.6513	-0.9151
		τ_k	-0.6581	7.6664	3.9704	1.8155	-0.8400
Labor	Output Mult.	τ_c	0.4635	0.6842	0.5381	0.0481	0.9077
		τ_n	0.9685	1.3983	1.1690	0.0764	0.6606
		τ_k	0.9688	1.6842	1.2076	0.1550	0.9524
	Welfare Mult.	τ_c	-18.9918	-6.2815	-12.9327	2.7139	0.6560
		τ_n	-5.0761	10.2708	3.6279	3.3805	-0.8330
		τ_k	-0.0560	4.7214	2.3159	0.7109	0.1308

Note: This table shows properties of simulated and output welfare multipliers. Before simulation the model is re-estimated under four different scenarios about how taxes adjust to stabilize debt and react to output growth. These scenarios are described in the left most column, and correspond to (i) all taxes can react to debt and output, (ii) only distortionary taxes may react (i.e. the lump sum tax is fixed), (iii) only labor and capital tax rates may react (i.e. the lump sum tax and consumption tax rate are fixed), and (iv) only the labor income tax may react (i.e. all other tax rates are fixed). Estimated parameters under different scenarios can be found in the different columns of Table 2. The third column indicates which tax rate is being shocked – τ_c for consumption, τ_n for labor, and τ_k for capital.

Table 9: **Properties of Output and Welfare Multipliers**
Rule-of-Thumb Households

|			Multiplier				
			Min	Max	Mean	Std Dev	$\text{corr}(\ln Y_t)$
$\lambda = 0.05$	Output Mult.	τ_c	0.5176	0.6594	0.5955	0.0242	0.7953
		τ_n	0.7003	1.2648	0.9843	0.0933	0.8372
		τ_k	1.0928	1.9361	1.5187	0.1484	0.8915
	Welfare Mult.	τ_c	10.3621	12.8124	11.5624	0.4427	-0.7599
		τ_n	7.8732	10.5819	9.3855	0.4863	-0.5930
		τ_k	10.2930	14.1115	12.3808	0.6480	-0.5004
$\lambda = 0.25$	Output Mult.	τ_c	0.5569	0.7245	0.6476	0.0294	0.8166
		τ_n	0.7477	1.3383	1.0468	0.0984	0.8367
		τ_k	1.1262	2.0043	1.5671	0.1551	0.8819
	Welfare Mult.	τ_c	11.8466	14.9110	13.3517	0.5583	-0.7794
		τ_n	9.0013	12.2506	10.7865	0.5813	-0.6383
		τ_k	8.3424	11.3594	10.0297	0.5243	-0.5128
$\lambda = 0.45$	Output Mult.	τ_c	0.5993	0.7995	0.7052	0.0367	0.8307
		τ_n	0.7957	1.4196	1.1104	0.1057	0.8400
		τ_k	1.1575	2.0701	1.6113	0.1621	0.8741
	Welfare Mult.	τ_c	12.9004	16.7207	14.8144	0.7113	-0.7962
		τ_n	9.9332	14.0681	12.1558	0.7456	-0.6931
		τ_k	6.1099	8.4266	7.4032	0.4060	-0.5480

Note: This table shows output and welfare multiplier summary statistics generated by simulations of the baseline model augmented with a rule-of-thumb household type whose population share is measured by the parameter λ. A full description of the model is available in Appendix B. The third column indicates which tax rate is being shocked – τ_c for consumption, τ_n for labor, and τ_k for capital.

Table 10: **Properties of Output and Welfare Multipliers**
Passive Policy Regime

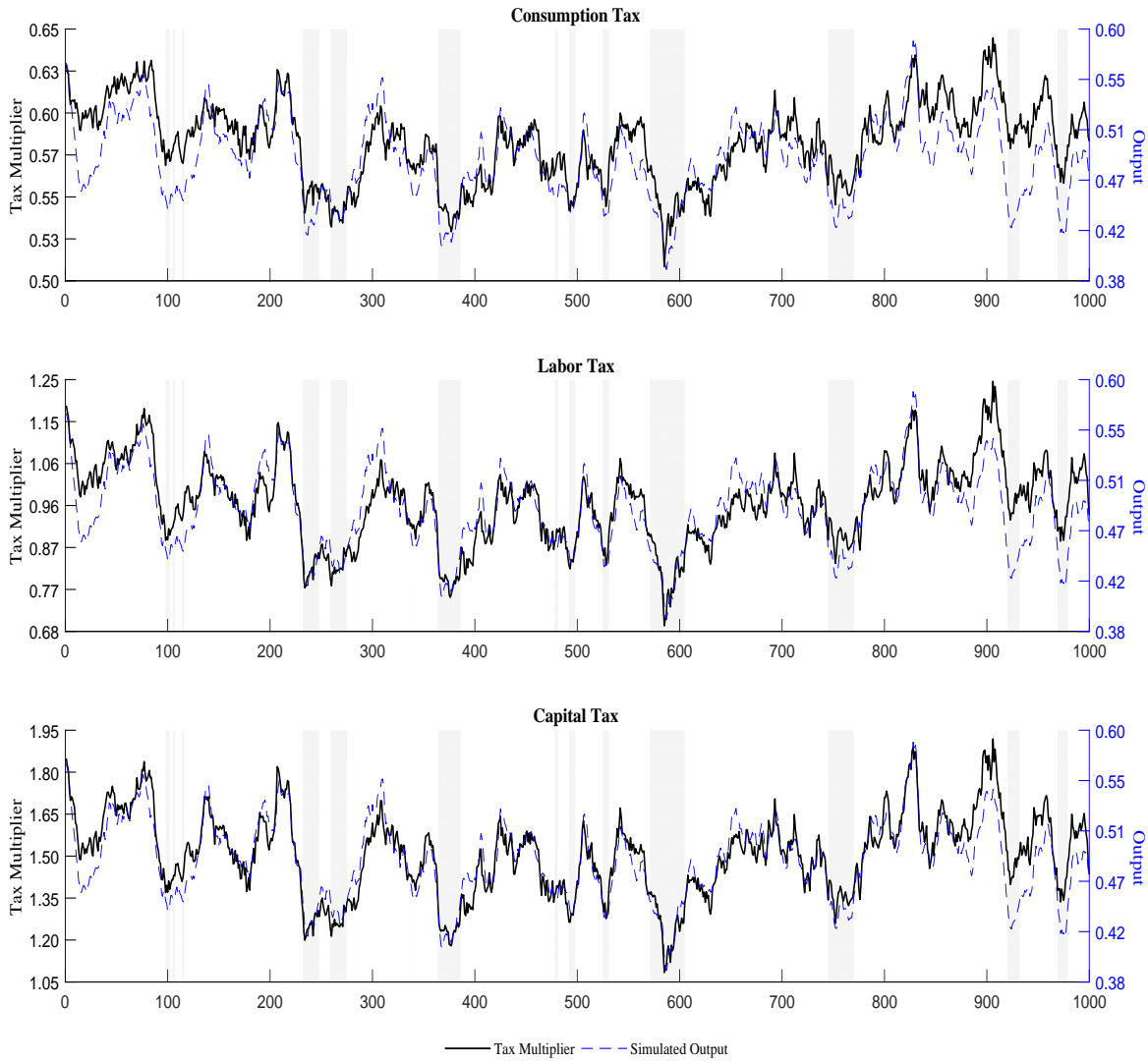|			Multiplier				
		Duration	Min	Max	Mean	Std Dev	$\text{corr}(\ln Y_t)$
Cons.	Output	2 Quarters	0.5303	0.6421	0.5847	0.0232	0.7963
		4 Quarters	0.5255	0.6328	0.5768	0.0215	0.8021
	Welfare	2 Quarters	9.9044	11.9586	10.9082	0.3645	-0.6973
		4 Quarters	9.8502	11.8790	10.8335	0.3627	-0.6979
Labor	Output	2 Quarters	0.7302	1.1704	0.9472	0.0879	0.8451
		4 Quarters	0.6509	1.0293	0.8358	0.0731	0.8435
	Welfare	2 Quarters	7.5111	10.0198	8.7719	0.4360	-0.4720
		4 Quarters	5.9495	8.5382	7.2264	0.4802	-0.3921
Capital	Output	2 Quarters	1.1242	1.8241	1.4566	0.1337	0.9052
		4 Quarters	0.9748	1.5962	1.2657	0.1120	0.9070
	Welfare	2 Quarters	10.4226	14.3724	12.5056	0.6307	-0.3749
		4 Quarters	9.3428	13.1139	11.1567	0.6316	-0.2851

Note: This table shows summary statistics for output and welfare multipliers when the nominal interest rate is pegged for the duration indicated in the third column.

Figure 1: **Output Impulse Responses**
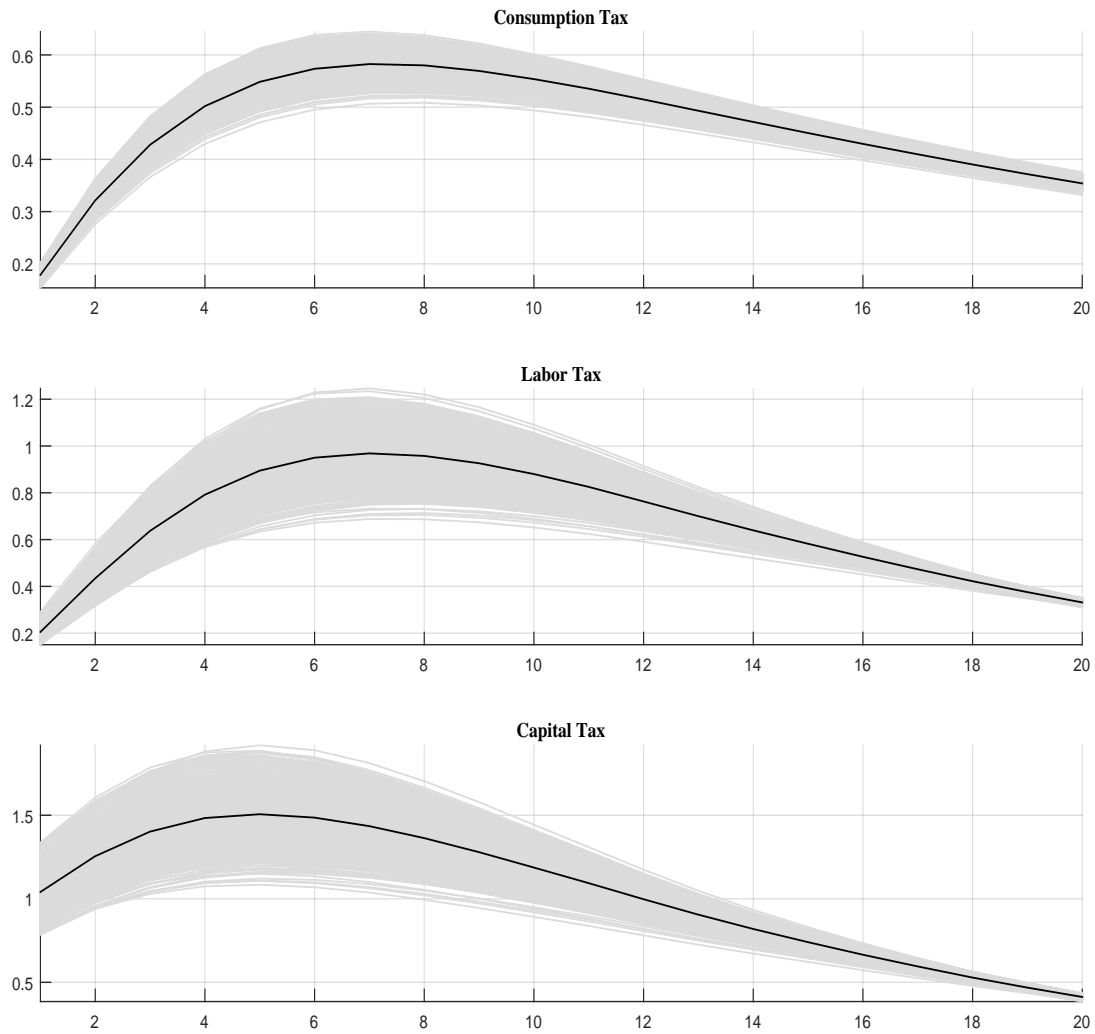
Note: This figure plots impulse response functions of output to shocks to distortionary consumption, labor, and capital tax rates. Gray lines correspond to different impulse responses for 1,000 different initial starting state vectors. The response averaged across states at each horizon is depicted by a solid black line. Impulse responses are scaled by the response of tax revenue (evaluated in the non-stochastic steady state).

Figure 2: **Multiplier Simulations**

Note: This figure plots output multipliers for consumption, labor, and capital tax shocks over the simulated state space. Gray shaded regions represent periods in which simulated output is in the bottom 20th percentile.

Figure 3: **Multipliers and the Labor Wedge**
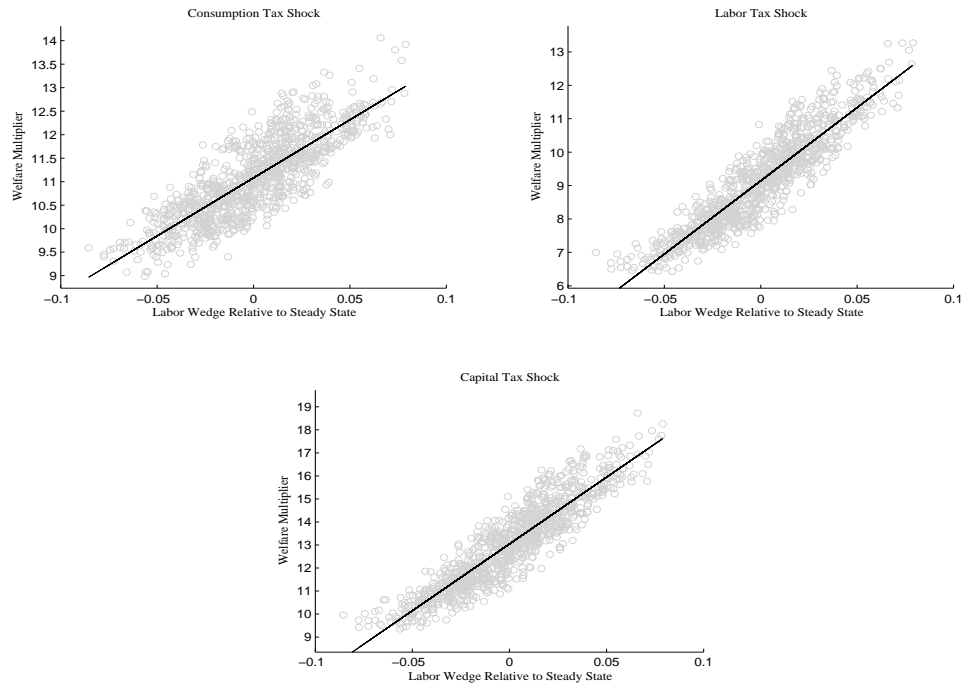
Note: This figure displays scatter plots of welfare multipliers for each type of tax rate on the vertical axes against simulated labor wedges (measured relative to the non-stochastic steady state) on the horizontal axes. Each dot represents a multiplier-labor wedge pair at a particular point in the simulated state space. The solid lines show best-fitting linear regression lines.

Figure 4: **Anticipation Impulse Response Functions**
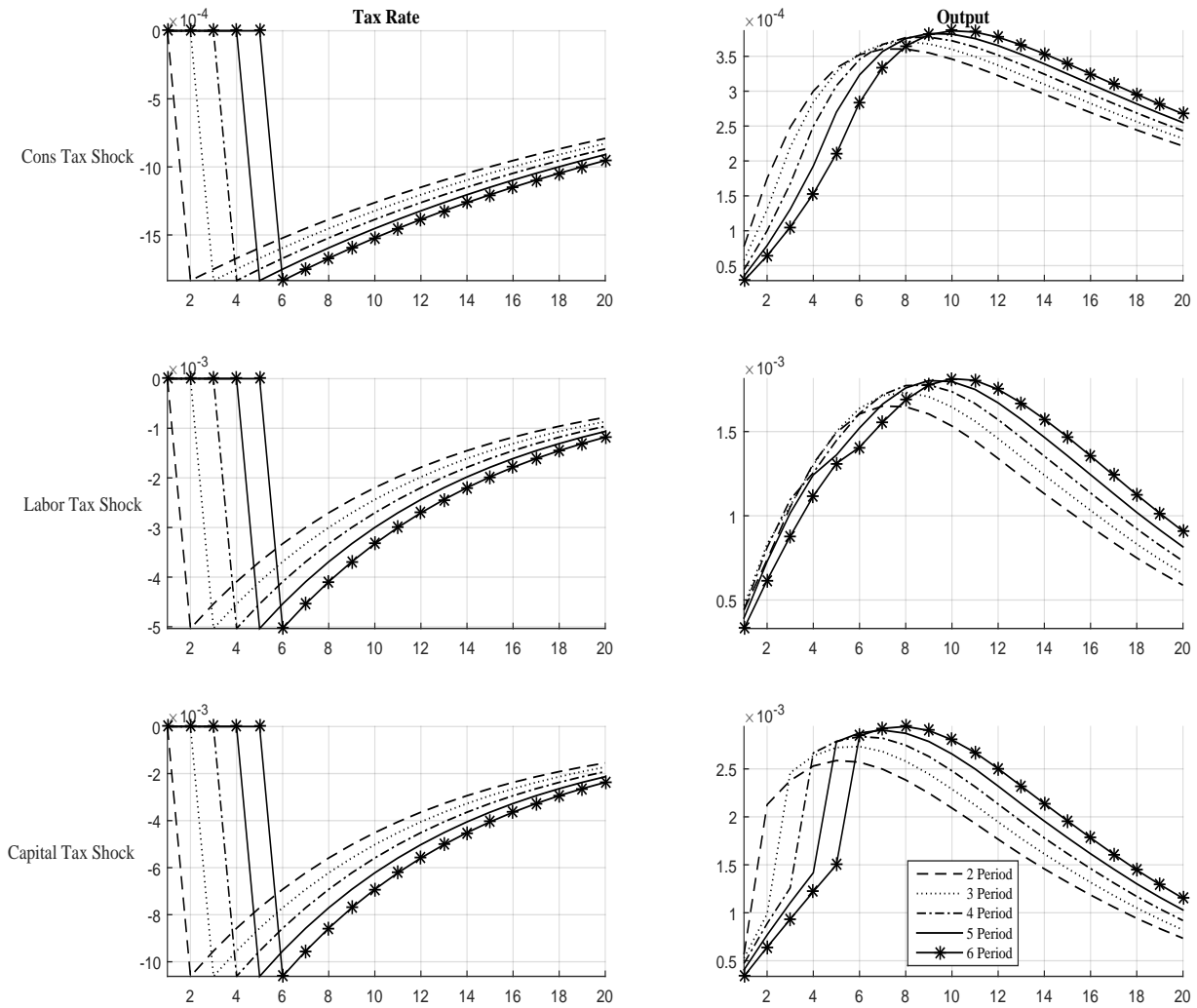
Note: This figure plots the steady state response of tax rates and output to fully anticipated shocks in each of the respective tax rates. Five unique anticipation horizons are presented with anticipation horizons ranging from 2 to 6 quarters.

Figure 5: **Passive Monetary Policy Impulse Response Functions**
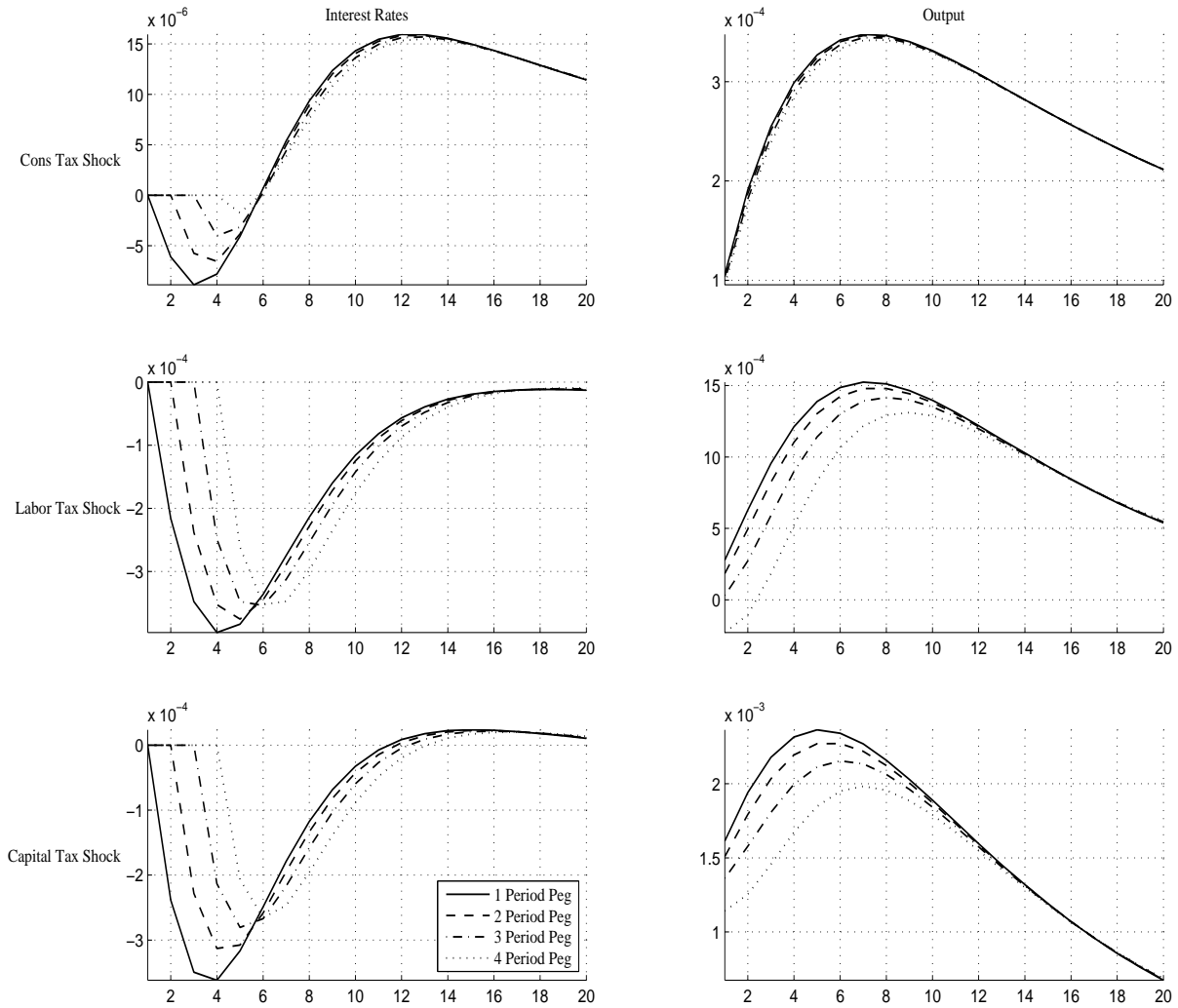
Note: This figure plots the steady state responses of the nominal interest rate and output to tax shocks when monetary policy is characterized by passive interest rate responses. Four unique passive policy regimes are presented with peg durations ranging from 1 to 4 quarters. In each scenario, the tax shock occurs in the first period.

A   Medium Scale Model

This appendix lays out the details of the medium scale DSGE model used for quantitative analysis in the paper. With the exception of a more detailed fiscal block, the model is similar to Christiano, Eichenbaum and Evans (2005), Schmitt-Grohé and Uribe (2005), Smets and Wouters (2007), and Justiniano, Primiceri and Tambalotti (2010, 2011). Hence the presentation is kept brief. The key actors in the economy are a competitive final good firm, a continuum of intermediate goods firms, a representative household, and a government. The subsections below discuss the problems and optimality conditions of each kind of agent. We then conclude the appendix with a definition of market-clearing and a concept of equilibrium.

A.1   Final Good Firm

A single, perfectly competitive final good firm bundles the output of each of the $j \in (0,1)$ intermediate goods 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:

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

The output of this final good firm is denoted by Y_t while the output of intermediate goods 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 goods firm j:

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

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

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

A.2   Intermediate Goods Firms

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

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

The exogenous variable A_t is a neutral productivity shock common to all intermediate goods firms. Capital services (the product of physical capital and utilization) are rented on a period-by-period

basis from the household 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 goods firm j results in the following optimality conditions:

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

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

Real marginal cost is defined as mc_t and is given by (A.5). All intermediate firms face common factor prices. This, coupled with the assumption that all firms face a common productivity shock, implies that intermediate goods 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:

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

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

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

The variable μ_t is the household's marginal utility of income. Equations (A.5)-(A.9) characterize the optimal behavior of the production side of the economy. The exogenous variable $u_{p,t}$ is a reduced-form price markup shock as in Smets and Wouters (2007). While we do not model its microfoundations, it could be motivated as a time-varying elasticity of substitution (see, e.g., Justiniano, Primiceri and Tambalotti 2010).

A.3 Representative Household

We follow Schmitt-Grohé and Uribe (2005) 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:

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

The real wage charged in market h is given by $w_t(h)$, $N_{d,t}$ is aggregate labor demand from intermediate goods firms, and $\epsilon_w > 1$ is the elasticity of substitution among labor in different 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 condition with (A.10), we get:

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

The term inside the integral in (A.11) is a measure of wage dispersion, to be discussed below. Household welfare is defined as the present discounted value of flow utility from consumption, C_t, and leisure, $L_t = 1 - N_t$:

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

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 exogenous preference shock.

Physical capital, K_t, accumulates according to:

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

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:

$$(1 + \tau_{c,t}) C_t + I_t + \Gamma(u_t)K_t + \frac{B_t}{P_t} \leq$$
$$(1 - \tau_{n,t}) \int_0^1 w_t(h)N_t(h)dh + (1 - \tau_{k,t})r_t^k u_t K_t + (1 + i_{t-1})\frac{B_{t-1}}{P_t} + \Pi_t - T_t \tag{A.14}$$

The nominal price of goods is denoted by P_t. Distortionary tax rates on consumption, labor income, and capital income are denoted by $\tau_{c,t}$, $\tau_{n,t}$, and $\tau_{k,t}$, 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:

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

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

$$(1 - \tau_{k,t})r_t^k = \Gamma'(u_t) \tag{A.17}$$

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

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

$$w_t^{\#} = \frac{\epsilon_w}{\epsilon_w - 1}\frac{F_{1,t}}{F_{2,t}} u_{w,t} \tag{A.20}$$

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

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

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. Similarly to the price-setting problem of intermediate goods producers, $u_{w,t}$ is an exogenous reduced form wage markup shock. It could alternatively be interpreted as a time-varying intratemporal preference shock (Chari, Kehoe and McGrattan 2009).

A.4 Government

The fiscal block of the model is as described in the main text. Monetary policy is governed by a Taylor interest rate feedback rule which responds to deviations of inflation from a steady state target, π^*, as well as to output growth:

$$i_t = (1 - \rho_i)i^* + \rho_i i_{t-1} + (1 - \rho_i)\left[\phi_\pi(\pi_t - \pi^*) + \phi_y(\ln Y_t - \ln Y_{t-1}) \right] + s_i \varepsilon_{i,t} \tag{A.23}$$

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 consistent with a determinate rational expectations equilibrium.

A.5 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 five other exogenous processes. These are the neutral productivity variable, A_t, the marginal efficiency of investment, Z_t, the intertemporal flow utility shock, ν_t, and the price and wage markup shocks, $u_{p,t}$ and $u_{w,t}$. Each of these follow mean zero AR(1) processes in the log with shocks drawn from standard normal distributions. These distributions have time invariant standard deviations of s_a, s_z, s_ν, s_{u_p}, and s_{u_w}, respectively.

$$\ln A_t = \rho_a \ln A_{t-1} + s_a \varepsilon_{a,t}, \ \ 0 \le \rho_a < 1 \tag{A.24}$$

$$\ln Z_t = \rho_z \ln Z_{t-1} + s_z \varepsilon_{z,t}, \ \ 0 \le \rho_z < 1 \tag{A.25}$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + s_\nu \varepsilon_{\nu,t}, \ \ 0 \le \rho_\nu < 1 \tag{A.26}$$

$$\ln u_{p,t} = \rho_{u_p} \ln u_{p,t-1} + s_{u_p} \varepsilon_{p,t}, \ \ 0 \le \rho_{u_p} < 1 \tag{A.27}$$

$$\ln u_{w,t} = \rho_{u_w} \ln u_{w,t-1} + s_{u_w} \varepsilon_{w,t}, \ \ 0 \le \rho_{u_w} < 1 \tag{A.28}$$

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:

$$Y_t = \frac{A_t \widetilde{K}_t^\alpha N_{d,t}^{1-\alpha}}{v_t^p} \tag{A.29}$$

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

$$v_t^p = (1 + \pi_t)^{\epsilon_p} \left[(1 - \theta_p)(1 + \pi_t^{\#})^{-\epsilon_p} + \theta_p (1 + \pi_{t-1})^{-\epsilon_p \zeta_p} v_{t-1}^p \right] \tag{A.30}$$

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

$$N_t = N_{d,t} v_t^w \tag{A.31}$$

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 recursively as:

$$v_t^w = (1 - \theta_w) \left(\frac{w_t^{\#}}{w_t} \right)^{-\epsilon_w} + \theta_w \left(\frac{w_{t-1}}{w_t} \right)^{-\epsilon_w} \left(\frac{(1 + \pi_{t-1})^{\zeta_w}}{(1 + \pi_t)} \right)^{-\epsilon_w} v_{t-1}^w \tag{A.32}$$

Aggregate inflation evolves according to:

$$(1 + \pi_t)^{1-\epsilon_p} = (1 - \theta_p)(1 + \pi_t^{\#})^{1-\epsilon_p} + \theta_p(1 + \pi_{t-1})^{\zeta_p(1-\epsilon_p)} \tag{A.33}$$

Similarly, the aggregate real wage obeys:

$$w_t^{1-\epsilon_w} = (1 - \theta_w)\left(w_t^{\#}\right)^{1-\epsilon_w} + \theta_w w_{t-1}^{1-\epsilon_w}(1 + \pi_{t-1})^{\zeta_w(1-\epsilon_w)}(1 + \pi_t)^{\epsilon_w-1} \tag{A.34}$$

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

$$Y_t = C_t + I_t + G_t + \Gamma(u_t)K_t \tag{A.35}$$

When studying properties of the welfare multiplier, we include as an equilibrium condition a recursive representation of the household's value function. In writing this, we write labor supply in terms of labor demand using (A.31):

$$V_t = \nu_t U(C_t - bC_{t-1}, 1 - N_{d,t}v_t^w) + \beta E_t V_{t+1} \tag{A.36}$$

A.6   Functional Forms

We assume that period utility from consumption and leisure takes the following form:

$$U(C_t - bC_{t-1}, 1 - N_t) = \frac{((C_t - bC_{t-1})^\gamma (1 - N_t)^{1-\gamma})^{1-\sigma} - 1}{1 - \sigma}, \qquad \sigma > 0, \ \ 0 < \gamma < 1 \tag{A.37}$$

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:

$$\Gamma(u_t) = \left(\psi_0(u_t - 1) + \frac{\psi_1}{2}(u_t - 1)^2\right) \tag{A.38}$$

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{A.39}$$

B   Incorporating Rule-of-Thumb Households into the Model

Except where otherwise noted, the model with rule-of-thumb (ROT) households is the same as the medium scale model detailed in Appendix A. A ROT household faces taxes and wages that are identical to the optimizing household. Variables with ^{r} superscripts correspond to the ROT population. The preference specification of ROT households is the same as for optimizing households, with the exception that we do not include habit formation for the ROT population. The optimization problem faced by a ROT household is:

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

$$\text{s.t.}$$

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

The following condition characterizes optimal behavior by the ROT household:

$$\frac{U_L(C_t^r, 1 - N_t^r)}{U_C(C_t^r, 1 - N_t^r)} = \frac{1 - \tau_t^n}{1 + \tau_t^c} w_t \tag{B.2}$$

Integrating over labor supplied by each household type, aggregate labor, $\hat{N}_t$, is:

$$\hat{N}_t = (1 - \lambda)N_t + \lambda N_t^r \tag{B.3}$$

Similarly, we can define aggregate consumption:.

$$\hat{C}_t = (1 - \lambda)C_t + \lambda C_t^r \tag{B.4}$$

Optimizing 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 total capital services available for rent in period t:

$$\hat{K}_t = (1 - \lambda)\widetilde{K}_t \tag{B.5}$$

Government revenue from taxes will also change with the addition of a second household type, as will our definition of aggregate welfare. Aggregate lump sum tax revenue is defined as follows.

$$\hat{T}_t = (1 - \lambda)T_t + \lambda T_t^r \tag{B.6}$$

Households of each type pay a share of lump sum taxes proportional to population shares, with total lump sum tax collection following (18). For these exercises, we assume that distortionary tax rates do not respond to debt or output growth. Lastly, we define aggregate welfare to be a population weighted average of present discounted flow utility to both household types:

$$V_t = (1 - \lambda)U(C_t - bC_{t-1}, 1 - N_t) + \lambda U(C_t^r, 1 - N_t^r) + \beta V_{t+1} \tag{B.7}$$

C Additional Quantitative Results

The correlations of output multipliers with simulated output presented in Table 3 are based on sample correlations taken over the full simulated vector of state variables. To investigate whether there are more interesting patterns of co-movement between multipliers and output at different parts of the state vector, Table C1 presents correlations between output multipliers and log output for different quantiles of the distribution of simulated log output. To construct this table, we pick out observations in which simulated log output is below the xth qauntile and compute the correlations between the tax multipliers and output over this sample of simulated data. For each type of tax rate, the output multipliers are positively correlated with output for each considered quantile.[19] Interestingly, the correlations are larger the more of the distribution of output is included in the sample. For example, focusing on the capital tax rate cut multiplier, the procyclicality is weakest when focusing on the bottom 10th percentile (0.64); is a bit larger when restricting the sample over which the correlation is taken to states in which output is below median (0.74); and is largest when all simulated periods are included (0.89). Qualitatively similar patterns hold for the consumption and labor tax rates as well.

Table C1: **Quantile Correlations**

	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Full Sample
Consumption	0.4890	0.5440	0.6150	0.7138	0.7402	0.7901
Labor	0.5969	0.6285	0.6788	0.7741	0.7923	0.8379
Capital	0.6425	0.6791	0.7482	0.8382	0.8597	0.8941

Note: This table shows correlation of (maximum) output multipliers for different types of tax cuts with simulated output across different quantiles of the distribution of simulated output. Each column corresponds to an output quantile in our simulation. As a result, the sample size neatly maps to 100, 250, 500, 750, 900, and 1,000 simulated observations.

The properties of tax rate cut multipliers presented in the text are unconditional in the sense that multipliers are constructed by simulating states from the model with all shocks (other than tax rate shocks themselves) turned on. We next investigate the extent to which the properties of the multipliers are influenced by the particular shocks driving movements in the state variables. Our quantitative exercise involves finding the magnitude of non-tax shocks which would in isolation generate the same volatility of output growth as our baseline model with all shocks operative. That is, we zero out all but one particular shock, and solve for the standard deviation of that shock necessary to generate the same volatility of output growth as in our baseline estimated model. We then generate states via simulation from the model with only one shock turned on. We then compute tax rate cut multipliers from each simulated vector of states. Results are summarized in Table C2. A couple of interesting results emerge. First, for all three types of tax rates, output multipliers are

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[19]While the correlation seems to grow across quantiles, drawing one hundred states from our distribution at random nearly always produces a correlation of simulated output and maximum tax multiplier approximately equal to average correlations across the full sample.

most variable across states conditional on neutral productivity and price markup shocks. When the only sources of volatility are preference, wage markup, or monetary policy shocks, multipliers are comparatively less volatile. Second, output multipliers are strongly procyclical in a conditional sense with the exception of the preference shock. Conditional on the preference shock, labor and capital tax rate shocks are mildly countercylical. This is consistent with our baseline results above because in the estimated model preference shocks are a relatively unimportant source of output volatility.

Table C2: **Properties of Output Multipliers, Shock-Specific**

	Neutral Productivity	Investment Efficiency	Saving/ Preference	Price Markup	Wage Markup	Monetary Policy
Consumption						
Mean	0.5698	0.5756	0.5778	0.5839	0.5786	0.5776
St. Dev.	0.0515	0.0155	0.0049	0.0400	0.0100	0.0025
Corr w/ Output	0.8441	0.3935	0.4683	0.8846	0.5861	0.6246
Labor						
Mean	0.9120	0.9096	0.9427	0.9457	0.9364	0.9376
St. Dev.	0.1821	0.0826	0.0261	0.1443	0.0446	0.0123
Corr w/ Output	0.9003	0.8203	-0.4195	0.9317	0.7221	0.5453
Capital						
Mean	1.4464	1.4384	1.4899	1.4993	1.4829	1.4891
St. Dev.	0.2554	0.1308	0.0447	0.2442	0.0945	0.0159
Corr w/ Output	0.9203	0.8716	-0.4367	0.9541	0.8210	0.5538

Note: This table presents properties of output multipliers for the three different types of tax rate cuts when states are simulated with only the shock listed in the columns operative. The numerical exercise used to construct this table is described in the text.

As we did for output multipliers, we also investigate the extent to which the properties of welfare multipliers depend on the shocks driving fluctuations. Table C3 is constructed similarly to Table C2 but focuses on welfare multipliers. The underlying numerical exercise is identical. Welfare multipliers are very strongly countercyclical conditional on price markup shocks. This is not particularly surprising – when output is low because of these shocks, the economy is very highly distorted, making the value of easing distortions particularly high. The results conditional on other shocks are more nuanced. Conditional on preference shocks, for example, welfare multipliers are strongly procyclical. This result should not be surprising either. When output is low because of preference shocks, the household places a small utility weight on additional consumption. Easing distortions by cutting taxes in such periods is not going to be particularly valuable, and is instead going to be more valuable in periods in which output is high. Welfare multipliers for all three types of tax rates are also procyclical conditional on marginal efficiency of investment shocks. Cuts in tax rates generally stimulate investment, and the welfare benefit to stimulating investment will not be particularly high in periods in which the efficiency of investment is low. Welfare multipliers are either acyclical or countercyclical conditional on neutral productivity and wage markup shocks, and procyclical conditional on monetary shocks. Overall, while welfare multipliers are quite countercyclical in an unconditional sense, these results suggest that some care needs to be taken in interpreting our normative results, because the type of shock driving fluctuations is potentially important, much more so than for the cyclicality of output multipliers.

Table C3: **Properties of Welfare Multipliers, Shock-Specific**

	Neutral Productivity	Investment Efficiency	Saving/ Preference	Price Markup	Wage Markup	Monetary Policy
Consumption						
Mean	11.0971	11.1165	10.9726	11.0078	10.1095	11.0466
St. Dev.	0.2869	0.1244	0.1147	0.8035	0.2615	0.0285
Corr w/ Output	-0.6460	0.0717	0.8298	-0.9229	-0.1707	0.1596
Labor						
Mean	9.0701	8.9550	9.2031	8.8234	8.9210	9.0625
St. Dev.	0.3261	0.2827	0.1954	0.8956	0.8002	0.2060
Corr w/ Output	-0.0026	0.7942	0.4414	-0.8873	0.3104	0.5109
Capital						
Mean Welfare Mult	13.1070	12.9403	13.0086	12.6866	12.6899	13.0849
St. Dev.	0.5177	0.4978	0.2303	1.2768	0.3927	0.1535
Corr w/ Output	0.0291	0.8204	0.9251	-0.8410	-0.2191	0.9168

Note: This table is similar to Table C2, but focuses on properties of welfare multipliers rather than output multipliers.