

# The Welfare and Distributional Effects of Fiscal Volatility: a Quantitative Evaluation

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## Abstract

This study explores the welfare and distributional effects of fiscal volatility using a neoclassical stochastic growth model with incomplete markets. In our model, households face uninsurable idiosyncratic risks in their labor income and discount factor processes, and we allow aggregate uncertainty to arise from both productivity and government purchases shocks. We calibrate our model to key features of the U.S. economy, before eliminating government purchases shocks. We then evaluate the distributional consequences of the elimination of fiscal volatility and find that, in our baseline case, welfare gains increase with private wealth holdings.

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# 1 Introduction

One consequence of the financial crisis followed by political turmoil has been the perception of high volatility in government policies in both the U.S. and in Europe.<sup>1</sup> In this paper, we study, from the viewpoint of the household, the welfare costs of the volatility of government purchases, both in the aggregate and across different wealth holdings. We do so in a neoclassical model with incomplete markets and a richly specified government sector, where we eliminate the volatility of government purchases once and for all.

Most of the existing research on the consequences of fiscal volatility has focused on the aggregate effects of short-run volatility fluctuations on various macroeconomic variables. In one study, Baker et al. (2016) analyze Internet news and find a (causal) relationship between high policy uncertainty and subdued aggregate economic activity. In another study, based on a New Keynesian DSGE model, Fernández-Villaverde et al. (2015) find large contractionary effects of fiscal volatility on economic activity accompanied by inflationary pressure, especially when the nominal interest rate is at the zero lower bound. By contrast, we study the effects of permanently eliminating fiscal volatility on household welfare with a particular emphasis on distributional aspects.<sup>2</sup> In studying the welfare effect of permanent changes in fiscal policy, we take a similar approach to McKay and Reis (2016). They focus on permanent changes in the automatic stabilizer role of fiscal policy. Our study complements theirs through its focus on government purchases rather than transfers (see below for a more detailed discussion of the literature).

To quantify the welfare costs of fluctuations in government purchases for households, we follow the approach of Krusell and Smith (1998) and use an incomplete market model where heterogeneous households face uninsurable idiosyncratic risks in their labor income and discount factor processes. We then calibrate this model with U.S. data, in particular data on U.S. wealth inequality. Our model has aggregate uncertainty arising from both productivity and government purchases shocks. We thus specify government purchases shocks as the only fundamental source of fiscal volatility.<sup>3</sup> In line with the data, we further assume that government purchases shocks are independent of aggregate productivity and employment conditions. Government purchases enter the utility function of the households as separable goods.<sup>4</sup>

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<sup>1</sup>This paper focuses on “fiscal volatility.” However, in describing the related literature, we follow the widespread use in the recent literature and treat “fiscal uncertainty” and “fiscal volatility” as synonymous.

<sup>2</sup>There are a few exceptions in an older literature with either no or rather limited heterogeneity: Bizer and Judd (1989), Chun (2001), and Skinner (1988).

<sup>3</sup>This might seem like an extreme assumption. It might be interesting to explore an alternative environment where government purchases are at least partly endogenously determined (see, e.g., Bachmann and Bai, 2013a,b). However, this assumption makes the implementation and interpretation of the thought experiment of eliminating fiscal volatility clean and transparent, and is akin to the original thought experiment about the elimination of business cycles in Lucas (1987, 2003).

<sup>4</sup>We consider other utility specifications with complementary and substitutable private-public good relationships,

Because the government partially funds its expenditures through taxation, purchases fluctuations generate volatile household-specific tax rates. To capture the distributional effects of fiscal shocks through taxation, we model key features of the progressive U.S. income tax system. In a progressive tax system, aggregate government purchases fluctuations may lead to changes in the distribution of household-specific tax rates and thus to idiosyncratic after-tax income uncertainty. We also employ an empirical aggregate tax revenue response rule, which includes government debt and is estimated from U.S. data.

To eliminate fiscal volatility, following Krusell and Smith (1999) and Krusell et al. (2009), we start from a stochastic steady state of the economy with both productivity and government purchases shocks, and remove the fiscal shocks at a given point in time by replacing them with their conditional expectations, while retaining the aggregate productivity process. We then compute the transition path towards the new stochastic steady state in full general equilibrium. Based on the quantitative solution for this transition path, we then compare the welfare of various household groups in the transition-path equilibrium to their welfare level with both aggregate shocks in place.

Our results show that the aggregate welfare costs from fiscal shocks are fairly small. The effect of removing fiscal volatility is equivalent to a 0.03% increase in the lifetime consumption on average. This is comparable to the welfare costs of business cycle fluctuations reported in Lucas (1987, 2003), even though in our model aggregate (spending) fluctuations lead to idiosyncratic uncertainty in income tax rate in addition to before-tax factor prices volatility, so that they, a priori, may lead to larger welfare costs than in Lucas (1987, 2003) (see Krusell et al., 2009).

Our results also reveal interesting variations in the welfare costs of fiscal volatility along the wealth distribution. The welfare gains of eliminating fiscal volatility are increasing in household wealth according to the baseline specification, where the implementation of the progressive U.S. federal income tax system and the aggregate tax revenue response rule is modeled to best match the cyclicity of important moments of the U.S. tax system.

Since volatile tax rates pre-multiply labor income levels, they generate – loosely speaking – multiplicative after-tax labor income risk.<sup>5</sup> Just as with the additive labor endowment risk in early incomplete market models, this after-tax labor income risk leads households to self-insure through precautionary saving. Wealth-rich households can thus achieve a higher degree of self-insurance relative to wealth-poor households. Consequently, from a precautionary saving perspective, wealth-poor households should gain more when fiscal volatility is eliminated.

However, due to the multiplicative nature of the after-tax capital income risk, the tax-rate

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respectively, in extensions to the baseline calibration.

<sup>5</sup>This is cleanest in a linear tax system. However, even in a progressive tax system, the fluctuating average tax rates work like multiplicative after-tax income risk.

uncertainty induced by government purchases fluctuations also creates a rate-of-return risk to savings, which in turn, impacts the quality of capital and bonds as saving vehicles.<sup>6</sup> In a realistic incomplete asset market model where the after-tax return of all the financial assets is subject to tax rate uncertainty, wealth-rich households have much larger exposure to such a rate-of-return risk. As a result, from the rate-of-return risk perspective, wealth-rich households should gain more when fiscal volatility is eliminated.

Finally, the distributional effects of eliminating fiscal volatility can depend on its effect on the average factor prices.<sup>7</sup> The precautionary saving and rate-of-return risk effects lead to endogenous responses of the aggregate capital stock, changing both the pre-tax capital rate-of-return and real wages. In our baseline specification, the aggregate capital stock first declines and then increases after the elimination of fiscal volatility, causing a higher interest rate and lower wage rate in the early transition periods followed by a reversal later on.

Whether the combination of these three effects favors the wealth-rich or the wealth-poor households depends *in principle* – as we will show – on the details of the implementation of the progressive tax system and the aggregate tax revenue rule. Under the baseline specification, which is calibrated to best mimic the cyclical behavior of key moments of the U.S. tax system, the wealth-rich households are significantly exposed to the rate-of-return risk caused by tax-rate uncertainty, and they also benefit from changes in average factor prices. As a result, we find that the welfare gains are increasing in household wealth. The first contribution of the paper is thus to provide a calibration strategy that allows us to quantify the net effect of the precautionary saving, the rate-of-return risk, and the average factor price effects.

In addition to our baseline, we consider alternative implementations of how the progressive tax system and the aggregate tax revenue rule interplay. The distributional effects of fiscal volatility vary in these exercises, and thus, despite their counterfactual implications, help us uncover the mechanisms through which fiscal volatility influences economic welfare. A second contribution of the paper is thus to map out the relationship between tax instruments in a progressive tax system used to obtain the cyclical adjustment of the government budget and the distributional effects of fiscal volatility.

We also consider three other fiscal regimes: a balanced budget regime with a progressive tax system, a linear tax system, and a lump-sum tax system, with the latter two again allowing for government debt. The welfare results under those three regimes are all in line with our baseline.

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<sup>6</sup>Angeletos and Calvet (2006), in a seminal contribution on risk in incomplete markets, discuss this tension between labor endowment risk and rate-of-return risk.

<sup>7</sup>There is also a direct utility effect because households are risk averse with respect to government purchases fluctuations.

In another variation, we show that when private and public consumption are complements, the overall welfare gains from eliminating government purchases fluctuations are higher, because a higher government purchases level leads to a higher marginal utility of private consumption when taxes are high (because government purchases are large). Finally, motivated by recent policy discussions of the possible permanence of heightened fiscal volatility, we examine the welfare consequences of doubling the historical government purchases volatility level. Our results suggest that the welfare effects of fiscal volatility are symmetric between zero and twice the pre-crisis volatility of government purchases.

In addition to its substantive contributions, our study makes a technical contribution to the literature. Specifically, we merge the algorithm for computing the *deterministic* transition path in heterogeneous-agent economies from Huggett (1997) and Krusell and Smith (1999), and the algorithm for computing a *stochastic* recursive equilibrium in Krusell and Smith (1998), to show that an approximation of the wealth distribution and its law of motion by a finite number of moments can also be applied to a stochastic transition path analysis. Recall that after fiscal volatility is eliminated, our economy is still subject to aggregate productivity shocks. This solution method should prove useful for other quantitative studies of stochastic transition-path equilibria.

#### *Related Literature*

Besides the general link to the literature on incomplete markets and wealth inequality (see Heathcote et al., 2009 for an overview), our study is most closely related to three strands of literature.

First, our paper contributes to research on the welfare costs of aggregate fluctuations (see Lucas, 2003 for a comprehensive discussion). As in Krusell and Smith (1999), Mukoyama and Sahin (2006) and Krusell et al. (2009), we quantify the welfare and distributional consequences of eliminating macroeconomic fluctuations. However, while these studies focus on TFP fluctuations, we examine the welfare consequences of eliminating fluctuations in government purchases. Our study complements theirs by examining fluctuations due to fiscal policy, arguably a more plausible candidate fluctuation to be (fully) eliminated by a policy maker – they are, after all, the result of a policy decision.

Second, our paper relates to the recent literature about the effects of economic uncertainty on aggregate economic activity. Most of the research in this stream of literature has focused on the amplification and propagation mechanisms for persistent, but temporary volatility shocks, which are typically modeled and measured as changes to the conditional variance of traditional economic shocks. These uncertainty shocks include second-moment shocks to aggregate productivity, and

policy and financial variables, which are often propagated through physical production factor adjustment costs, sticky prices, or financial frictions (see e.g., Arellano et al., 2016, Bachmann and Bayer, 2013, 2014, Baker et al., 2016, Basu and Bundick, 2017, Bloom, 2009, Bloom et al., 2012, Born and Pfeifer, 2014, Croce et al., 2012, Fernández-Villaverde et al., 2015, Gilchrist et al., 2014, Kelly et al., 2016, Mumtaz and Surico, 2015, Mumtaz and Zanetti, 2013, Nodari, 2014, Pastor and Veronesi, 2012, 2013, and Stokey, 2016). Other studies investigate the effects of uncertainty in the (time-varying) parameters of monetary or fiscal feedback rules (Bi et al., 2013, Davig and Leeper, 2011, and Richter and Throckmorton, 2015), or in the bargaining power parameter of search and matching models (Drautzburg et al., 2017). Our study complements this literature by focusing on the welfare and distributional effects of a permanent change in fiscal volatility.

Finally, our work contributes to the growing body of literature on macroeconomic policy in heterogeneous-agent environments (Auclert, 2017, Bachmann and Bai, 2013a, Bhandari et al., 2016, 2017a,b, Böhm, 2015, Brinca et al., 2016, Dyrda and Pedroni, 2017, Ferriere and Navarro, 2017, Gornemann et al., 2016, Gomes et al., 2013, Hagedorn et al., 2017, Heathcote, 2005, Hedlund et al., 2016, Kaplan and Violante, 2014; Kaplan et al., 2016, Li, 2013, McKay and Reis, 2016, and Röhrs and Winter, 2017). There is also a budding empirical literature on the distributional consequences of policy actions: see Coibion et al. (2017) for the case of monetary policy and Giorgi and Gambetti (2012) for the case of fiscal policy.

The remainder of the paper is structured as follows. Section 2 presents the model. Section 3 discusses its calibration. Section 4 describes our solution method. Section 5 presents the baseline findings on the welfare and distributional effects of eliminating government purchases fluctuations, while Section 6 investigates these welfare and distributional effects in alternative model specifications. We close in Section 7 with final comments and relegate the details of the quantitative procedure to various appendices.

## 2 Model

Following Aiyagari (1994) and Huggett (1993), we model an incomplete market setting where a continuum of infinitely-lived heterogeneous households face uninsurable idiosyncratic risks in their labor efficiency processes. We also include aggregate productivity shocks as well as shocks to a household's discount factor, as in Krusell and Smith (1998). We then add aggregate uncertainty from government purchases shocks. In our model exposition, we focus our discussion on the fiscal elements.

## 2.1 The private sector

Our households are *ex-ante* identical, with preferences given by:

$$E_0 \sum_{t=0}^{\infty} \beta_t u(c_t, G_t), \quad (2.1)$$

where  $\beta_t$  denotes the cumulative discount factor between period 0 and period  $t$ . In particular,  $\beta_t = \tilde{\beta} \beta_{t-1}$ , where  $\tilde{\beta}$  is an idiosyncratic shock following a three-state, first-order Markov process. Furthermore,  $c_t$  denotes private consumption, and  $G_t$  the public good provided by the government (government purchases).

The strictly concave flow utility function has constant relative risk aversion (CRRA) with respect to a constant-elasticity-of-substitution (CES) aggregate of  $c$  and  $G$ ,

$$u(c_t, G_t) = \frac{\left( \theta c_t^{1-\rho} + (1-\theta) G_t^{1-\rho} \right)^{\frac{1-\gamma}{1-\rho}} - 1}{1-\gamma}, \quad (2.2)$$

where  $\gamma$  is the risk aversion parameter and  $1/\rho$  is the elasticity of substitution between  $c$  and  $G$ . We discuss the details of the  $G_t$ -process in the next subsection.

Our households also face idiosyncratic employment shocks. We denote the employment process by  $\varepsilon$ , which follows a first-order Markov process with two states  $\{0, 1\}$ .  $\varepsilon = 1$  denotes that the household is employed, providing a fixed amount of labor  $\tilde{l}$  to the market, and is paid the market wage,  $w$ .  $\varepsilon = 0$  represents the unemployed state of a household who receives an unemployment insurance payment that equals a fraction  $\omega$  of the current wage income of an employed household.

We represent the aggregate production technology as a Cobb-Douglas function:

$$Y_t = z_t F(K_t, L_t) = z_t K_t^\alpha L_t^{1-\alpha}, \quad (2.3)$$

where  $K_t$  is aggregate capital,  $L_t$  is aggregate labor efficiency input, and  $z_t$  is the aggregate productivity level.  $z_t$  follows a two-state  $(z_g, z_b)$  first-order Markov process, where  $z_g$  and  $z_b$  denote aggregate productivity in good and bad times, respectively. Note that, because of the law of large numbers,  $L_t$  equals  $(1 - u_t)\tilde{l}$ , where  $u_t$  is the unemployment rate. We also allow the unemployment rate to take one of two values:  $u_g$  in good times and  $u_b$  in bad times. In this way,  $u_t$  and  $z_t$  move perfectly together.

We now specify the standard aggregate resource constraint:

$$C_t + K_{t+1} + G_t = Y_t + (1 - \delta)K_t, \quad (2.4)$$

where  $C_t$  represents aggregate consumption, and  $\delta$  the depreciation rate.

The markets in our model are perfectly competitive. Labor and capital services are traded on spot markets each period, at factor prices  $r(K_t, L_t, z_t) = \alpha z_t K_t^{\alpha-1} L_t^{1-\alpha} - \delta$  and  $w(K_t, L_t, z_t) =$

$(1 - \alpha)z_t K_t^\alpha L_t^{-\alpha}$ . In addition, we assume that the households can trade one-period government bonds on the asset market in each period  $t$ . For computational tractability, we follow Heathcote (2005) and assume that government bonds pay the same rate-of-return as physical capital in all future states in  $t + 1$ . Because of the assumed perfect substitutability between capital and bonds, each household has access to effectively only one asset in self-insuring against stochastic shocks. We use  $a$  to denote a household's total asset holdings, i.e., the sum of physical capital and government bonds.

## 2.2 Fiscal volatility and the government budget

Our model has three government spending components: government purchases,  $G_t$ , aggregate unemployment insurance payments,  $Tr_t$ , and aggregate debt repayments,  $(1 + r_t)B_t$ . Government purchases are the only fundamental source of fiscal volatility. They follow an AR(1) process in logarithms:

$$\log(G_{t+1}) = (1 - \rho_g) \overline{\log(G)} + \rho_g \log(G_t) + (1 - \rho_g^2)^{\frac{1}{2}} \sigma_g \epsilon_{g,t+1}, \quad (2.5)$$

where  $\rho_g$  is a persistence parameter,  $\overline{\log(G)}$  is the unconditional mean of  $\log(G_t)$ ,  $\epsilon_{g,t+1}$  is an innovation term which is normally distributed with mean zero and variance one, and  $\sigma_g$  is the unconditional standard deviation of  $\log(G_t)$ . Note that the government purchases process is independent of the process for aggregate productivity. As is well known and as we show below, government purchases are roughly acyclical in U.S. quarterly data.

The aggregate unemployment insurance payment,  $Tr_t = u_t \omega w_t \tilde{l}$ , depends on both the unemployment rate,  $u_t$ , and the size of the unemployment insurance payment for each household,  $\omega w_t \tilde{l}$ .

We assume that government spending at time  $t$  is financed through a combination of aggregate tax revenue,  $T_t$ , and new government debt,  $B_{t+1}$ . As in Bohn (1998) and Davig and Leeper (2011), we model the aggregate tax revenue net of transfers (as a fraction of GDP) as an (increasing) function of the debt-to-GDP ratio, making the debt-to-GDP ratio stationary. We can thus specify the following tax revenue response rule for determining tax revenue:

$$\frac{T_t - Tr_t}{Y_t} = \rho_{T,0} + \rho_{T,Y} \log\left(\frac{Y_t}{\bar{Y}}\right) + \rho_{T,B} \frac{B_t}{\bar{Y}} + \rho_{T,G} \frac{G_t}{\bar{Y}}, \quad (2.6)$$

where  $(\rho_{T,0}, \rho_{T,Y}, \rho_{T,B}, \rho_{T,G})$  is a vector of positive coefficients and  $\bar{Y}$  is a constant number equal to the unconditional mean of GDP in the ergodic distribution.<sup>8</sup> Furthermore,  $\rho_{T,Y}$  captures the

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<sup>8</sup> $\bar{Y}$  serves as a normalization to make the coefficients of the tax revenue response rule scale-free (we obtain  $\bar{Y}$  through a fixed-point iteration procedure as it endogenously affects the average income of the economy through the tax revenue response rule). Also, while  $\rho_{T,B} > 0$  is necessary for the debt-to-GDP ratio to be stationary, this condition is not imposed. Instead, all coefficients in equation (2.6) are estimated from the data, and this estimated



automatic stabilizer role of the U.S. tax system when  $\rho_{T,Y} > 0$ , and  $\rho_{T,B}$  and  $\rho_{T,G}$  reflect the capability of the endogenous revenue adjustment system in maintaining long-run fiscal sustainability. Note that our tax revenue response rule implies that the government purchases level (relative to GDP) and the GDP gap are the main non-debt determinants of the primary surplus.

Given the total tax revenue in (2.6), we can use the government budget constraint to determine the dynamics of aggregate government debt  $B_{t+1}$ :

$$B_{t+1} = (1 + r_t)B_t + (G_t + Tr_t - T_t). \quad (2.7)$$

### 2.3 The progressive tax system

Because the distribution of the tax burden across households is important for quantifying the distributional effects of fiscal policies, we model the tax system to approximate the current U.S. tax regime as realistically as possible while maintaining a certain tractability. Specifically, the government uses a flat-rate consumption tax and a progressive income tax to raise the aggregate tax revenue  $T_t$ . The consumption tax is given by:

$$\tau^c(c_t) = \tau_c c_t. \quad (2.8)$$

This specification allows the model to capture sources of tax revenue other than income taxes, which in turn provides a total income tax burden that is in line with the data.

Following Castañeda et al. (2003), we specify the progressive income tax function as:

$$\tau^y(y_t) = \begin{cases} \tau_1 \left[ y_t - (y_t^{-\tau_2} + \tau_3)^{-\frac{1}{\tau_2}} \right] + \tau_0 y_t & \text{if } y_t > 0 \\ 0 & \text{if } y_t \leq 0, \end{cases} \quad (2.9)$$

where  $(\tau_0, \tau_1, \tau_2, \tau_3)$  is a vector of tax coefficients and  $y_t$  is taxable household income; or  $y_t = r_t a_t + w_t \varepsilon_t \tilde{l}$ .<sup>9</sup> The first term in the above equation is based on Gouveia and Strauss' (1994) characterization of the effective federal income tax burden of U.S. households.<sup>10</sup> The federal income tax accounts for about 40% of federal government revenue and is the main driver of progressivity in the U.S. tax system (Piketty and Saez, 2007). The linear term,  $\tau_0 y_t$ , is used to capture any remaining tax revenue, including state income taxes, property taxes and excise taxes.

With these tax specifications, a household's budget constraint can be written as:

$$(1 + \tau_c)c_t + a_{t+1} = a_t + y_t - \tau^y(y_t) + (1 - \varepsilon_t)\omega w(K_t, L_t, z_t)\tilde{l}. \quad (2.10)$$

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$\rho_{T,B}$  just turns out to be positive.

<sup>9</sup>Unlike in Castañeda et al. (2003), where households cannot borrow and thus cannot have negative income,  $y_t$  can be negative in our model in rare cases, so that we have to specify the tax function also for the case of  $y_t < 0$ .

<sup>10</sup>The definition of income in Gouveia and Strauss (1994) is total taxable income including realized capital gains, which is consistent with our treatment in the model.

Note that equation (2.6) specifies a tax revenue response rule to calculate the aggregate government tax revenue. Equations (2.8) and (2.9), on the other hand, model the concrete tax instruments with which the government collects tax revenue. These two sets of equations are compatible only if we treat one of the parameters in equation (2.9) as an endogenous tax instrument, to be determined in equilibrium, rather than a fixed tax parameter. We choose, in the baseline specification,  $\tau_1$  for this endogenous parameter,  $\tau_{1,t}$ , and denote the resulting tax function by  $\tau^y(y_t; \tau_{1,t})$ . Adjusting  $\tau_1$  means that the top marginal (average) tax rates,  $\tau_0 + \tau_1$ , are the main instruments for the required tax schedule adjustments.<sup>11</sup> As we will show in Section 3, choosing  $\tau_1$  to be the endogenous tax instrument best matches certain time series evidence on the progressivity measures of the federal income tax code documented in Gouveia and Strauss (1994). This adjustment can satisfy the empirical tax revenue response rule that describes aggregate U.S. tax adjustments well, and, more importantly, ensures the stationarity of the debt-to-GDP ratio. Consequently, we take the empirical tax revenue response rule as given and endogenously adjust one aspect of the tax system to make the two sets of equations compatible, as in Davig and Leeper (2011) and Fernández-Villaverde et al. (2015).

Given our tax function specification, we can now specify total tax revenue as follows:

$$T_t = \tau_c C_t + \int_0^1 \left[ \tau_0 y_{i,t} + \tau_{1,t} \left( y_{i,t} - (y_{i,t}^{-\tau_2} + \tau_3)^{-\frac{1}{\tau_2}} \right) \right] * \mathbb{1}(y_{i,t} > 0) di. \quad (2.11)$$

Equation (2.11) defines an implicit function of  $\tau_{1,t}$ . Recall that  $T_t$  is governed by  $G_t$ ,  $Y_t$ ,  $B_t$ , and  $Tr_t$  through the tax revenue response rule specified in equation (2.6). This means that, for a given inherited level of bond holdings,  $B_t$ ,  $\tau_{1,t}$  fluctuates in response to changes in both  $G_t$  and the income distribution. As a result, in our baseline model the *aggregate* volatility in  $G_t$  translates into *idiosyncratic* tax rate uncertainty.

## 2.4 The household's decision problem and the competitive equilibrium

In this subsection, we discuss the household's dynamic decision problem, which is determined by both the idiosyncratic state vector  $(a, \varepsilon, \tilde{\beta})$  and the aggregate state vector  $(\Gamma, B, z, G)$ , where  $\Gamma$  denotes the measure of households over  $(a, \varepsilon, \tilde{\beta})$ . We begin by letting  $H_\Gamma$  denote the equilibrium transition function for  $\Gamma$ :<sup>12</sup>

$$\Gamma' = H_\Gamma(\Gamma, B, z, G, z'). \quad (2.12)$$

<sup>11</sup>Both derivatives of equation (2.9) and equation (2.9) divided by  $y_t$  converge to  $\tau_0 + \tau_1$  for large  $y_t$ . In Section 6, we examine three alternative specifications, where we let  $\tau_0$ ,  $\tau_2$ , and  $\tau_3$ , respectively, be the tax instruments that adjust endogenously.

<sup>12</sup>Note that  $z'$ , but not  $G'$ , is an argument of  $H_\Gamma$ . This is because, in our setting, which reflects the setting in Krusell and Smith (1998), the future  $z$  affects the employment transition process, while the  $G$ -process is independent of other processes. Note that we also leave time subscripts and switch into recursive notation now.

We next let  $H_B$  denote the (exogenous) transition function for  $B$ , as described in equation (2.7):

$$B' = H_B(\Gamma, B, z, G). \quad (2.13)$$

Finally, we let  $\Theta$  denote the equilibrium function for the endogenous tax parameter  $\tau_1$ , which is implicitly determined in equation (2.11):

$$\tau_1 = \Theta(\Gamma, B, z, G). \quad (2.14)$$

The dynamic programming problem faced by a household can now be written as follows:

$$V(a, \varepsilon, \tilde{\beta}, \Gamma, B, z, G; H_\Gamma, \Theta) = \max_{c, a'} \{u(c, G) + \tilde{\beta} E[V(a', \varepsilon', \tilde{\beta}', \Gamma', B', z', G'; H_\Gamma, \Theta) | \varepsilon, \tilde{\beta}, z, G]\}$$

$$\text{subject to: } (1 + \tau_c)c + a' = a + y - \tau^y(y; \tau_1) + (1 - \varepsilon)\omega w(K, L, z)\tilde{l}$$

$$y = r(K, L, z)a + w(K, L, z)\varepsilon\tilde{l},$$

$$a' \geq \underline{a},$$

$$\Gamma' = H_\Gamma(\Gamma, B, z, G, z'),$$

$$B' = H_B(\Gamma, B, z, G),$$

$$\tau_1 = \Theta(\Gamma, B, z, G),$$

where  $\varepsilon$  and  $\tilde{\beta}$  follow the processes specified in Section 2.1,  $G$  follows the process specified in equation (2.5), and  $\underline{a}$  is an exogenously set borrowing constraint. Finally, we can summarize the optimal saving decision for households in the following policy function:

$$a' = h(a, \varepsilon, \tilde{\beta}, \Gamma, B, z, G; H_\Gamma, \Theta). \quad (2.15)$$

Our recursive competitive equilibrium is then defined as: the law of motion  $H_\Gamma$ ,<sup>13</sup> individual value and policy functions  $\{V, h\}$ , pricing functions  $\{r, w\}$ , and the  $\Theta$ -function for the endogenous parameter  $\tau_1$ , such that:

1.  $\{V, h\}$  solve the household's problem.
2.  $\{r, w\}$  are competitively determined.
3.  $\Theta$  satisfies equation (2.11) with the tax revenue response rule (2.6) replacing  $T_t$ .
4.  $H_\Gamma$  is generated by  $h$ .<sup>14</sup>

The economy without a fluctuating  $G_t$  is identical, except for the deterministic  $G_t$ -process.

<sup>13</sup>Note that since  $H_B$  is exogenously determined by equation (2.7), it is not an equilibrium object.

<sup>14</sup>Note that, aggregate asset holdings in this economy equal  $K + B$  (capital and bonds are perfectly substitutable for households). Therefore,  $H_\Gamma$  and  $H_B$  determine the evolution of the supply of physical capital,  $K$ . The competitively determined  $r$  then clears the capital market.

### 3 Calibration

In this section, we discuss our model calibration beginning with basic parameters. The frequency of our model economy is quarterly. We parameterize the model to match important aggregate and cross-sectional statistics of the U.S. economy (Table 1).

Table 1: Summary of parameters

Parameter	Value	Description	Source / Target
Taken from the literature			
$1/\rho$	1.00	Elasticity of substitution between $c$ and $G$	Standard value
$\gamma$	1.00	Relative risk aversion	Standard value
$\alpha$	0.36	Capital share	Standard value
$\delta$	0.025	Depreciation rate	Standard value
$\tilde{l}$	0.3271	Hours of labor supply of employed	Normalization
$(z_l, z_h)$	(0.99, 1.01)	Support of aggr. productivity process	Krusell and Smith (1998)
$\Pi_{z, z'}$	See text	Transition matrix of aggr. productivity process	Krusell and Smith (1998)
$(u_g, u_b)$	(4%, 10%)	Possible unemployment rates	Krusell and Smith (1998)
$\Pi_{\varepsilon \varepsilon'   z z'}$	See text	Transition matrix of employment process	Krusell and Smith (1998)
$\omega$	0.10	Replacement rate	Krusell and Smith (1998)
$\tau_2$	0.768	Parameter in the progressive tax function	Gouveia and Strauss (1994)
Estimated from the data			
$\tau_0$	5.25%	Income tax parameter	
$\tau_c$	8.14%	Consumption tax rate	
$\rho_{T, B}$	0.0173	Debt coefficient of fiscal rule	
$\rho_{T, Y}$	0.2820	Output coefficient of fiscal rule	
$\rho_{T, G}$	0.4835	Government purchases coefficient of fiscal rule	
$(G_l/G_m, G_h/G_m)$	(0.951, 1.049)	Size of the $G$ -shock	
$\Pi_{G, G'}$	See text	Transition matrix of the $G$ -process	
Calibrated in the model			
$\theta$	0.7221	Weight on private consumption in utility	Lindahl-Samuelson condition
$G_m$	0.2318	Value of the middle grid of the $G$ -process	Mean $G/Y$ (20.86%)
$\underline{a}$	-4.15	Borrowing constraint	Negative wealth share (11%)
$\rho_{T, 0}$	0.1007	Intercept of tax revenue rule	Average annualized $B/Y$ (30%)
$\tilde{\beta}_m$	0.9919	Medium value of discount factor	Average annualized $K/Y$ (2.5)
$\tilde{\beta}_h - \tilde{\beta}_m, \tilde{\beta}_m - \tilde{\beta}_l$	0.0046	Size of discount factor variation	Gini coeff. (0.79)
$\Pi_{\tilde{\beta}, \tilde{\beta}'}$	See text	Transition matrix of discount factor	Top 1% wealth share (30%)
$\tau_3$	1.776	Parameter in the progressive tax function	Mean of $\tau_1$ (25.8%)

#### 3.1 Basic parameters

We set the relative risk aversion parameter  $\gamma = 1$ , and the elasticity of substitution between private consumption and the public good  $1/\rho = 1$ . To calibrate the weight of private consumption in the utility function,  $\theta$ , we assume that the Lindahl-Samuelson condition holds for our economy in the long-run. This means that there is efficient provision of public goods, i.e., there are equalized marginal utilities from private and public goods. Mathematically, this is represented as  $\int_0^1 \frac{(1-\theta)/G_t}{\theta/c_{it}} di = 1$ , on average over many time periods. With this procedure,  $\theta$  is calibrated to 0.722.

We take other parameter values directly from Krusell and Smith (1998): the depreciation rate is  $\delta = 0.025$ , the capital elasticity of output in the production function is  $\alpha = 0.36$ , and labor supply is normalized to  $\tilde{l} = 0.3271$ . We allow our aggregate productivity process,  $z_t$ , to take on two values,  $z_g = 1.01$  and  $z_b = 0.99$ , with unemployment rates of  $u_g = 0.04$  and  $u_b = 0.1$ ,

respectively. The transition matrix for  $z_t$  is as follows:

$$\begin{bmatrix} 0.875 & 0.125 \\ 0.125 & 0.875 \end{bmatrix},$$

where rows represent the current state and columns represent the next period's state. The first row and column correspond to  $z_g$ . The transition matrix for the employment status,  $\varepsilon$ , is a function of both the current aggregate state ( $z$ ) and the future aggregate state ( $z'$ ). There are thus four possible cases,  $(z_g, z_g)$ ,  $(z_g, z_b)$ ,  $(z_b, z_g)$ , and  $(z_b, z_b)$ , corresponding to the following employment status transition matrices:<sup>15</sup>

$$\begin{bmatrix} 0.33 & 0.67 \\ 0.03 & 0.97 \end{bmatrix}, \begin{bmatrix} 0.75 & 0.25 \\ 0.07 & 0.93 \end{bmatrix}, \begin{bmatrix} 0.25 & 0.75 \\ 0.02 & 0.98 \end{bmatrix}, \begin{bmatrix} 0.60 & 0.40 \\ 0.04 & 0.96 \end{bmatrix},$$

where the first row and column correspond to  $\varepsilon = 0$  (unemployed).

We calibrate the borrowing constraint and the idiosyncratic time preference process to match key features of the overall wealth distribution in the U.S. The borrowing constraint is set to  $\underline{a} = -4.15$  to match the fraction of U.S. households with negative wealth holdings, 11%.<sup>16</sup>

$\tilde{\beta}$  takes on values from a symmetric grid, ( $\tilde{\beta}_l = 0.9873, \tilde{\beta}_m = 0.9919, \tilde{\beta}_h = 0.9965$ ). In the invariant distribution, 96.5% of the population is in the middle state, and 1.75% is distributed across either of the extreme points. The expected duration of the extreme discount factors is set at 50 years, to capture a dynastic element in the evolution of time preferences (Krusell and Smith, 1998). In addition, transitions occur only across adjacent values, where the transition probability from either extreme value to the middle grid is  $1/200$ , and the transition probability from the middle grid to either extreme value is  $7/77200$ . This Markov chain for  $\tilde{\beta}$  allows our model to generate a long-run U.S. capital-output ratio of 2.5, and a Gini coefficient for the U.S. wealth distribution of 0.79. It also allows our model to match the wealth share of the top 1% (Krusell and Smith, 1998). An accurate calibration of this moment is important because, as we will show, the welfare effects of fiscal volatility for top wealth holders, characterized by high levels of buffer-stock savings and high capital income, can be quantitatively rather different from those for other households.

<sup>15</sup>The numbers are rounded to the second decimal point.

<sup>16</sup>We check that the total resources available to a household, taking into account unemployment insurance benefits and the borrowing limit, are never negative under this calibration.

## 3.2 Fiscal parameters

### 3.2.1 Fiscal volatility and tax revenue rule

To estimate the parameters related to fiscal volatility and the aggregate tax revenue rule, we use U.S. quarterly data from the first quarter of 1960 to the last quarter of 2007. We restrict the data window up to 2007IV because, arguably, fiscal policy was special during and after the Great Recession and for calibration purposes we want to focus on “normal” times. We provide the details of our fiscal parameter estimation in Appendix A. Here we briefly outline the general procedure.

For the government purchases process (equation 2.5), we use the Rouwenhorst method (Rouwenhorst, 1995) to construct a three-state first-order Markov chain approximation to the AR(1) process of the linearly detrended  $\log(G)$  series.<sup>17</sup> The middle grid point of the  $G$ -process,  $G_m$ , is calibrated using the average  $G/Y$ -ratio in the data; see Appendix A.1 for the details.

To determine the parameters of our tax revenue rule (equation (2.6)), we first estimate the federal revenue rule as in Bohn (1998) and Davig and Leeper (2011), and the state and local rule without debt. We then take the weighted average of the federal rule and the state and local rule to get the general government tax revenue function, the empirical counterpart of our model. We describe the details of this procedure in Appendix A.2.

$TR$  in equation (2.6) is aggregate unemployment insurance payments. We set the unemployment insurance replacement rate,  $\omega$ , to 10% of the current market wage income, in line with the data. From Stone and Chen (2014) we know that the overall replacement rate from unemployment insurance is about 46% of a worker’s wage, and its average pre-2008 benefits duration is 15 weeks. This translates to about 53% of a worker’s quarterly wage. In our case, since we spread the unemployment benefits through the agent’s whole unemployment period and the average duration of unemployment in the model is about 2 quarters, this translates to about 27% of the quarterly wage level. Moreover, from Auray et al. (2014) we know that about 60% out of all the unemployed workers were eligible for unemployment benefits from 1989 to 2012, and that about 75% of those eligible for benefits actually collected them. Thus, we set our unemployment insurance payment to be 10% of the market wage.<sup>18</sup>

### 3.2.2 Tax instruments

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<sup>17</sup>Kopecky and Suen (2010) show that the Rouwenhorst method has an exact fit in terms of five important statistical properties: unconditional mean, unconditional variance, correlation, conditional mean and conditional variance. The last two properties are important for our elimination of fiscal volatility, where both the conditional mean and variance matter for the transition-path equilibrium.

<sup>18</sup>Our calibration also matches the aggregate data on unemployment insurance well: 0.0049 for the average unemployment insurance to output ratio (0.0041 in the data), and 0.0021 for its standard deviation, after removing a linear trend (0.0019 in the data). In both the model and the data, the unemployment-insurance-to-output ratio is countercyclical. Also note that in Krusell and Smith (1998), the unemployment insurance is treated as a fixed amount,  $\psi$ , and calibrated to be about 10% of the long-run quarterly wage.

Recall that to satisfy the tax revenue rule (equation 2.6) we need to treat one of the tax parameters in the income tax function as an endogenous equilibrium object:

$$\tau_1 \left[ y - (y^{-\tau_2} + \tau_3)^{-\frac{1}{\tau_2}} \right] + \tau_0 y. \quad (3.1)$$

Which tax parameter we choose to be an endogenous variable then influences how the distribution of the tax burden across income changes over the business cycles. We thus run the model with each of  $\tau_0$ ,  $\tau_1$ ,  $\tau_2$ , and  $\tau_3$  as the endogenous variable one by one, and examine the cyclicity of the tax system in each case. We then select the case where the cyclicalities of both the tax parameters and the (average) residual income elasticity (RIE, defined in equation 3.2) of the federal income tax part in equation 3.1, a classical (inverse) summary measure of tax progressivity in the public finance literature (see Musgrave and Thin, 1948), best match the data. RIE is the elasticity of after-tax income to pre-tax income. It is a decreasing function of tax progressivity, because the more progressive the tax system is, the smaller the proportional increase in the after-tax income, compared to that in the before-tax income.<sup>19</sup>

$$RIE = \int_0^1 \frac{\partial (y_i - \tau^y(y_i)) / \partial y_i}{(y_i - \tau^y(y_i)) / y_i} di = \int_0^1 \frac{1 - \tau_1 + \tau_1 (1 + \tau_3 y_i^{\tau_2})^{-\frac{1}{\tau_2} - 1}}{1 - \tau_1 + \tau_1 (1 + \tau_3 y_i^{\tau_2})^{-\frac{1}{\tau_2}}} di. \quad (3.2)$$

We focus on matching the cyclicity of tax progressivity because, as we show later, this turns out to be the main determinant of the distributional effects of fiscal volatility. Gouveia and Strauss (1999) provide U.S. time series data for the federal income tax system not only on RIE, but also on their estimates of  $\tau_1$ ,  $\tau_2$  and  $\tau_3$ . According to this data, the RIE correlates negatively with output and tax revenue net of transfers; see the first two columns of Panel A, Table 2. And the first two columns of Panel B, Table 2, show that our model can obtain the right cyclicity of RIE only when we use either  $\tau_0$  or  $\tau_1$  as the tax instrument to cyclically adjust the government budget. The intuition for this result is: to have a negative correlation between the RIE and tax revenue (a positive correlation between tax progressivity and tax revenue), the tax burden on income-rich individuals from the federal income tax must increase with tax revenue. This means, given the specification of our federal income tax function, that  $\tau_1$  has to adjust instead of  $\tau_2$  or  $\tau_3$ , because adjustments in  $\tau_1$  lead to differential changes in individual marginal tax rates proportional to the existing progressive rates. In contrast, adjustments in  $\tau_2$  or  $\tau_3$  affect the poor- and medium-income households more than the high income group, since they leave the highest marginal tax rate unaffected.<sup>20</sup>

To make the further choice between  $\tau_0$ - and  $\tau_1$ -adjustments, we examine how  $\tau_0$  and  $\tau_1$

<sup>19</sup>In equation 3.2,  $\tau^y$  refers, with a slight abuse of notation, only to the federal income tax part in equation 3.1, because our data on RIE are from the federal tax system.

<sup>20</sup>Analytically, holding the income distribution constant, we can show that  $\partial RIE / \partial \tau_1$  is negative. By construction,  $\partial RIE / \partial \tau_0$  is zero holding the income distribution constant, so the negative correlation between RIE and the tax revenue in the  $\tau_0$ -adjustment specification is solely driven by changes in the income distribution.

themselves are correlated with tax revenue net of transfers.<sup>21</sup> The third and fourth columns of Table 2 report these two correlations in the data (Panel A), negative for  $\tau_0$  and positive for  $\tau_1$ , whereas the model implies positive correlations for both cases (Panel B), and hence  $\tau_1$  appears to be the driver for the empirical cyclical of RIE. Therefore, we choose  $\tau_1$  as the endogenous equilibrium object in the baseline model. We thus show that time series data on the progressivity of the U.S. tax system are informative of which tax instruments are likely to be used for cyclical government budget adjustment. It is top marginal tax rates, which is also consistent with their strong cyclical as documented in Mertens and Montiel Olea (2013).

Table 2: Moments for tax instrument choice

A: Data (1966 - 1989)						
	$\rho(\text{RIE}, Y)$	$\rho(\text{RIE}, T-\text{Tr})$	$\rho(\tau_0, T-\text{Tr})$	$\rho(\tau_1, T-\text{Tr})$	$\rho(\tau_2, T-\text{Tr})$	$\rho(\tau_3, T-\text{Tr})$
	-0.3353	-0.3652	-0.1865	0.3235	-0.2184	-0.0344
B: Model simulation						
	$\rho(\text{RIE}, Y)$	$\rho(\text{RIE}, T-\text{Tr})$	$\rho(\tau_0, T-\text{Tr})$	$\rho(\tau_1, T-\text{Tr})$	$\rho(\tau_2, T-\text{Tr})$	$\rho(\tau_3, T-\text{Tr})$
$\tau_0$ -adjustment	-0.2978 (0.2689)	-0.3108 (0.2675)	0.3986 (0.3056)	- -	- -	- -
$\tau_1$ -adjustment	-0.2900 (0.3187)	-0.3803 (0.3077)	- -	0.2999 (0.2788)	- -	- -
$\tau_2$ -adjustment	0.2887 (0.2105)	0.3744 (0.1951)	- -	- -	-0.3333 (0.2320)	- -
$\tau_3$ -adjustment	0.1615 (0.2886)	0.2478 (0.2880)	- -	- -	- -	0.3261 (0.2199)

Notes: In Panel A,  $Y$  and  $T - Tr$  are HP-filtered (with a smoothing parameter of 6.25) real log series of output and tax revenue net of transfers, respectively.  $\tau_0$ ,  $\tau_1$ ,  $\tau_2$  and  $\tau_3$  are linearly-detrended tax parameters, where  $\tau_0$  is estimated by the authors (see Appendix A.3) and  $\tau_1$ ,  $\tau_2$  and  $\tau_3$  are from Gouveia and Strauss (1999). RIE is the quadratic-detrended residual income elasticity from Gouveia and Strauss (1999). In Panel B, all variables are defined and filtered the same way as those in Panel A. The reported numbers are the average values from 2,000 independent simulations of the same length as the data (24 years), where quarterly data are converted to annual data to match the data frequency in Panel A. We show the standard deviations across these simulations in parentheses.

We then calibrate the remaining tax parameters in the progressive part of the income tax function based on the values estimated by Gouveia and Strauss (1994) for U.S. data from 1989 (see Castañeda et al., 2003 and Conesa and Krüger, 2006), the last year in their sample. Note that equation 3.1 is linearly homogeneous in  $y$ , if  $\tau_3$  is readjusted appropriately. Therefore, we use their values for  $\tau_2$  (0.768), and calibrate  $\tau_3$  such that the average value of  $\tau_1$  from the model matches the estimated value from Gouveia and Strauss (1994).<sup>22</sup>

For the consumption tax rate and the linear part of the income tax function, we follow standard procedures and calculate the time series of the corresponding tax rates from the quarterly NIPA

<sup>21</sup>The time series of  $\tau_1$ ,  $\tau_2$ , and  $\tau_3$  are reported in Gouveia and Strauss (1999), while that of  $\tau_0$  is obtained from our own estimation (see below and Appendix A.3). For completeness we also report the correlations for  $\tau_2$  and  $\tau_3$ , although these two models do not pass our first criterion for model selection.

<sup>22</sup>Note that the estimation in Gouveia and Strauss (1994) is carried out on annual federal income tax data, whereas our model frequency is quarterly. Given the nonlinear nature of the tax function (equation (3.1)), this may raise a time aggregation issue. We therefore checked the implied tax function from simulated annual income and annual tax payment data from our model (aggregated from simulated quarterly observations). The results from this estimation are very close to those from the annual data.



data (see, e.g., Fernández-Villaverde et al., 2015 and Mendoza et al., 1994). We then take the time-series average values to obtain the following tax rates:  $\tau_c = 8.14\%$  and  $\tau_0 = 5.25\%$ ; see Appendix A.3 for the details.

### 3.3 The wealth distribution and business cycle moments

In this section, we examine the wealth distribution and the business cycle moments, focusing on the fiscal variables, generated by our calibrated model. For our model to be a suitable laboratory for the experiment of eliminating fiscal volatility, and for producing reliable quantitative answers to our welfare and distributional questions, it should broadly match these aspects of the data.

Table 3 compares the long-run wealth distribution generated by our model with both the data and the model results in Krusell and Smith (1998). From Table 3, we see that our wealth distribution is a good match for the U.S. wealth distribution, especially for those in the top 1 percent.<sup>23</sup>

Table 3: Wealth distribution

	% of wealth held by top					Fraction with wealth < 0	Gini coefficient
	1%	5%	10%	20%	30%		
Model	31%	59%	71%	80%	86%	10%	0.78
K&S	24%	54%	72%	87%	91%	11%	0.81
Data	30%	51%	64%	79%	88%	11%	0.79

Notes: The wealth distribution in the data is taken from Krusell and Smith (1998). Household wealth in our model is the sum of physical capital and government bonds.

Table 4 provides the results of a comparison between the key business cycle moments generated by the model and those from the data. This comparison includes output, tax revenue, and government purchases volatility and persistence. We calculate the same moments for the output ratios of tax revenue, government purchases and federal government debt. Finally, we examine the co-movements of these series with output and government purchases.

From Table 4, we see that our baseline model is successful in matching most of the business cycle moments, with the exception of output volatility (which is about 70% larger in the model). We checked that, even without fiscal volatility, as in Krusell and Smith (1998), the model produces higher output fluctuations than found in the data, while the introduction of fiscal volatility does not contribute substantially to the volatility of output. To check whether our welfare results are affected by this feature of the model, we conduct a robustness check where we recalibrate the aggregate productivity process so that the model matches the output volatility in the data. The

<sup>23</sup>While Krusell and Smith (1998) exogenously fix the share of households in each extreme  $\tilde{\beta}$  state at 10%, we use this share as a parameter to be calibrated to target the top 1% wealth share. This calibration makes that share 1.75%.

Table 4: Business cycle moments

A: Data (1960 I - 2007 IV)						
	Y	T-Tr	G	(T-Tr/Y)	(G/Y)	(B/Y)
Standard deviation	0.0149	0.0543	0.0134	0.0123	0.0083	0.0772
Autocorrelation	0.8616	0.8134	0.7823	0.9045	0.9573	0.9945
Corr(Y,X)	1	0.7242	0.0992	0.4791	-0.3826	-0.0472
Corr(G,X)	0.0992	0.0352	1	0.0345	0.4806	-0.0281
B: Model simulation						
	Y	T-Tr	G	(T-Tr/Y)	(G/Y)	(B/Y)
Standard deviation	0.0235 (0.0018)	0.0414 (0.0043)	0.0123 (0.0025)	0.0063 (0.0009)	0.0086 (0.0012)	0.0403 (0.0151)
Autocorrelation	0.5840 (0.0561)	0.5870 (0.0558)	0.6978 (0.0582)	0.8183 (0.0575)	0.8252 (0.0546)	0.9732 (0.0341)
Corr(Y,X)	1 (0)	0.9892 (0.0043)	-0.0012 (0.1294)	0.6941 (0.1053)	-0.6436 (0.0939)	-0.1822 (0.1685)
Corr(G,X)	-0.0012 (0.1294)	0.1316 (0.1296)	1 (0)	0.2499 (0.1121)	0.3805 (0.1079)	-0.0089 (0.0577)

Notes: In Panel A,  $Y$ ,  $T - Tr$  and  $G$  are HP-filtered (with a smoothing parameter of 1600) real log series of output, tax revenue net of transfers and government purchases, respectively.  $(T - Tr)/Y$ ,  $G/Y$  and  $B/Y$  are linearly detrended output ratios of tax revenue net of transfers, government purchases and federal government debt, respectively. The data sources are documented in Appendix A.2. In Panel B, all variables are defined and filtered the same way as those in Panel A. The reported numbers are the average values from 1,000 independent simulations of the same length as the data (192 quarters). We show the standard deviations across these simulations in parentheses.

results remain unchanged.

## 4 Computation

### 4.1 Stochastic steady state

To compute the model's equilibrium with two aggregate shocks, we use the approximate aggregation technique proposed by Krusell and Smith (1998).<sup>24</sup> This technique assumes that households act as if only a limited set of moments of the wealth distribution matters for predicting the future of the economy, and that the aggregate result of their actions is consistent with their perceptions of how the economy evolves. However, in contrast to Krusell and Smith (1998), we find that higher moments of the wealth distribution are necessary in our model with progressive taxation. That is, the accurate description of our economy's evolution requires a combination of average physical capital and the Gini coefficient of the wealth distribution.

Furthermore, the optimization problem in our model requires households to know the endogenous tax parameter,  $\tau_1$ . We therefore approximate the function  $\Theta$ , as defined in equation (2.14), with a parameterized function of the same moments that represent the wealth distribution.<sup>25</sup> We

<sup>24</sup>The solution method for the stochastic steady state of the model with only aggregate productivity shocks is the same, except that  $G_t = G_m, \forall t$ .

<sup>25</sup>This is in the same spirit as the bond price treatment in Krusell and Smith (1997).

can now state the following functional forms for  $H_\Gamma$  and  $\Theta$ :

$$\begin{aligned} \log(K') = & a_0(z, G) + a_1(z, G)\log(K) + a_2(z, G)B + a_3(z, G)(\log(K))^2 + a_4(z, G)B^2 \\ & + a_5(z, G)B^3 + a_6(z, G)\log(K)B + a_7(z, G)Gini(a), \end{aligned} \quad (4.1)$$

$$\begin{aligned} Gini(a') = & \tilde{a}_0(z, G) + \tilde{a}_1(z, G)\log(K) + \tilde{a}_2(z, G)B + \tilde{a}_3(z, G)(\log(K))^2 + \tilde{a}_4(z, G)B^2 \\ & + \tilde{a}_5(z, G)B^3 + \tilde{a}_6(z, G)\log(K)B + \tilde{a}_7(z, G)Gini(a), \end{aligned} \quad (4.2)$$

$$\begin{aligned} \tau_1 = & b_0(z, G) + b_1(z, G)\log(K) + b_2(z, G)B + b_3(z, G)(\log(K))^2 + b_4(z, G)B^2 \\ & + b_5(z, G)B^3 + b_6(z, G)\log(K)B + b_7(z, G)Gini(a), \end{aligned} \quad (4.3)$$

where  $K$  denotes the average physical capital, and  $Gini(a)$  denotes the Gini coefficient of the wealth distribution.<sup>26</sup> We compute the equilibrium using a fixed-point iteration procedure from the parameters in equations (4.1)-(4.3) onto themselves; see Appendix B.1 for the details of the computational algorithm and Appendix B.2 for the estimated equilibrium laws of motions.

A check of the one-step-ahead forecast accuracy yields  $R^2$ s above 0.999993 for  $H_\Gamma$  (equations (4.1) and (4.2)), and above 0.99998 for  $\Theta$  (equation (4.3)). However, as den Haan (2010) points out, high  $R^2$ -statistics are not necessarily indicative of multi-step-ahead forecast accuracy. Hence, we also examine the 10-year ahead forecast errors of our model. This check shows that our forecast errors are small and unbiased; see Appendix B.2 for the details.

## 4.2 Transition-path equilibrium

To study the welfare effects of eliminating fiscal volatility, we start with the ergodic distribution of the two-shock equilibrium. From time  $t = 1$ , we let  $G_t$  follow its deterministic conditional mean along the transition path until it converges to  $G_m$ . While we do not take a stance on how this stabilization is brought about (Lucas, 1987 and Krusell et al., 2009), we do note that, in contrast to stabilizing aggregate productivity shocks, the  $G_t$ -process is arguably under more direct government control.

As stated, during the transition periods  $G_t$  follows a time-dependent deterministic conditional-mean process until it converges to  $G_m$ , i.e.,

$$G_t = [\mathbb{1}(G_1 = G_l), \mathbb{1}(G_1 = G_m), \mathbb{1}(G_1 = G_h)] \Pi_{GG'}^{t-1} [G_l, G_m, G_h]^T \quad (4.4)$$

where  $\Pi_{GG'}$  is the transition probability matrix of the  $G$ -process in the two-shock economy discussed in Appendix A. Note that, depending on  $G_1$ , the  $G_t$ -paths will have different dynamics. For example, if  $G_1 = G_m$ ,  $G_t$  will stay at  $G_m$  for all  $t \geq 1$ , and the economy will immediately transition to its long-run  $G$  level. However, if the economy starts the transition away from

<sup>26</sup>These specific functional forms perform best among a large set of (relatively parsimonious) functional forms tested.

$G_m, G_t$  converges to  $G_m$  over time through the deterministic process described in (4.4). In this case, the counterfactual economy will go through transitional dynamics to eventually reach the productivity-shock-only stochastic steady state.

Recall the assumption that the government purchases process is independent from other stochastic processes, which implies that none of the other exogenous stochastic processes changes during or after the elimination of the fiscal shocks. Therefore, our counterfactual economy features aggregate productivity shocks both during and after the transition. This creates a new technical challenge in addition to those present in previous transition path analyses of heterogeneous-agent economies (e.g., Huggett, 1997 and Krusell and Smith, 1999). While these studies model a deterministic aggregate economy along the transition path, our stochastic setting with aggregate uncertainty produces an exponentially higher number of possible aggregate paths as the transition period lengthens. This feature precludes computation of the equilibrium for all possible realizations of aggregate shocks. To address this challenge, we extend the approximate aggregation technique to the transition-path setting: that is, we postulate that time-dependent prediction functions govern the evolution of the economy on the transition path, through the following set of laws of motions:

$$\Gamma_{t+1} = H_{\Gamma,t}^{trans}(\Gamma_t, B_t, z_t), \quad (4.5)$$

$$\tau_{1,t} = \Theta_t^{trans}(\Gamma_t, B_t, z_t), \quad (4.6)$$

where  $t$  denotes an arbitrary period along the transition path. At the end of the transition path, the laws of motions converge to those in our one-shock equilibrium. Consequently, solving for the transition-path equilibrium is equivalent to finding the appropriate approximations for (4.5) and (4.6), such that the realized evolution of the economy is consistent with the postulated evolution; see Appendix B.3 for the details of the algorithm. We find that the same functional forms we use for the stochastic steady state economy yield accurate predictions also for the transition-path equilibrium. That is, for every period on the transition path, we achieve a similar forecast accuracy as in the stochastic steady state two-shock economy; see Appendix B.4 for the details.

## 5 Results

Following Lucas (1987), we measure the welfare costs of fiscal volatility as the proportional change in a household's life-time consumption (Consumption Equivalent Variation or  $\lambda$ ), such that:

$$E_1\left[\sum_{t=1}^{\infty} \beta_t u((1+\lambda)c_t, G_t)\right] = E_1\left[\sum_{t=1}^{\infty} \beta_t u(\tilde{c}_t, \tilde{G}_t)\right], \quad (5.1)$$

where  $c_t$  is consumption in the baseline economy with  $G_t$ -fluctuations, while  $\tilde{c}_t$  is consumption in the counterfactual economy with a deterministic  $\tilde{G}_t$ -process.

## 5.1 Baseline results

To obtain our baseline results, we first calculate welfare gains conditional on wealth, employment status and time preference for every sample economy in the transition-path computation,<sup>27</sup> using the value functions from our two-shock and transition-path equilibria.<sup>28</sup> We then average these across the sample economies, including all possible values of  $G_1$ , the government purchases level when fiscal volatility is eliminated. The results, presented in Table 5, can thus be interpreted as the *ex-ante* expected welfare gains from eliminating fiscal volatility.

Table 5: Expected welfare gains  $\lambda$  (%)

	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
All	0.0293	0.0289	0.0295	0.0296	0.0293	0.0290	0.0287	0.0313	0.0371
$\varepsilon = 1$	0.0293	0.0288	0.0294	0.0296	0.0293	0.0290	0.0287	0.0313	0.0371
$\varepsilon = 0$	0.0294	0.0291	0.0297	0.0297	0.0294	0.0291	0.0287	0.0312	0.0371
$\tilde{\beta} = \tilde{\beta}_l$	0.0277	0.0278	0.0277	0.0276	0.0275	0.0274	0.0268	0.0272	0.0314
$\tilde{\beta} = \tilde{\beta}_m$	0.0292	0.0300	0.0299	0.0296	0.0293	0.0290	0.0285	0.0302	0.0356
$\tilde{\beta} = \tilde{\beta}_h$	0.0360	0.0329	0.0327	0.0326	0.0326	0.0326	0.0336	0.0377	0.0440

Notes: The wealth groups are presented in ascending order from left to right. The welfare number for a particular combination of  $\varepsilon$  (or  $\tilde{\beta}$ ) and a wealth group is calculated as follows: we first draw a large set (16,000) of independent joint distributions over  $(a, \varepsilon, \tilde{\beta})$  from the simulation of the two-shock equilibrium. These distributions are used to start the computation of the transition-path equilibria. For each sample economy, we then find all the individuals that fall into a particular wealth $\times$ employment status or wealth $\times$ preference category, and calculate their welfare gain according to equation (5.1). We then take the average over the individuals in a particular category to find the welfare numbers for a given sample economy. To arrive at the numbers in this table, we finally take the average across all the 16,000 samples.

The results in Table 5 show that the aggregate welfare gain, i.e., the average welfare change across the whole population, is about 0.03%, comparable in size to the results in Lucas (1987) and Krusell et al. (2009). We further find that the welfare gains increase with wealth and patience while employment status does not affect the welfare changes. In the next sub-section, we examine the mechanisms affecting the welfare gains along the wealth dimension.

## 5.2 The mechanisms

Our analyses show that the increasing-with-wealth welfare gain pattern is the result of three interacting channels: a direct utility channel, an income risk channel, and an average factor price

<sup>27</sup>To start the transition-path simulation, we draw a large set (16,000) of independent joint distributions over  $(a, \varepsilon, \tilde{\beta})$  from the simulation of the two-shock equilibrium; see Appendix B.3 for the details.

<sup>28</sup>The right side of (5.1) is the value function from the transition-path equilibrium. Given the log-log utility assumption in the baseline calibration, the left side of (5.1) can be expressed using the value function from the two-shock equilibrium and  $\lambda$ ; see Appendix B.5 for the details of the derivation.

channel. The direct utility channel isolates the utility gains resulting from household risk aversion with respect to government purchases fluctuations. In the income risk channel, two types of fiscal risk arising from tax rate fluctuations coexist: an after-tax-wage risk and an after-tax-rate-of-return risk. These risks have different distributional effects through the precautionary saving behavior of households and the risk exposure of households' resources. Finally, the average factor price channel reflects changes in average factor prices along the transition path.

In the following sub-sections, we discuss each channel in turn. We can exactly and quantitatively separate the direct utility channel from the other two. Although an exact quantitative separation of the income risk channel from the average factor price channel is not feasible as they are intertwined in the economy, we can illustrate the distinct ways of how they work.

### 5.2.1 The direct utility channel

Since a household's utility over  $G$  is strictly concave, eliminating fluctuations in  $G$  leads to a direct increase in expected lifetime utility. To isolate this direct utility gain, we first compute a  $\lambda_c$  such that:

$$E_1\left[\sum_{t=1}^{\infty} \beta_t u((1 + \lambda_c)c_t, G_t)\right] = E_1\left[\sum_{t=1}^{\infty} \beta_t u(\tilde{c}_t, G_t)\right], \quad (5.2)$$

where  $c_t$ ,  $\tilde{c}_t$ , and  $G_t$  are defined in the same way as before. Note that,  $\lambda_c$  is by definition insulated from any utility change caused by direct changes in the  $G$ -process, since the stochastic  $G$ -process now enters both sides of equation (5.2). Therefore,  $\lambda_c$  represents welfare changes that result solely from changes in private consumption profiles. The difference between  $\lambda$  and  $\lambda_c$  thus characterizes the direct utility channel.

Furthermore, with a separable flow utility function,  $\lambda_c$  can be computed using the following simpler equation:

$$E_1\left[\sum_{t=1}^{\infty} \beta_t \log((1 + \lambda_c)c_t)\right] = E_1\left[\sum_{t=1}^{\infty} \beta_t \log(\tilde{c}_t)\right]. \quad (5.3)$$

The results, presented in Table 6, show positive, albeit smaller welfare changes when fiscal volatility is eliminated (after the gain from the direct utility channel is subtracted). Thus, we conclude that the direct utility channel is quantitatively important for the overall level of welfare changes, but, distributionally, the other two channels are the ones that matter.

In addition to the direct utility channel, fluctuations in government purchases can contribute to the welfare of households through affecting factor prices (pre-tax labor and capital income) and individual income tax rates, both of which determine households' after-tax income. The government purchases process can directly change individual income tax rates due to the aggregate

Table 6: Expected welfare gains from private consumption changes,  $\lambda_c$  (%)

	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
All	0.0082	0.0081	0.0085	0.0085	0.0082	0.0079	0.0076	0.0101	0.0159
$\varepsilon = 1$	0.0082	0.0081	0.0085	0.0085	0.0082	0.0079	0.0076	0.0101	0.0159
$\varepsilon = 0$	0.0083	0.0083	0.0087	0.0086	0.0083	0.0080	0.0076	0.0101	0.0159
$\tilde{\beta} = \tilde{\beta}_l$	0.0072	0.0073	0.0073	0.0072	0.0071	0.0069	0.0064	0.0068	0.0110
$\tilde{\beta} = \tilde{\beta}_m$	0.0082	0.0089	0.0088	0.0085	0.0082	0.0079	0.0074	0.0091	0.0145
$\tilde{\beta} = \tilde{\beta}_h$	0.0142	0.0111	0.0109	0.0108	0.0108	0.0108	0.0118	0.0159	0.0222

Notes: The welfare numbers in this table are calculated as those in Table 5, using (5.3) instead of (5.1).

tax revenue rule. Indirectly, the government purchases process influences the amount of physical capital (hence factor prices) in the economy, through changes in the split of aggregate wealth between capital and government bonds (due to the effect of government spending on government debt), and also through changes in the saving behavior of households facing changes in the tax rate process.

In the following two subsections, we separately consider the volatility and the level effects on households' after-tax income from fluctuations in government purchases. We denote the volatility effect as the *income risk channel*, and the level effect as the *average factor price channel*.

### 5.2.2 The income risk channel

Fluctuations in government purchases lead to more volatile after-tax income through both tax rates and factor prices. The distributional welfare implications of eliminating this after-tax income risk are, however, not straightforward. This is because the two components of after-tax income risk, labor income risk and rate-of-return risk (or capital income risk), have opposite distributional effects.

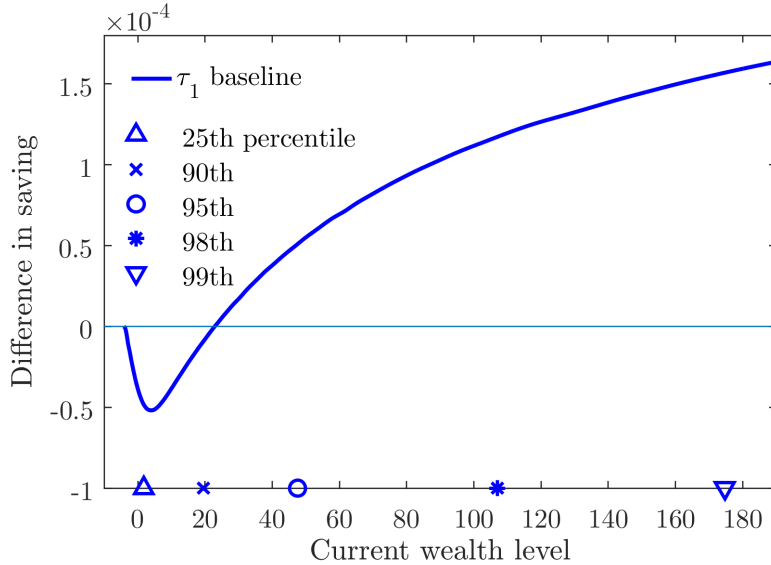
On the one hand, the effect of eliminating after-tax labor income uncertainty depends on a household's (heterogeneous) degree of self-insurance against labor income risks. As in other Bewley-type incomplete market economies, our households engage in precautionary saving. Wealthier households can better insure themselves against after-tax labor income risk. As a result, wealth-poor households should benefit more from the elimination of this uncertainty. Hereafter, we refer to this as the *precautionary saving effect*.

On the other hand, the tax-rate uncertainty induced by the  $G$ -shocks also creates a rate-of-return risk on after-tax capital income. This rate-of-return risk makes households' intertemporal transfer of resources riskier. In our model with a realistic incomplete financial market, wealth-rich households' financial wealth, which is subject to the rate-of-return risk, accounts for a larger

share of their expected life-time resources than is the case for the wealth-poor. Therefore, the wealth-rich households have more exposure to the rate-of-return risk, and they should benefit more from the elimination of fiscal volatility. Hereafter, we refer to this as the *rate-of-return risk effect*. In Appendix C, we employ a partial equilibrium model, to build up the intuition further and illustrate the distributional consequences of both the precautionary saving and rate-of-return risk effects.

The precautionary saving and rate-of-return risk effects, in turn, have different effects on saving behavior. The wealth-poor, whose saving is mainly driven by the precautionary saving motive, have less incentives to save with a reduction in their after-tax labor income uncertainty, and hence reduce their saving after the elimination of fiscal volatility. By contrast, the wealth-rich, for whom the rate-of-return risk is the more important factor in their saving decision, may increase their saving. Figure 1 confirms this conjecture showing that agents reduce their saving in the first period of the transition-path equilibrium compared to the two-shock equilibrium until approximately the 90<sup>th</sup> wealth percentile, whereas above this threshold, the wealth-rich increase their saving after the elimination of fiscal volatility.<sup>29</sup>

Figure 1: Policy function comparison - saving



Notes: This figure shows the difference between the first-period policy function for saving from the transition equilibrium (with  $G_1 = G_m$ ) and that from the two-shock equilibrium (with  $G_1 = G_m$ ), evaluated at  $z = z_g$ ,  $\varepsilon = 1$ ,  $\tilde{\beta} = \tilde{\beta}_m$ , and the long-run averages of  $(K, B, Gini)$  conditional on  $G_1 = G_m$  and  $z = z_g$ .

In short, the income risk channel is an amalgam of the aforementioned two competing effects.

<sup>29</sup>The policy function difference for saving is evaluated at  $G_1 = G_m$ ,  $z = z_g$ ,  $\varepsilon = 1$ ,  $\tilde{\beta} = \tilde{\beta}_m$ , and the long-run averages of  $(K, B, Gini)$  conditional on  $G_1 = G_m$  and  $z = z_g$ . However, similar patterns hold for other combinations of state variables. The comparison also looks similar when the policy functions from other periods on the transition path are used.



As will be made clear in Section 6.1, through alternative counterfactual tax adjustment mechanisms, the distributional effects from this channel depend on how the tax rate volatility burden is distributed in a given tax system. Note that when  $\tau_1$  is adjusted to satisfy the aggregate tax revenue rule as in the baseline case, the wealth-rich face significant uncertainty in after-tax returns from their savings, because  $\tau_1$  determines the top marginal tax rates, which renders the rate-of-return risk effect strong in the baseline case. The rate-of-return risk effect, accompanied by an average factor price effect that initially also favors the wealth-rich, as we will show in the next subsection, results in the increasing-with-wealth welfare gain pattern in Table 6.

### 5.2.3 The average factor price channel

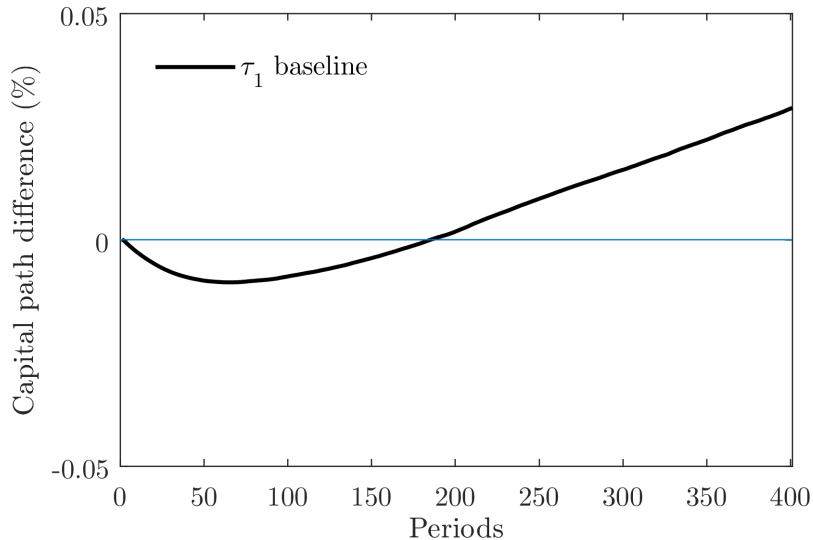
We next examine the average factor price channel. In our model with a representative neoclassical firm, factor price changes follow aggregate capital stock changes. If the aggregate capital stock drops after the elimination of fiscal volatility, then pre-tax capital returns, all else equal, will increase relative to wages. Because wealth-rich (wealth-poor) households have higher (lower) capital income shares, the wealth-rich (wealth-poor) households will benefit (lose) from this relative factor price change. As a result, changes in the aggregate capital stock will have distributional effects.

To examine the direction of the average factor price channel for our baseline scenario, we compute the percentage difference between the expected aggregate capital path in the transition-path equilibrium and the two-shock equilibrium. The results in Figure 2 show that the expected aggregate capital path in the transition-path equilibrium falls at first slightly below, then returns to, and finally goes above of that in the two-shock equilibrium.

The differential saving adjustment in the cross section after the elimination of fiscal volatility examined in Figure 1 explains the aggregate capital adjustment pattern in Figure 2. In particular, in response to the elimination of fiscal volatility, the majority wealth-poor households decrease their saving while the wealth-rich households increase their saving. What is more, simulation results show that the pace of saving adjustments is faster for the poor. Therefore, aggregate capital drops at first and gradually increases.

To further illustrate the average factor price channel, we examine the welfare gains from eliminating fiscal volatility *conditional* on  $G_1$ , government purchases at the time the policy change is instituted. The results in Table 7 reveal similar overall increasing-with-wealth welfare gain patterns. However, the slope of the welfare gains are steeper (flatter) when  $G_1 = G_h$  ( $G_1 = G_l$ ), compared to that from the case with  $G_1 = G_m$ . We trace the causes of those differences to the

Figure 2: Expected aggregate capital path comparison



Notes: This figure shows the percentage difference between the expected aggregate capital path in the transition-path equilibrium and the two-shock equilibrium. We use the same 16,000 sample economies and the same sequences of  $z$ -shocks (for both the transition and the two-shock aggregate capital paths) as in the transition-path computation and then take the average. The  $G$ -shock sequences in the two-shock simulations are constructed in such a way that the cross-sectional joint distribution of  $(z, G)$ -shocks in each period is close to the invariant joint distribution.

Table 7: Expected welfare gains from private consumption,  $\lambda_c$  (%), conditional on  $G_1$

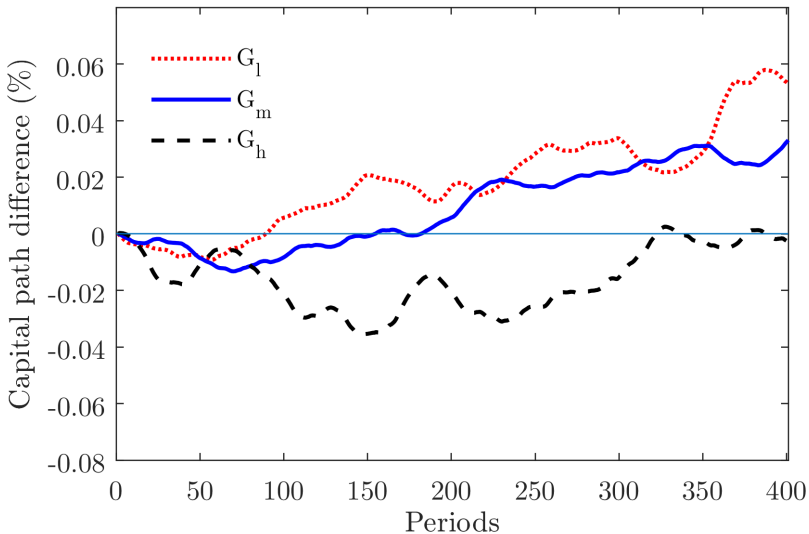
	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
$G_1 = G_l$									
All	0.0135	0.0141	0.0144	0.0142	0.0138	0.0133	0.0124	0.0130	0.0179
$\varepsilon = 1$	0.0135	0.0141	0.0144	0.0142	0.0138	0.0133	0.0124	0.0130	0.0179
$\varepsilon = 0$	0.0137	0.0143	0.0146	0.0144	0.0139	0.0134	0.0124	0.0130	0.0178
$\tilde{\beta} = \tilde{\beta}_l$	0.0131	0.0134	0.0133	0.0131	0.0128	0.0125	0.0111	0.0096	0.0126
$\tilde{\beta} = \tilde{\beta}_m$	0.0134	0.0149	0.0147	0.0142	0.0138	0.0133	0.0122	0.0120	0.0163
$\tilde{\beta} = \tilde{\beta}_h$	0.0185	0.0176	0.0172	0.0169	0.0167	0.0166	0.0166	0.0194	0.0248
$G_1 = G_m$									
All	0.0085	0.0084	0.0088	0.0088	0.0085	0.0082	0.0078	0.0102	0.0160
$\varepsilon = 1$	0.0085	0.0084	0.0088	0.0088	0.0085	0.0082	0.0078	0.0102	0.0160
$\varepsilon = 0$	0.0086	0.0085	0.0089	0.0089	0.0086	0.0083	0.0078	0.0102	0.0160
$\tilde{\beta} = \tilde{\beta}_l$	0.0075	0.0076	0.0076	0.0075	0.0073	0.0072	0.0066	0.0070	0.0111
$\tilde{\beta} = \tilde{\beta}_m$	0.0084	0.0092	0.0091	0.0088	0.0085	0.0082	0.0076	0.0093	0.0146
$\tilde{\beta} = \tilde{\beta}_h$	0.0143	0.0112	0.0111	0.0110	0.0110	0.0110	0.0119	0.0160	0.0223
$G_1 = G_h$									
All	0.0025	0.0015	0.0020	0.0023	0.0022	0.0021	0.0023	0.0068	0.0137
$\varepsilon = 1$	0.0025	0.0015	0.0020	0.0023	0.0022	0.0021	0.0023	0.0068	0.0137
$\varepsilon = 0$	0.0025	0.0017	0.0022	0.0023	0.0022	0.0021	0.0023	0.0068	0.0137
$\tilde{\beta} = \tilde{\beta}_l$	0.0008	0.0007	0.0007	0.0008	0.0008	0.0009	0.0012	0.0036	0.0091
$\tilde{\beta} = \tilde{\beta}_m$	0.0024	0.0024	0.0024	0.0023	0.0022	0.0021	0.0021	0.0059	0.0124
$\tilde{\beta} = \tilde{\beta}_h$	0.0097	0.0042	0.0043	0.0044	0.0045	0.0047	0.0066	0.0123	0.0195

Notes: The welfare numbers in this table are calculated as in Table 6, but separately for  $G_1 = G_l, G_m, G_h$ , using 8,000 simulations for  $G_1 = G_m$  and 4,000 simulations each for  $G_1 = G_l, G_h$ .

average factor price channel.<sup>30</sup> Figure 3 plots the percentage difference between the expected ag-

<sup>30</sup>The reduction in the volatility of the after-tax income is similar across different  $G_1$  values.

Figure 3: Expected aggregate capital path comparison, conditional on  $G_1$



Notes: This figure shows the percentage difference between the expected aggregate capital path in the transition-path equilibrium and the two-shock equilibrium conditional on  $G_1$ . We use the same 16,000 sample economies and the same sequences of  $z$ -shocks (for both the transition and the two-shock aggregate capital paths) as in the transition-path computation and then average by  $G_1$ : 8,000 simulations for  $G_1 = G_m$ , and 4,000 simulations each for  $G_1 = G_l, G_h$ . Note that, due to our conditioning on  $G_1$  and the subsequent smaller sample sizes, the expected aggregate capital paths in Figure 3 are more volatile compared to those in Figure 2.

gregate capital path in the transition-path equilibrium and the two-shock equilibrium, conditional on  $G_1$ . The differences in capital path adjustment are consistent with the welfare patterns across different  $G_1$  cases. For  $G_1 = G_h$ , the aggregate capital declines more after the elimination of fiscal volatility, benefiting the wealth-rich more (compared to the case with  $G_1 = G_m$ ). By contrast, for  $G_1 = G_l$ , the reduction in the aggregate capital occurs for a much shorter period of time, which benefits the wealth-poor more (compared to the case with  $G_1 = G_m$ ).

In sum, in our baseline setup, the elimination of fiscal volatility favors the wealthy distributionally, because the rate-of-return risk effect as part of the income risk channel, and, at least initially, the average factor price effect favor the wealth-rich.

## 6 Alternative specifications and additional experiments

In this section, we examine the welfare and distributional consequences of eliminating fiscal volatility under the following alternative model specifications: different adjustments to the progressive tax function, other fiscal regimes, different flow utility functions, and alternative TFP and labor income processes. In addition, we examine our results when we double fiscal volatility, as well as when the elimination of fiscal volatility is accompanied by a sudden change in the level of government purchases. In each case, we re-calibrate parameter values when necessary to preserve target

moment-data consistency. We summarize the welfare change results in terms of  $\lambda_c$  in Table 8. Table 18 in Appendix D.1 reports the corresponding  $\lambda$ -measures.

## 6.1 Alternative specifications

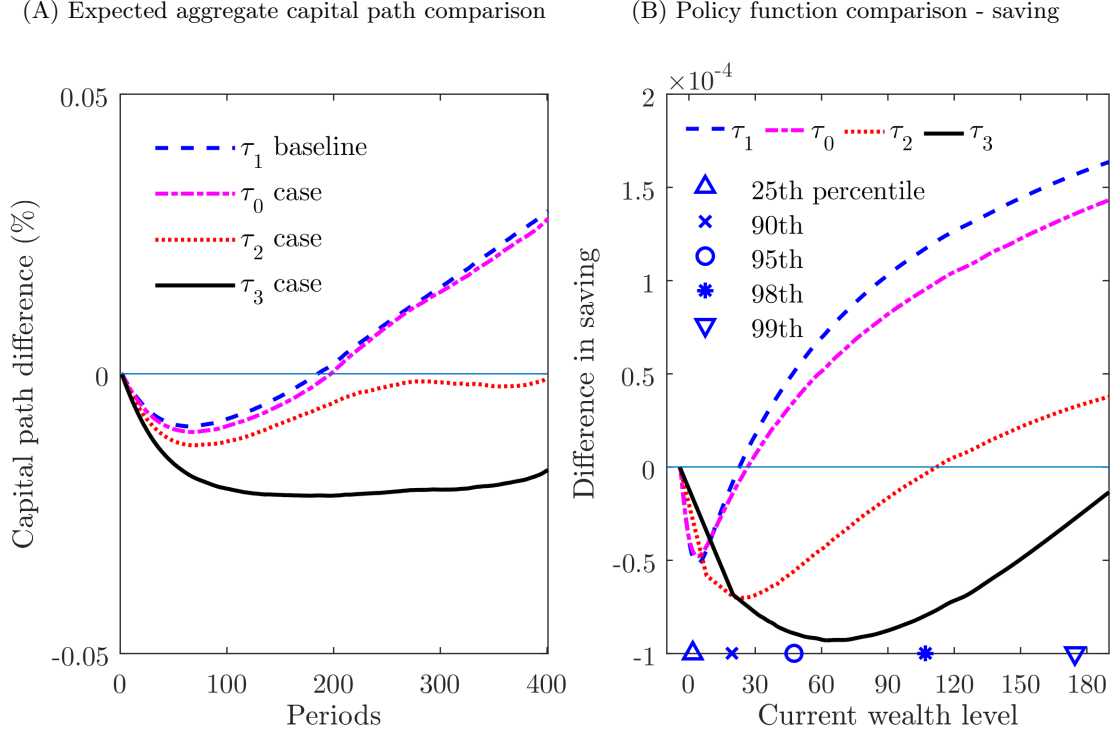
**Tax function adjustments.** Recall that, in our baseline specification, the top marginal rate of the progressive income tax ( $\tau_1$ ) is determined endogenously to satisfy the government’s tax revenue response rule (equation 2.6), while the linear tax rate ( $\tau_0$ ) and the tax function parameters  $\tau_2$  and  $\tau_3$  in the progressive tax function are fixed. Although we have argued that a fluctuating  $\tau_1$  can best represent the cyclicity of the progressivity of the U.S. tax system, here we consider the following three alternative adjustments in the tax function: adjusting  $\tau_0$ , the linear part in the income tax function, and adjusting  $\tau_2$  and  $\tau_3$ , the tax parameters that govern the progressivity of the tax system.

Table 8: Expected welfare gains from private consumption,  $\lambda_c$  (%), under different cases

	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
Baseline	0.0082	0.0081	0.0085	0.0085	0.0082	0.0079	0.0076	0.0101	0.0159
Different Tax Function Adjustment									
Adjusting $\tau_0$	0.0084	0.0083	0.0086	0.0087	0.0084	0.0082	0.0077	0.0091	0.0135
Adjusting $\tau_2$	0.0088	0.0093	0.0095	0.0095	0.0093	0.0091	0.0080	0.0051	0.0065
Adjusting $\tau_3$	0.0087	0.0095	0.0097	0.0096	0.0093	0.0090	0.0078	0.0028	0.0030
Other Fiscal Regimes									
Balanced Budget	0.0112	0.0109	0.0109	0.0108	0.0107	0.0107	0.0110	0.0159	0.0242
Linear Tax	0.0072	0.0067	0.0068	0.0070	0.0070	0.0070	0.0071	0.0103	0.0163
Lump-sum Tax	0.0073	0.0070	0.0070	0.0070	0.0069	0.0068	0.0071	0.0129	0.0204
Non-separable Utility Function									
Substitute	0.0008	0.0015	0.0028	0.0028	0.0003	0.0020	-0.0017	-0.0019	0.0014
Complement	0.0278	0.0258	0.0281	0.0284	0.0236	0.0305	0.0285	0.0322	0.0294
Alternative TFP and labor income processes									
Constant TFP	0.0089	0.0084	0.0089	0.0090	0.0087	0.0085	0.0084	0.0119	0.0191
Richer Income Process	0.0054	0.0058	0.0059	0.0059	0.0057	0.0052	0.0046	0.0050	0.0107
Additional Experiments									
Double Volatility	-0.0070	-0.0070	-0.0074	-0.0073	-0.0070	-0.0067	-0.0063	-0.0089	-0.0148
Sudden Change	0.0108	0.0125	0.0123	0.0118	0.0111	0.0104	0.0092	0.0100	0.0158

The average and distributional welfare results from the case with  $\tau_0$ -adjustment turn out to be quite similar to those from the baseline (row 2 of Table 8). To understand this outcome, we first note that the distributional implications are pretty similar when either  $\tau_0$  and  $\tau_1$  is adjusted. To be more precise, in the first case, all households face the same tax rate changes in terms of absolute magnitude; while in relative terms, the tax rate change is decreasing with income levels. In the second case, all households face the same percentage change in their tax rates; while in terms of absolute magnitude, the tax rate change is increasing with income levels. Regardless of the specific differences, the wealth-rich households, whose marginal tax rates are close to the upper bound  $\tau_0 + \tau_1$ , face a similar rate-of-return risk in both cases. The analogues of Figures 1 and 2 look essentially the same for the  $\tau_0$ -adjustment case (see Figure 4), which confirms our intuition.

Figure 4: Comparing various tax adjustment cases with the baseline



Notes: Panel (A) compares the percentage difference between the expected aggregate capital path in the transition-path equilibrium and the two-shock equilibrium in the baseline scenario with those from the  $\tau_0$ -,  $\tau_2$ -, and  $\tau_3$ -adjustment cases. The calculation of each case is done in exactly the same manner as that of Figure 2. Panel (B) compares the difference between the first-period policy function for saving from the transition equilibrium and that from the two-shock equilibrium in the baseline scenario with those from the  $\tau_0$ -,  $\tau_2$ -, and  $\tau_3$ -adjustment cases. The calculation of each case is done in exactly the same manner as that of Figure 1. The wealth percentiles in Panel (B) are from the baseline model (they are, however, very similar across different tax adjustment specifications).

The results in row 3 and 4 of Table 8 show that adjustment through  $\tau_2$  or  $\tau_3$  yields similar overall welfare gains as in the baseline case. However, unlike in the baseline scenario, the welfare gain for the top 5% of households is *smaller* than the average welfare gain in both cases. First note that the average factor price channel cannot explain the lower welfare gain for the wealthy. In each of the two cases, the expected aggregate capital stock decreases (more than in the baseline case) after the elimination of fiscal volatility (see Panel A in Figure 4), which leads to lower wages and a higher pre-tax capital rate-of-return, favoring the wealth-rich households. The difference is rather due to the fact that in these cases the rate-of-return risk effect plays a limited role for the wealth-rich households. A fluctuating  $\tau_2$  or  $\tau_3$  does not generate substantial tax-rate uncertainty for the very rich households as their marginal tax rate is close to the upper bound, a (constant)  $\tau_0 + \tau_1$ . By contrast, it is the tax rates for the middle of the income distribution that respond the most to changes in  $\tau_2$  and  $\tau_3$ . Therefore the wealth-rich households do not benefit much from the fiscal volatility reduction in these cases.

Panel (B) in Figure 4 compares the changes in saving behavior for the  $\tau_2$ -adjustment and the  $\tau_3$ -

adjustment cases with those of the baseline case. In both the  $\tau_2$ -adjustment and the  $\tau_3$ -adjustment cases, more households decrease their savings compared to the baseline case, which is consistent with the aggregate capital adjustment path comparisons in Panel (A). In particular, there is little (no) saving increase from the wealth-rich households in the  $\tau_2$ -adjustment case ( $\tau_3$ -adjustment case), which confirms that the rate-of-return effect is rather limited.

The different welfare gain patterns in the baseline scenario vis-à-vis the  $\tau_2$ - and  $\tau_3$ -adjustment scenarios have important policy implications: the distributional effects of eliminating fiscal volatility depend on which wealth group experiences the tax volatility burden that is caused by government purchases shocks. In the U.S. this group appears to be the wealth-rich.

The comparison between the baseline case and the  $\tau_2$ - and  $\tau_3$ -adjustment cases also allows us to gauge the quantitative importance of the income risk channel. The average factor price change in the baseline case is more favorable to the wealth-poor than those in the  $\tau_2$ - and  $\tau_3$ -adjustment cases. Nonetheless, the welfare gain is increasing across wealth in the baseline case while it is decreasing in the latter cases. Therefore, it appears that the income risk channel is the main driver behind the opposite distributional effects of the baseline case vis-à-vis the  $\tau_2$ - and  $\tau_3$ -adjustment cases.

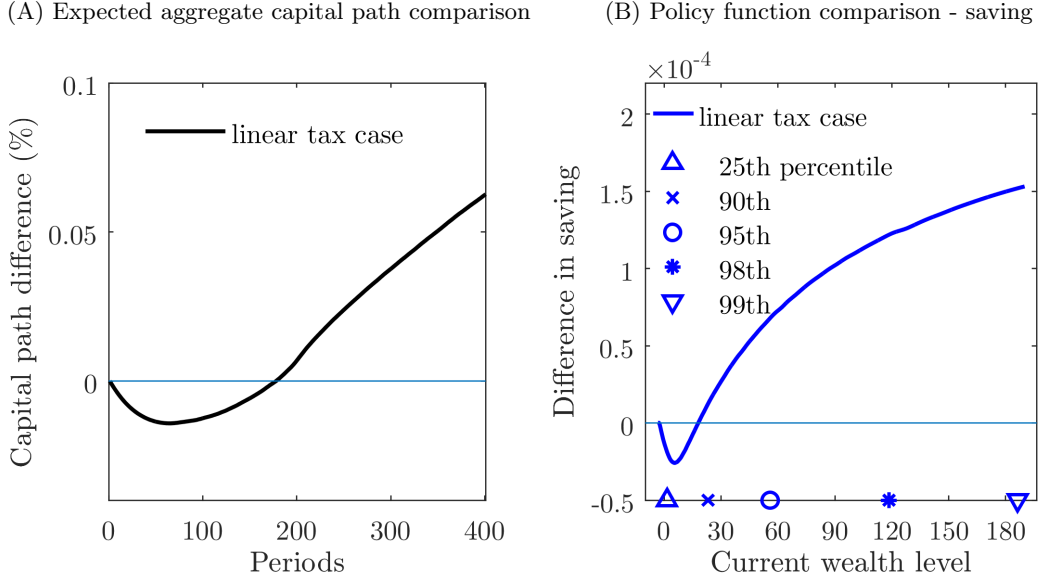
**Other fiscal regimes.** We next present distributional welfare results under three additional fiscal regimes. These analyses will shed additional light on the mechanisms behind the welfare effects of the elimination of fiscal volatility. In our first regime, a balanced budget scenario, we dispense with the tax revenue response rule (equation (2.6)) and assume that government spending is financed exclusively through tax revenue. In our next two regimes, a linear (lump-sum) tax scenario, we keep the tax revenue response rule but change the progressive tax system to a linear (lump-sum) tax, by setting  $\tau_1 = 0$  ( $\tau_0 = 0$  and  $\tau_2 = -1$ ). The linear tax rate (the lump-sum tax amount) are then endogenously determined to satisfy the aggregate tax revenue response rule.

We present the results of this set of analyses in rows 5 to 7 of Table 8. In the balanced budget regime, the welfare gain is larger than in the baseline case across the wealth distribution, even though the distributional effects are similar. This implies that allowing the government to borrow helps to smooth out tax revenue changes (and tax rate fluctuations) caused by government spending shocks, which in turn reduces the welfare cost of fiscal volatility.

Turning next to the linear tax case, we find that the welfare gains are very similar to those in the baseline  $\tau_1$ -adjustment case, both in terms of magnitude and pattern, as shown in row 6 of Table 8. Indeed, the mechanisms work in a similar way: in a linear tax regime, cyclical adjustments in tax rates cause after-tax rate-of-return uncertainty, especially for the wealth-rich.

Consequently, the elimination of this uncertainty benefits them. Indeed, when we compare the saving policy function between the two-shock and the transition-path equilibrium, we find an almost identical pattern as that in the baseline case (see Figure 5).

Figure 5: Analysis of the linear tax case

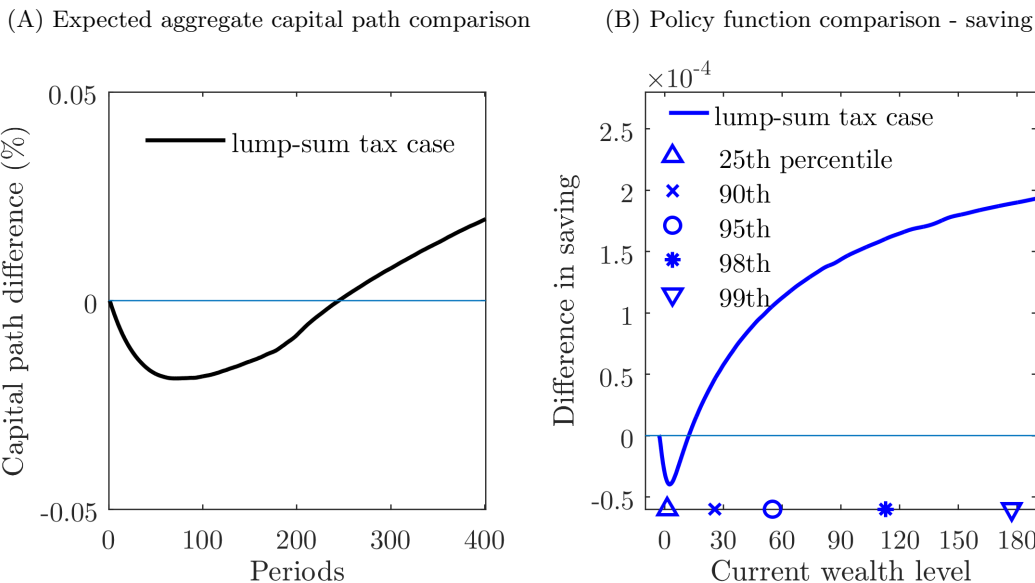


Notes: Panel (A) shows the percentage difference between the expected aggregate capital path in the transition-path equilibrium and the two-shock equilibrium in the linear tax case. The calculation is done in exactly the same manner as that of Figure 2. Panel (B) shows the difference between the first-period policy function for saving from the transition equilibrium and that from the two-shock equilibrium in the linear tax case. The calculation of each case is done in exactly the same manner as that of Figure 1. The wealth percentiles in Panel (B) are from the linear tax model, calculated in the same way as those in Figure 1.

Finally, our results for the lump-sum tax case (row 7 of Table 8) show that the welfare gains from eliminating fiscal volatility are again increasing in wealth, even more so than in the baseline case.<sup>31</sup> Indeed, Panel (A) of Figure 6 shows that the expected aggregate capital stock in the lump-sum tax case decreases for almost 300 periods after the elimination of volatility and thus longer (and initially steeper with a shallower rebound) than in the baseline case, which implies that the average factor price channel favors the wealth-rich very strongly here. Overall, since there is no distortion when taxes are lump-sum, the average factor price channel is particularly powerful here (and without a direct impact on after-tax capital returns and wages in this case we also have a less powerful income risk channel): the higher return makes capital more attractive as a saving vehicle after the elimination of volatility (see Panel B of Figure 6), leading to benefits for the wealth-rich.

<sup>31</sup>We note that the lump-sum tax is imposed only on employed households to avoid negative after-tax incomes. This treatment is slightly different from all the other cases, where tax payments are zero if and only if  $y \leq 0$ . With lump sum taxes, this could potentially introduce a discontinuity in the budget constraint of the unemployed at  $y = 0$  (for the employed, it must hold that  $y - T \geq 0$  at the borrowing limit, and thus, *a fortiori*, for all employed households).

Figure 6: Analysis of the lump-sum tax case



Notes: Panel (A) shows the percentage difference between the expected aggregate capital path in the transition-path equilibrium and the two-shock equilibrium in the lump-sum tax case. The calculation is done in exactly the same manner as that of Figure 2. Panel (B) shows the difference between the first-period policy function for saving from the transition equilibrium and that from the two-shock equilibrium in the lump-sum tax case. The calculation of each case is done in exactly the same manner as that of Figure 1. The wealth percentiles in Panel (B) are from the lump sum tax model, calculated in the same way as those in Figure 1.

**Non-separable utility.** Recall that our baseline specification assumes a separable flow utility function in private and public consumption ( $\rho = 1$ ), which implies that government purchases volatility affects the household decisions only indirectly, through equilibrium tax rate changes. By contrast, if public and private consumption are non-separable, then this volatility has a direct effect on the consumption-saving decision, since the government purchases level affects the marginal utility of private consumption.<sup>32</sup> We thus examine two alternative specifications where public consumption is an Edgeworth substitute (complement),  $\rho = 0.5$  ( $\rho = 1.5$ ), to private consumption.<sup>33</sup>

The results in rows 8 and 9 of Table 8 show that when  $G$  and  $c$  are complements (substitutes), the welfare gains from the elimination of fiscal volatility are larger (smaller) than in the baseline scenario. This is because the positive conditional comovement between  $G$  and taxes in the estimated tax revenue response rule makes volatility in  $G$  more costly when  $c$  and  $G$  are complements.<sup>34</sup> Since households face higher tax rates (lower disposable income) when  $G$  and the marginal utility of private consumption are high, the utility gain from fiscal volatility elimination

<sup>32</sup>See Fiorito and Kollintzas (2004) for an overview of utility specifications for public consumption.

<sup>33</sup>To calculate  $\lambda_c$  with a non-separable utility function, we calculate the left-hand side of (5.2) as a discounted sum of flow utilities under various values of  $\lambda_c$ , using the equilibrium policy functions. We then find a value of  $\lambda_c$  that satisfies the equation numerically, using a bisection search.

<sup>34</sup>In the estimated aggregate tax revenue response rule, the tax-output ratio responds to the government-purchases-output ratio with a coefficient of  $\rho_{T,G} = 0.484$ ; see Appendix A.2. for the details.



in the case of complements is larger than in the separable case. An analogous argument applies when  $G$  and  $c$  are substitutes.

**Alternative TFP and labor income processes.** Recall that our baseline scenario adopts the same TFP and unemployment processes as used in Krusell and Smith (1998). However, these choices produce an output volatility in the model that is 70% larger than that in the data (Section 3.3). To examine whether this difference affects our welfare results, we match the output volatility in the data by keeping TFP constant (at  $z = 1$ ), but allowing unemployment rate fluctuations. The results in row 10 in Table 8 are very similar to those from the baseline model, suggesting that the excess output volatility in our model does not influence our welfare results.

Our baseline specification, to ease the computational burden, also does not allow for any labor income heterogeneity conditional on being employed. However, a realistically richer income process might matter for our welfare results. It can affect the implications of the progressive tax system as well as the degree of precautionary saving motive. Moreover, it provides an additional channel through which wealth inequality is generated in the model (Krueger et al., 2016). To examine whether this feature affects our welfare results, we introduce individual-specific productivity shocks as in McKay and Reis (2016). The idiosyncratic productivity process is assumed to be independent from any other processes and determines the labor earnings for employed households.<sup>35</sup> The welfare numbers in row 11 of Table 8 indicate that the richer labor income dynamics does not change the main message of the baseline model. The average welfare change is slightly smaller than that in the baseline case, but the wealth-rich still benefit more from the fiscal volatility elimination.

## 6.2 Additional experiments

**Transition to a higher level of fiscal volatility.** As mentioned, one topic that has received some debate is how permanently heightened fiscal policy volatility might impact aggregate economic activity and welfare. To address this question, we let the economy transit to a level of fiscal volatility which has twice the variance of government purchases than that in our baseline economy.<sup>36</sup> Appendix D.1 provides the details of the computational implementation of this experiment.

The penultimate row in Table 8 shows the welfare changes from this magnified volatility experiment. As in the baseline experiment, higher fiscal volatility leads to a welfare loss for every wealth

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<sup>35</sup>In particular, building on McKay and Reis (2016), we calibrate the idiosyncratic productivity process to follow the following discretized Markov chain: grids take values from  $[0.49, 0.90, 1.61]$ , a transition can only happen between adjacent grids, and it happens with a probability of 0.02.

<sup>36</sup>To put this exercise into historical context, had we started our data sample in 1950I instead of 1960I to include the Korean War period when estimating the government purchases process, its variance would be about 1.5 times larger than that used in the baseline model.

group, with wealth-rich households experiencing a larger loss. Overall, the numbers suggest that, at least for the range between zero and twice the pre-crisis level of fiscal volatility, the welfare effects of fiscal volatility are roughly symmetric.

**Sudden change in the level of government purchases.** In this experiment, we examine the consequences of a concomitant sudden change in the government purchases level by letting government purchases move to and stay at their unconditional mean value,  $G_m$ , immediately after the elimination of fiscal volatility. We view this and the baseline scenario, where government purchases gradually converge to their long-run level, as two extreme ways of how fiscal volatility can be eliminated.

Table 9: Conditional expected welfare gains from private consumption,  $\lambda_c$  (%), sudden change

$G_1 = G_l$	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
All	-0.3749	-0.5121	-0.4826	-0.4469	-0.4198	-0.3922	-0.3030	0.0078	0.2184
$\varepsilon = 1$	-0.3748	-0.5134	-0.4833	-0.4471	-0.4200	-0.3924	-0.3036	0.0074	0.2182
$\varepsilon = 0$	-0.3762	-0.5054	-0.4764	-0.4455	-0.4179	-0.3897	-0.2952	0.0132	0.2212
$\tilde{\beta} = \tilde{\beta}_l$	-0.4978	-0.5347	-0.5213	-0.4932	-0.4636	-0.4369	-0.3232	-0.0537	0.1555
$\tilde{\beta} = \tilde{\beta}_m$	-0.3786	-0.4904	-0.4732	-0.4465	-0.4198	-0.3924	-0.3090	-0.0032	0.2056
$\tilde{\beta} = \tilde{\beta}_h$	-0.0521	-0.4158	-0.3934	-0.3644	-0.3380	-0.3097	-0.1665	0.0754	0.2759
$G_1 = G_h$	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
All	0.4010	0.5452	0.5142	0.4767	0.4472	0.4174	0.3243	0.0119	-0.1873
$\varepsilon = 1$	0.4008	0.5463	0.5149	0.4768	0.4474	0.4176	0.3249	0.0123	-0.1870
$\varepsilon = 0$	0.4026	0.5389	0.5088	0.4756	0.4455	0.4151	0.3166	0.0064	-0.1904
$\tilde{\beta} = \tilde{\beta}_l$	0.5268	0.5653	0.5513	0.5209	0.4893	0.4610	0.3417	0.0673	-0.1356
$\tilde{\beta} = \tilde{\beta}_m$	0.4045	0.5244	0.5055	0.4763	0.4472	0.4176	0.3300	0.0210	-0.1772
$\tilde{\beta} = \tilde{\beta}_h$	0.0825	0.4525	0.4280	0.3968	0.3689	0.3393	0.1938	-0.0442	-0.2321

From the results in the last row of Table 8, we see that the unconditional welfare gains with a sudden change in the level of government purchases are very similar to those in the baseline case. However, the results in Table 9 show that the welfare changes conditional on  $G_1 = G_l$  and  $G_1 = G_h$  are one order of magnitude larger than those in the baseline case (Table 7). For the  $G_1 = G_l$ -case, the welfare changes are increasing in the wealth level, while the opposite pattern holds for the case of  $G_1 = G_h$ . However, these patterns are not driven by the elimination of fiscal volatility *per se*. The sudden change in the level of government purchases (and hence taxation) leads to a faster aggregate capital stock adjustment and a larger effect on welfare. For instance in the  $G_1 = G_l$ -case, the sudden increase in government purchases leads to a faster decrease in aggregate capital, output, and average welfare. However, since lower aggregate capital levels (higher pre-tax rates of return) favor the wealth-rich capital income earners, the welfare change pattern increases with wealth. Following a similar intuition, the distributional effect for the  $G_1 = G_h$ -case is reversed.

## 7 Conclusion

The recent recession, the economy's slow recovery, and political turmoil have sparked a debate over the economic effects of fiscal volatility and uncertainty. In this study, we quantify the welfare effects of fiscal volatility and their distribution in a neoclassical stochastic growth environment with incomplete markets. In our model, aggregate uncertainty arises from both productivity and government purchases shocks. Government spending is financed by a progressive tax system, modeled to match important features of the U.S. tax system. We calibrate the model to U.S. data and evaluate the welfare and distributional consequences of eliminating government purchases shocks.

Our baseline results show that the welfare costs of fiscal volatility are fairly small on average. However, distributionally, the welfare costs are increasing in wealth. This distributional implication follows because the cyclical nature of the overall progressivity of the U.S. tax system implies a strong role for top marginal tax rates in the cyclical adjustment of the tax system to satisfy the government budget constraint.

While our study provides insight into the impact of eliminating fiscal volatility, it should be viewed as a first step towards a more comprehensive analysis of the welfare and distributional implications of fiscal volatility. Future research could explore how our results change if nominal frictions that cause relative price distortions are added to the model. There is also no role in our model for a direct influence of government purchases on the unemployment process and thus cyclical idiosyncratic risk. Including this feature in a future quantitative analysis would require the development of a statistical model of how government purchases influence idiosyncratic unemployment processes, but such a model is elusive in the literature. Instead, since government purchases appear to be independent of the cycle in U.S. post-war quarterly frequency data, we have also used this assumption in the model. Furthermore, we have chosen to place exogenous volatility fundamentally on the level of government purchases, while the volatility of individual tax rates is derived from our model. Among fiscal data, we view the official aggregate data on government purchases as cleanest and least subject to construction choices, but recognize that the data on tax rates collected in Mertens and Montiel Olea (2013) could provide an alternative route. Finally, we model government purchases as a symmetric autoregressive process. However, future research could examine fiscal uncertainty in an economy facing the risk of very large government purchases as a very rare and dramatic event.

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## A Appendix: Estimation of the fiscal parameters

For the calibration, we use quarterly data from 1960I to 2007IV.

### A.1 Government purchases process

We first construct a real government purchases ( $G$ ) series by deflating the “Government consumption expenditures and gross investment” series (from NIPA table 3.9.5, line 1) with the GDP deflator (from NIPA table 1.1.9, line 1). We then estimate an AR(1) process for the linearly detrended real  $\log(G)$  series. The estimated AR(1) coefficient is 0.9603 and the standard deviation of the innovation term is 0.0096. We use the Rouwenhorst method (see Rouwenhorst (1995)) to approximate this zero-mean AR(1) process with a three-state Markov Chain. This gives us a transition probability matrix, and a grid in the form  $(-m, 0, m)$ , where  $m$  represents the percentage deviation from the middle grid point. The middle grid point of the  $G$ -process,  $G_m$ , is then calibrated to match the time series average of nominal  $G$  over nominal GDP from U.S. national accounting data (nominal GDP is from NIPA table 1.1.5, line 1), 20.86%. The grid for  $G$  is given by  $(G_l, G_m, G_h)$ , where  $G_h = (1 + m)G_m$  and  $G_l = (1 - m)G_m$ , and the discretized  $G$ -process on  $[0.2205, 0.2319, 0.2433]$  has the following transition matrix:

$$\begin{bmatrix} 0.9607 & 0.0389 & 0.0004 \\ 0.0195 & 0.9611 & 0.0195 \\ 0.0004 & 0.0389 & 0.9607 \end{bmatrix}.$$

### A.2 Fiscal rule

#### A.2.1 Methodology and estimation results

We first estimate the fiscal rule separately at two levels of government: the federal government level and the state/local level, allowing for debt only at the federal level.<sup>37</sup> We then construct a composite rule, using the share of federal government purchases in total government purchases.

The empirical specification for the federal fiscal rule is based on Bohn (1998) and Davig and Leeper (2011) and takes the following form:

$$\frac{T_t^F - T_t^{rF}}{Y_t} = \rho_{T,0}^F + \rho_{T,B}^F \frac{B_t}{Y_t} + \rho_{T,Y}^F \log\left(\frac{Y_t}{\bar{Y}}\right) + \rho_{T,G}^F \frac{G_t^F}{Y_t}, \quad (\text{A.1})$$

where:

$Y_t$ : Nominal GDP (Line 1 of NIPA table 1.1.5).

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<sup>37</sup>When we estimate one equation, using the sum of federal and the state-local level data, the estimation result implies a non-stationary government debt process.

$T_t^F - Tr_t^F$ : Federal government current receipts (Line 1 of NIPA table 3.2) minus federal government transfer expenditure (Line 25 of NIPA table 3.2).

$B_t$ : Market value of privately held gross federal debt at the beginning of a quarter: data are from the Federal Reserve Bank of Dallas (<http://www.dallasfed.org/research/econdata/govdebt.cfm>).

$\bar{Y}_t$ : Nominal CBO potential GDP: data are from the CBO website (<http://www.cbo.gov/publication/42912>).

$G_t^F$ : Nominal federal government consumption expenditures and gross investment (Line 23 of NIPA table 1.1.5).

At the state and local level, we drop the debt-to-GDP ratio term, yielding the following equation for the state and local level:

$$\frac{T_t^{SL} - Tr_t^{SL}}{Y_t} = \rho_{T,0}^{SL} + \rho_{T,Y}^{SL} \log\left(\frac{Y_t}{\bar{Y}_t}\right) + \rho_{T,G}^{SL} \frac{G_t^{SL}}{Y_t}, \quad (\text{A.2})$$

where:

$T_t^{SL} - Tr_t^{SL}$ : State and local government receipts (Line 1 of NIPA table 3.3) minus state and local government transfer expenditure (Line 24 of NIPA table 3.3).

$G_t^{SL}$ : Nominal state and local government consumption expenditures and gross investment (Line 26 of NIPA table 1.1.5).

We then linearly detrend all ratio variables, except for  $\log(Y_t/\bar{Y}_t)$ , before estimating equations (A.1) and (A.2).

Table 10 summarizes the estimation results.

Table 10: Estimated coefficients of the fiscal rule

	constant	$B_t/Y_t$	$\log(Y_t/\bar{Y}_t)$	$G_t/Y_t$
Federal	-0.009 (0.001)	0.017 (0.004)	0.321 (0.032)	0.146 (0.096)
State and local	0.001 (0.001)	– –	-0.039 (0.015)	0.771 (0.063)

### A.2.2 The composite fiscal rule

The composite fiscal rule used in our model is given by:

$$\begin{aligned} \frac{T_t - Tr_t}{Y_t} &= \rho_{T,0} + \rho_{T,B} \frac{B_t}{Y_t} + \rho_{T,Y} \log\left(\frac{Y_t}{\bar{Y}_t}\right) + \rho_{T,G} \frac{G_t}{Y_t} \\ &= \rho_{T,0} + \rho_{T,B}^F \frac{B_t}{Y_t} + (\rho_{T,Y}^F + \rho_{T,Y}^{SL}) \log\left(\frac{Y_t}{\bar{Y}_t}\right) + (\gamma^F \rho_{T,G}^F + (1 - \gamma^F) \rho_{T,G}^{SL}) \frac{G_t}{Y_t}, \end{aligned} \quad (\text{A.3})$$

where  $\gamma^F$  is calibrated as the average share of federal government purchases within total government purchases: 0.46. This yields the following fiscal rule parameters:

$$\rho_{T,B} = 0.017, \quad \rho_{T,Y} = 0.282, \quad \rho_{T,G} = 0.484.$$

We use  $\rho_{T,0}$  to match the average debt-to-GDP ratio in the data: 30%.

### A.3 Consumption and income tax parameters

For the consumption tax function and the linear part of the income tax function, we use the average tax rate calculated from the data.

To be specific, the average tax rate on consumption is defined as:

$$\tau_c = \frac{TPI - PRT}{PCE - (TPI - PRT)}, \quad (\text{A.4})$$

where the numerator is taxes on production and imports (TPI, NIPA table 3.1, line 4) minus state and local property taxes (PRT, NIPA table 3.3, line 8). The denominator is personal consumption expenditures (PCE, NIPA table 1.1.5, line 2) net of the numerator. We calculate the average  $\tau_{c,t}$  over our sample period as our  $\tau_c$  parameter: 8.14%.

For income taxes, we use the state level tax revenue to approximate the linear part:

$$\tau_0 = \frac{PIT + CT + PRT}{\text{Taxable Income}}, \quad (\text{A.5})$$

where PIT (NIPA table 3.3, line 4) is state income tax, CT (NIPA table 3.3, line 10) is state tax on corporate income, and PRT (NIPA table 3.3, line 8) is state property taxes. Note that we exclude the social insurance contribution in the numerator since we do not have social security expenditures in the model. The denominator is GDP minus consumption of fixed capital (NIPA table 1.7.5, line 6), since our model has a depreciation allowance for capital income. Averaging  $\tau_{0,t}$  from 1960I to 2007IV yields  $\tau_0 = 5.25\%$ .

## B Appendix: Computational algorithm

### B.1 Computational algorithm for the two-shock stochastic steady state

*Step 0:* We first select a set of summary statistics for the wealth distribution,  $\{K, Gini(a)\}$ , and fix the functional form of the equilibrium rules in equations (4.1)-(4.3). We then set the interpolation grids for  $(a, K, Gini(a), B)$  to be used in the approximation of the household's continuation value function and policy function. We use an initial guess of coefficients  $\{a_0^0, \dots, a_7^0\}$ ,  $\{\tilde{a}_0^0, \dots, \tilde{a}_7^0\}$ ,  $\{b_0^0, \dots, b_7^0\}$  to obtain initial conjectures for  $\{H_\Gamma^0, \Theta^0\}$ , and set up a convergence criterion  $\varepsilon = 10^{-4}$ .

*Step 1:* At the  $n$ th iteration, imposing  $\{H_\Gamma^n, \Theta^n\}$  in the household optimization problem, we use a value function iteration to solve the household's parametric dynamic programming problem as defined in Section 2.4. From this process, we obtain the continuation value function  $V^n(a, \varepsilon, \tilde{\beta}, K, Gini(a), B, z, G; H_\Gamma^n, \Theta^n)$ .

*Step 2:* We next simulate the economy using  $N_H$  households and  $T$  periods. In each period  $t$  of the simulation, we first calculate the equilibrium  $\tau_{1,t}^{eq,n}$  using equation (2.11) and  $\{H_\Gamma^n\}$ . Then we solve the household's optimization problem for the current  $(K_t^n, Gini_t^n(a), B_t^n, z_t^n, G_t^n, \tau_{1,t}^{eq,n})$  using  $V^n(a, \varepsilon, \tilde{\beta}, K, Gini(a), B, z, G; H_\Gamma^n, \Theta^n)$  as the continuation value function and  $\{H_\Gamma^n, H_B\}$ . This is a one-shot optimization problem. The aggregate states in the next period follow from our aggregation of the optimal household decisions. From this step, we collect the time series  $\{K_t^n, Gini_t^n(a), B_t^n, z_t^n, G_t^n, \tau_{1,t}^{eq,n}\}_{t=1}^T$ .

*Step 3:* With these time series, we obtain separate OLS estimates of  $\{\hat{a}_0^n, \dots, \hat{a}_7^n\}$ ,  $\{\hat{a}_0^n, \dots, \hat{a}_7^n\}$ ,  $\{\hat{b}_0^n, \dots, \hat{b}_7^n\}$ , for each  $z$  and  $G$  combination, which, with a slight abuse of notation, we summarize as  $(\hat{H}_\Gamma^n, \hat{\Theta}^n)$ .

*Step 4:* If  $|H_\Gamma^n - \hat{H}_\Gamma^n| < \epsilon$  and  $|\Theta^n - \hat{\Theta}^n| < \epsilon$ , we stop. Otherwise, we set

$$\begin{aligned} H_\Gamma^{n+1} &= \alpha_H \times \hat{H}_\Gamma^n + (1 - \alpha_H) \times H_\Gamma^n \\ \Theta^{n+1} &= \alpha_\Theta \times \hat{\Theta}^n + (1 - \alpha_\Theta) \times \Theta^n \end{aligned}$$

with  $\alpha_H, \alpha_\Theta \in (0, 1]$ , and go to Step 1.

*Step 5:* Finally, we check whether the  $R2s$  (the multiple-step-ahead forecast errors) of the final OLS regressions are sufficiently high (small) for the equilibrium rules to be well approximated. If they are not, we change the functional forms in Step 0 and repeat the algorithm.

In Step 1, we iterate on the value function until it converges at a set of collocation points, chosen to be the grid points of  $(a, K, Gini(a), B)$  defined in Step 0. In each step of the value function iteration, we use multi-dimensional cubic splines on this interpolation grid to approximate the continuation value function. For each collocation point of the state variables  $(a, K, Gini(a), B)$  as well as the exogenous aggregate state variables  $(z, G)$ , we use  $\{H_\Gamma^n, \Theta^n, H_B\}$  to infer the values of  $(K', Gini'(a), B', \tau_1)$ . Given the aggregate variables  $(K', Gini'(a), B', \tau_1)$ , we maximize the Bellman equation numerically along the  $a'$ -dimension using Brent's method, as described in Press et al. (2007). The same method is used in the numerical optimization part of Step 2.

In Step 2, we use  $N_H = 90,000$  households and run 12 parallel simulations of length  $T = 18,000$

each.<sup>38</sup> Following Krusell and Smith (1998), we also enforce that at each  $t$  these 90,000 households are distributed according to the stationary distribution of the Markov chains governing  $\varepsilon$  and  $\beta$ . We thus avoid introducing artificial aggregate uncertainty due to small deviations from the law of large numbers. To eliminate sampling error, we use the same series of aggregate shocks for all iterations and all model simulations.

The algorithm is implemented in a mixture of C/C++ and MATLAB, which are then connected through MATLAB's CMEX interface.<sup>39</sup>

## B.2 Results for the stochastic steady state

### B.2.1 Estimated laws of motions for the two-shock equilibrium

$H_\Gamma$  for aggregate capital in *good* times (state  $z_g$ ), with low ( $G_l$ ), medium ( $G_m$ ), and high ( $G_h$ ) government purchases levels are, respectively (in the above order):

$$\log(K') = 0.1310 + 0.9219\log(K) - 0.0015B + 0.0104(\log(K))^2 + 0.0000B^2 \quad (G_l)$$

$$+ 0.0000B^3 + 0.0005\log(K)B + 0.0007Gini(a), \quad R2 = 0.999999,$$

$$\log(K') = 0.1251 + 0.9256\log(K) - 0.0014B + 0.0098(\log(K))^2 + 0.0000B^2 \quad (G_m)$$

$$+ 0.0000B^3 + 0.0005\log(K)B + 0.0007Gini(a), \quad R2 = 0.999999,$$

$$\log(K') = 0.1200 + 0.9287\log(K) - 0.0015B + 0.0093(\log(K))^2 + 0.0000B^2 \quad (G_h)$$

$$+ 0.0000B^3 + 0.0005\log(K)B + 0.0006Gini(a), \quad R2 = 0.999999.$$

$H_\Gamma$  for aggregate capital in *bad* times (state  $z_b$ ), with low, medium, and high government purchases levels are, respectively:

$$\log(K') = 0.1050 + 0.9357\log(K) - 0.0015B + 0.0082(\log(K))^2 + 0.0000B^2 \quad (G_l)$$

$$+ 0.0000B^3 + 0.0005\log(K)B + 0.0010Gini(a), \quad R2 = 0.999999,$$

$$\log(K') = 0.1024 + 0.9366\log(K) - 0.0014B + 0.0081(\log(K))^2 + 0.0000B^2 \quad (G_m)$$

$$+ 0.0000B^3 + 0.0005\log(K)B + 0.0009Gini(a), \quad R2 = 0.999999,$$

$$\log(K') = 0.0968 + 0.9402\log(K) - 0.0014B + 0.0075(\log(K))^2 + 0.0000B^2 \quad (G_h)$$

$$+ 0.0000B^3 + 0.0005\log(K)B + 0.0008Gini(a), \quad R2 = 0.999999.$$

<sup>38</sup>Although each simulation has 19,000 periods, we discard the initial 1,000 observations in the estimation.

<sup>39</sup>On a 12-core 2.67 GHz Intel Xeon X5650 Linux workstation, the typical run time for the value function iteration lies around several hours (it gets shorter as the initial guess gets more accurate), while that for one simulation loop is about 40 minutes. Starting from a guess close to the equilibrium, it takes about 40 iterations to converge.

$H_\Gamma$  for the Gini coefficient of the wealth distribution in *good* times (state  $z_g$ ), with low, medium, and high government purchases levels are, respectively:

$$\begin{aligned} Gini(a') &= -0.0661 + 0.0387\log(K) + 0.0035B - 0.0046(\log(K))^2 - 0.0000B^2 & (G_l) \\ &+ 0.0000B^3 - 0.0013\log(K)B + 0.9975Gini(a), \quad R2 = 0.999998, \end{aligned}$$

$$\begin{aligned} Gini(a') &= -0.0712 + 0.0428\log(K) + 0.0036B - 0.0054(\log(K))^2 - 0.0000B^2 & (G_m) \\ &+ 0.0000B^3 - 0.0013\log(K)B + 0.9974Gini(a), \quad R2 = 0.999998, \end{aligned}$$

$$\begin{aligned} Gini(a') &= -0.0744 + 0.0455\log(K) + 0.0035B - 0.0059(\log(K))^2 - 0.0000B^2 & (G_h) \\ &+ 0.0000B^3 - 0.0013\log(K)B + 0.9974Gini(a), \quad R2 = 0.999998. \end{aligned}$$

$H_\Gamma$  for the Gini coefficient of the wealth distribution in *bad* times (state  $z_b$ ), with low, medium, and high government purchases levels are, respectively:

$$\begin{aligned} Gini(a') &= -0.1201 + 0.0846\log(K) + 0.0039B - 0.0143(\log(K))^2 - 0.0000B^2 & (G_l) \\ &- 0.0000B^3 - 0.0015\log(K)B + 0.9991Gini(a), \quad R2 = 0.999992, \end{aligned}$$

$$\begin{aligned} Gini(a') &= -0.1195 + 0.0844\log(K) + 0.0039B - 0.0142(\log(K))^2 - 0.0000B^2 & (G_m) \\ &- 0.0000B^3 - 0.0015\log(K)B + 0.9991Gini(a), \quad R2 = 0.999993, \end{aligned}$$

$$\begin{aligned} Gini(a') &= -0.1177 + 0.0829\log(K) + 0.0039B - 0.0139(\log(K))^2 - 0.0000B^2 & (G_h) \\ &- 0.0000B^3 - 0.0015\log(K)B + 0.9991Gini(a), \quad R2 = 0.999993. \end{aligned}$$

$\Theta$  in *good* times (state  $z_g$ ), with low, medium, and high government purchases levels are, respectively:

$$\begin{aligned} \tau_1 &= 0.2708 - 0.1890\log(K) + 0.0080B + 0.0712(\log(K))^2 - 0.0003B^2 & (G_l) \\ &- 0.0000B^3 + 0.0058\log(K)B - 0.0063Gini(a), \quad R2 = 0.999991, \end{aligned}$$

$$\begin{aligned} \tau_1 &= 0.2835 - 0.1895\log(K) + 0.0067B + 0.0709(\log(K))^2 - 0.0003B^2 & (G_m) \\ &- 0.0000B^3 + 0.0063\log(K)B - 0.0069Gini(a), \quad R2 = 0.999988, \end{aligned}$$

$$\begin{aligned} \tau_1 &= 0.3038 - 0.1960\log(K) + 0.0049B + 0.0718(\log(K))^2 - 0.0003B^2 & (G_h) \\ &- 0.0000B^3 + 0.0069\log(K)B - 0.0075Gini(a), \quad R2 = 0.999987. \end{aligned}$$

$\Theta$  in *bad* times (state  $z_b$ ), with low, medium, and high government purchases levels are, respectively:

$$\tau_1 = 0.3093 - 0.2284\log(K) + 0.0096B + 0.0794(\log(K))^2 - 0.0003B^2 \quad (G_l)$$

$$- 0.0000B^3 + 0.0065\log(K)B - 0.0072Gini(a), \quad R2 = 0.999988,$$

$$\tau_1 = 0.3218 - 0.2280\log(K) + 0.0080B + 0.0790(\log(K))^2 - 0.0003B^2 \quad (G_m)$$

$$- 0.0000B^3 + 0.0071\log(K)B - 0.0079Gini(a), \quad R2 = 0.999986,$$

$$\tau_1 = 0.3226 - 0.2179\log(K) + 0.0070B + 0.0766(\log(K))^2 - 0.0003B^2 \quad (G_h)$$

$$- 0.0000B^3 + 0.0075\log(K)B - 0.0088Gini(a), \quad R2 = 0.999985.$$

### B.2.2 Multi-step ahead forecast errors

To compute the multi-step ahead forecast errors, we compare the aggregate paths from the equilibrium simulation with those generated by the approximate equilibrium rules. To be specific, starting from the first period, we pick a set of aggregate states 80 periods apart along the final simulation of the stochastic steady state calculation,  $\{K_{(i-1)\times 80+1}, B_{(i-1)\times 80+1}, Gini_{(i-1)\times 80+1}(a)\}_{i \in \{1, 2, \dots\}}$ . We then simulate each set of aggregate states for 40 periods with the equilibrium laws of motions  $H_\Gamma$  and  $H_B$  (with the same aggregate shock sequences as those in the equilibrium simulation), and record the aggregate capital level in the last period of each simulation  $\{K_{(i-1)\times 80+1+40}^H\}_{i \in \{1, 2, \dots\}}$ . We then calculate the  $i$ th 10-year (40-period) ahead forecast error for aggregate capital as  $u_i^{40} = K_{(i-1)\times 80+1+40} - K_{(i-1)\times 80+1+40}^H$ , where  $K_t$  is the aggregate capital level at period  $t$  from the equilibrium simulation. Note that the forecast errors generated this way are independent of each other because 40 periods are discarded between each simulation. With the large number of simulations in the stochastic steady state calculation (12 parallel simulations each for 18,000 periods), we generate about 2,700 such forecast errors. The mean of these 10-year-ahead forecast errors is 0.0004%, and the root mean squared error (RMSE) of the 10-year-ahead forecast is about 0.05% of the long-run average capital level, suggesting little bias and high overall forecast accuracy in our laws of motions.



### B.2.3 Estimated laws of motions for the one-shock equilibrium

$H_\Gamma$  for aggregate capital in *good* times (state  $z_g$ ) and *bad* times (state  $z_b$ ) are, respectively:

$$\begin{aligned} \log(K') &= 0.1273 + 0.9238\log(K) - 0.0015B + 0.0101(\log(K))^2 + 0.0000B^2 & (z_g) \\ &\quad - 0.0000B^3 + 0.0005\log(K)B + 0.0007Gini(a), \quad R2 = 0.999999, \end{aligned}$$

$$\begin{aligned} \log(K') &= 0.1020 + 0.9370\log(K) - 0.0014B + 0.0080(\log(K))^2 + 0.0000B^2 & (z_b) \\ &\quad + 0.0000B^3 + 0.0005\log(K)B + 0.0009Gini(a), \quad R2 = 0.999999. \end{aligned}$$

$H_\Gamma$  for Gini coefficient of wealth distribution in *good* times (state  $z_g$ ) and *bad* times (state  $z_b$ ) are, respectively:

$$\begin{aligned} Gini(a') &= -0.0735 + 0.0447\log(K) + 0.0035B - 0.0058(\log(K))^2 - 0.0000B^2 & (z_g) \\ &\quad + 0.0000B^3 - 0.0012\log(K)B + 0.9976Gini(a), \quad R2 = 0.999998, \end{aligned}$$

$$\begin{aligned} Gini(a') &= -0.1308 + 0.0935\log(K) + 0.0040B - 0.0161(\log(K))^2 - 0.0000B^2 & (z_b) \\ &\quad - 0.0000B^3 - 0.0015\log(K)B + 0.9993Gini(a), \quad R2 = 0.999991. \end{aligned}$$

$\Theta$  in *good* times (state  $z_g$ ) and *bad* times (state  $z_b$ ) are, respectively:

$$\begin{aligned} \tau_1 &= 0.2763 - 0.1833\log(K) + 0.0068B + 0.0696(\log(K))^2 - 0.0003B^2 & (z_g) \\ &\quad - 0.0000B^3 + 0.0062\log(K)B - 0.0072Gini(a), \quad R2 = 0.999987, \end{aligned}$$

$$\begin{aligned} \tau_1 &= 0.3096 - 0.2176\log(K) + 0.0083B + 0.0768(\log(K))^2 - 0.0003B^2 & (z_b) \\ &\quad - 0.0000B^3 + 0.0070\log(K)B - 0.0083Gini(a), \quad R2 = 0.999984. \end{aligned}$$

### B.3 Computational algorithm for the transition-path equilibrium

*Step 0:* Set up:

We choose the starting  $G$  level (three possibilities) and guess a length for the transition period

$$T_{trans}.$$

We next assume specific functional forms for  $\{H_{\Gamma,t}^{trans}, \Theta_t^{trans}\}_{t=1}^{T_{trans}}$ .

We then select the interpolation grid for  $(a, K, Gini(a), B)$  used in the spline approximation of the household's continuation value function.

This calculation also requires the following inputs:

1.  $H_\Gamma^{1s}$  and  $\Theta^{1s}$ : laws of motions from the one-shock equilibrium.
2.  $V_{1s}(a, \varepsilon, \tilde{\beta}, K, Gini(a), B, z; H_\Gamma^{1s}, \Theta^{1s})$ : the value function for households from the one-shock equilibrium.

3.  $N_{trans}$  independent joint distributions over  $(a, \varepsilon, \tilde{\beta})$  (each with  $N_H$  households) drawn from the two-shock equilibrium simulation to start the transition-path equilibrium simulations. To get a balanced sample for each combination of  $z$  and  $t$ , exactly half of these distributions are collected during good times ( $z = z_g$ ).
4.  $N_{trans}$  different aggregate productivity shock paths  $\{\{z_t^i\}_{t=1}^{T_{trans}}\}_{i=1}^{N_{trans}}$ , where  $z_1^i$  matches with the productivity level in the  $i$ th collected joint distribution and the  $z_{t>1}^i$  are randomly drawn following its Markov process.

*Step 1:* We start from an initial coefficient guess  $\{\{a_{0,t}^0, \dots, a_{7,t}^0\}, \{\tilde{a}_{0,t}^0, \dots, \tilde{a}_{7,t}^0\}, \{b_0^{0,t}, \dots, b_{7,t}^0\}\}_{t=1}^{T_{trans}}$  to get our initial conjectures  $\{H_{\Gamma,t}^{trans,0}, \Theta_t^{trans,0}\}_{t=1}^{T_{trans}}$ . Set up a convergence criterion  $\varepsilon$ .

*Step 2:* In the  $n$ th iteration, we compute the household's value function at each period by backward induction, with imposed laws of motions  $\{H_{\Gamma,t}^{trans,n}, \Theta_t^{trans,n}\}_{t=1}^{T_{trans}}$ . To be specific,  $\forall t \in \{1, \dots, T_{trans}\}$ , given the continuation value  $V_{t+1}^{trans,n}(a, \varepsilon, \tilde{\beta}, K, Gini(a), B, z; H_{\Gamma,t+1}^{trans,n}, \Theta_{t+1}^{trans,n})$ , we calculate  $V_t^{trans,n}(a, \varepsilon, \tilde{\beta}, K, Gini(a), B, z; H_{\Gamma,t}^{trans,n}, \Theta_t^{trans,n})$ . Note that  $V_{T_{trans}+1}^{trans,n}(\cdot) = V_{1s}(\cdot)$ . We store the value functions at each point in time of the transition path.

*Step 3:* In this step, we simulate the  $N_{trans}$  economies with the corresponding productivity shock paths. For the simulation of the  $i$ th economy, in each period  $t$ , we first calculate the equilibrium  $\tau_{1,t}^{eq,n,i}$  using equation (2.11) and  $H_{\Gamma,t}^{trans,n}$ . Then we solve the household's optimization problem for  $(K_t^{n,i}, Gini_t^{n,i}(a), B_t^{n,i}, z_t^{n,i}, \tau_{1,t}^{eq,n,i})$  using  $V_{t+1}^{trans,n}(a, \varepsilon, \tilde{\beta}, K, Gini(a), B, z; H_{\Gamma,t+1}^{trans,n}, \Theta_{t+1}^{trans,n})$  and  $\{H_{\Gamma,t}^{trans,n}, \Theta_t^{trans,n}, H_B\}$ . The aggregate states in the next period follow from aggregating the optimal household decisions. We finally collect the following panel data  $\{K_t^{n,i}, Gini_t^{n,i}(a), B_t^{n,i}, z_t^{n,i}, \tau_{1,t}^{eq,n,i}\}_{t=1}^T\}_{i=1}^{N_{trans}}$ .

*Step 4:*  $\forall t \in \{1, \dots, T_{trans}\}$ , we run OLS for each point in time along the transition path to get estimates of  $\{\hat{a}_{0,t}^n, \dots, \hat{a}_{7,t}^n\}, \{\hat{\tilde{a}}_{0,t}^n, \dots, \hat{\tilde{a}}_{7,t}^n\}, \{\hat{b}_{0,t}^n, \dots, \hat{b}_{7,t}^n\}$ , which, with a slight abuse of notation, we summarize as  $\{\hat{H}_{\Gamma,t}^{trans,n}, \hat{\Theta}_t^{trans,n}\}_{t=1}^{T_{trans}}$ .

*Step 5:* If  $\max_t |H_{\Gamma,t}^{trans,n} - \hat{H}_{\Gamma,t}^{trans,n}| < \varepsilon$  and  $\max_t |\Theta_t^{trans,n} - \hat{\Theta}_t^{trans,n}| < \varepsilon$ , we stop. Otherwise,  $\forall t \in \{1, \dots, T\}$ , we set:

$$\begin{aligned} H_{\Gamma,t}^{trans,n+1} &= \alpha_H \times \hat{H}_{\Gamma,t}^{trans,n} + (1 - \alpha_H) \times H_{\Gamma,t}^{trans,n} \\ \Theta_t^{trans,n+1} &= \alpha_\Theta \times \hat{\Theta}_t^{trans,n} + (1 - \alpha_\Theta) \times \Theta_t^{trans,n} \end{aligned}$$

with  $\alpha_H, \alpha_\Theta \in (0, 1]$ , and go to Step 2.

*Step 6:* We check the convergence of the last period's laws of motion to those from the one-shock equilibrium. To be specific, starting from the aggregate states observed in the last period's

simulations,  $\{z_T^i, K_T^i, B_T^i, Gini_T^i(a)\}_{i=1}^{N_{trans}}$ , we calculate the differences in the predicted values of aggregate capital, the wealth Gini coefficient and  $\tau_1$ , between when we use the converged last period's laws of motions of the transition-path equilibrium,  $\{H_{\Gamma, T_{trans}}^{trans}, \Theta_{T_{trans}}^{trans}\}$ , and when we use the laws of motions from the one-shock economy,  $\{H_{\Gamma, 1s}, \Theta_{1s}\}$ . If the differences are comparable in size to those of the one-step prediction errors of the laws of motions from the one-shock stochastic steady state equilibrium, we go to Step 7. Otherwise, we go back to Step 0 and increase  $T_{trans}$ .

*Step 7:* We check whether the  $R^2$ s (the multiple-step-ahead forecast errors) of the final OLS regressions are sufficiently high (small) for the equilibrium rules to be well approximated. If they are not, we change the functional forms in Step 0 and repeat the algorithm.<sup>40</sup>

The numerical methods for interpolation and optimization used to solve the household's maximization problem in Step 2 and Step 3 are the same as those in the computation of the stochastic steady state. The only difference is that the procedure does not involve a value function iteration since we use backward induction to solve for the value function for each period, starting from the value function from the stochastic steady state without fiscal volatility.

<sup>40</sup>We choose  $\varepsilon = 10^{-4}$  and  $N_H = 90,000$ .  $T_{trans}$  is set to be shorter (200) when we start from  $G_m$  compared to the two other cases (400), because in the former case the  $G$ -process immediately transition to its deterministic conditional expectation.  $N_{trans}$  is set to be 8,000 when we start from  $G_m$  and 4,000 for the other two cases, to keep the ratios between the numbers of observations across different cases the same as those implied by the ergodic distribution of the  $G$ -process. On a 32-core 2.4 GHz Intel Xeon E5-4640 Linux workstation, the typical run time for the value function calculation takes about an hour, and for one simulation loop, it takes about six hours. Starting from a guess based on the weighted average between the two-shock and the one-shock laws of motion, it takes about 40 to 50 iterations to converge.

## B.4 Estimated laws of motions for transition-path equilibrium

Here we present the estimated laws of motions for selected periods and every combination of  $z_t$  and  $G_1$ .

Table 11: Transition-path equilibrium: starting from  $G_1 = G_l$ ,  $z_t = z_g$

t	$a_{0,t}$	$a_{1,t}$	$a_{2,t}$	$a_{3,t}$	$a_{4,t}$	$a_{5,t}$	$a_{6,t}$	$a_{7,t}$	G values	R2
1	0.1309	0.9220	-0.0015	0.0104	0.0000	-0.0000	0.0005	0.0008	0.2205	0.999999
2	0.1321	0.9210	-0.0015	0.0106	0.0000	-0.0000	0.0005	0.0007	0.2210	0.999999
3	0.1350	0.9186	-0.0016	0.0111	0.0000	-0.0000	0.0006	0.0007	0.2214	0.999999
...	...	...	...	...	...	...	...	...	...	...
398	0.1285	0.9228	-0.0016	0.0103	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
399	0.1274	0.9237	-0.0015	0.0101	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
400	0.1290	0.9225	-0.0016	0.0104	0.0000	0.0000	0.0006	0.0007	0.2319	0.999999
$\tilde{a}_{0,t}$	$\tilde{a}_{1,t}$	$\tilde{a}_{2,t}$	$\tilde{a}_{3,t}$	$\tilde{a}_{4,t}$	$\tilde{a}_{5,t}$	$\tilde{a}_{6,t}$	$\tilde{a}_{7,t}$	G values	R2	
1	-0.0673	0.0396	0.0036	-0.0047	-0.0000	0.0000	-0.0013	0.9974	0.2205	0.999998
2	-0.0620	0.0353	0.0035	-0.0038	-0.0000	0.0000	-0.0012	0.9974	0.2210	0.999998
3	-0.0719	0.0434	0.0036	-0.0055	-0.0000	0.0000	-0.0013	0.9974	0.2214	0.999998
...	...	...	...	...	...	...	...	...	...	...
398	-0.0741	0.0452	0.0034	-0.0059	-0.0000	-0.0000	-0.0012	0.9975	0.2319	0.999998
399	-0.0689	0.0410	0.0033	-0.0050	-0.0000	0.0000	-0.0012	0.9975	0.2319	0.999998
400	-0.0762	0.0469	0.0035	-0.0062	-0.0000	-0.0000	-0.0012	0.9975	0.2319	0.999998
$b_{0,t}$	$b_{1,t}$	$b_{2,t}$	$b_{3,t}$	$b_{4,t}$	$b_{5,t}$	$b_{6,t}$	$b_{7,t}$	G values	R2	
1	0.2922	-0.2064	0.0067	0.0746	-0.0003	-0.0000	0.0063	-0.0060	0.2205	0.999991
2	0.2975	-0.2103	0.0067	0.0754	-0.0003	-0.0000	0.0063	-0.0061	0.2210	0.999991
3	0.3049	-0.2159	0.0064	0.0766	-0.0003	-0.0000	0.0064	-0.0061	0.2214	0.999990
...	...	...	...	...	...	...	...	...	...	...
398	0.2774	-0.1848	0.0071	0.0699	-0.0003	-0.0000	0.0061	-0.0066	0.2319	0.999987
399	0.2653	-0.1749	0.0072	0.0679	-0.0003	-0.0000	0.0061	-0.0065	0.2319	0.999987
400	0.2691	-0.1780	0.0071	0.0685	-0.0003	-0.0000	0.0061	-0.0066	0.2319	0.999987

Table 12: Transition-path equilibrium: starting from  $G_1 = G_l$ ,  $z_t = z_b$

t	$a_{0,t}$	$a_{1,t}$	$a_{2,t}$	$a_{3,t}$	$a_{4,t}$	$a_{5,t}$	$a_{6,t}$	$a_{7,t}$	G values	R2
1	0.1042	0.9363	-0.0015	0.0080	0.0000	0.0000	0.0005	0.0010	0.2205	0.999999
2	0.1108	0.9309	-0.0016	0.0092	0.0000	0.0000	0.0006	0.0010	0.2210	0.999999
3	0.1067	0.9342	-0.0015	0.0085	0.0000	0.0000	0.0005	0.0010	0.2214	0.999999
...	...	...	...	...	...	...	...	...	...	...
398	0.1011	0.9377	-0.0015	0.0079	0.0000	-0.0000	0.0005	0.0009	0.2319	0.999999
399	0.1026	0.9366	-0.0015	0.0081	0.0000	-0.0000	0.0005	0.0009	0.2319	0.999999
400	0.1030	0.9362	-0.0015	0.0082	0.0000	-0.0000	0.0005	0.0009	0.2319	0.999999
$\tilde{a}_{0,t}$	$\tilde{a}_{1,t}$	$\tilde{a}_{2,t}$	$\tilde{a}_{3,t}$	$\tilde{a}_{4,t}$	$\tilde{a}_{5,t}$	$\tilde{a}_{6,t}$	$\tilde{a}_{7,t}$	G values	R2	
1	-0.1310	0.0937	0.0043	-0.0161	-0.0000	-0.0000	-0.0016	0.9989	0.2205	0.999992
2	-0.1253	0.0889	0.0043	-0.0151	-0.0000	-0.0000	-0.0016	0.9989	0.2210	0.999992
3	-0.1152	0.0804	0.0043	-0.0133	-0.0000	0.0000	-0.0016	0.9990	0.2214	0.999992
...	...	...	...	...	...	...	...	...	...	...
398	-0.1146	0.0802	0.0038	-0.0133	-0.0000	-0.0000	-0.0014	0.9991	0.2319	0.999991
399	-0.1300	0.0928	0.0042	-0.0159	-0.0000	-0.0000	-0.0016	0.9991	0.2319	0.999991
400	-0.1261	0.0896	0.0042	-0.0153	-0.0000	-0.0000	-0.0016	0.9990	0.2319	0.999991
$b_{0,t}$	$b_{1,t}$	$b_{2,t}$	$b_{3,t}$	$b_{4,t}$	$b_{5,t}$	$b_{6,t}$	$b_{7,t}$	G values	R2	
1	0.3518	-0.2630	0.0077	0.0864	-0.0003	-0.0000	0.0073	-0.0069	0.2205	0.999998
2	0.3475	-0.2593	0.0081	0.0857	-0.0003	-0.0000	0.0071	-0.0068	0.2210	0.999998
3	0.3635	-0.2719	0.0076	0.0883	-0.0003	-0.0000	0.0073	-0.0069	0.2214	0.999998
...	...	...	...	...	...	...	...	...	...	...
398	0.3240	-0.2302	0.0082	0.0795	-0.0003	-0.0000	0.0070	-0.0076	0.2319	0.999997
399	0.3308	-0.2357	0.0080	0.0806	-0.0003	-0.0000	0.0071	-0.0076	0.2319	0.999997
400	0.3304	-0.2354	0.0081	0.0805	-0.0003	-0.0000	0.0071	-0.0075	0.2319	0.999997

Table 13: Transition-path equilibrium: starting from  $G_1 = G_m$ ,  $z_t = z_g$

t	$a_{0,t}$	$a_{1,t}$	$a_{2,t}$	$a_{3,t}$	$a_{4,t}$	$a_{5,t}$	$a_{6,t}$	$a_{7,t}$	G values	R2
1	0.1251	0.9256	-0.0015	0.0098	0.0000	-0.0000	0.0005	0.0007	0.2319	0.999999
2	0.1232	0.9272	-0.0014	0.0094	0.0000	-0.0000	0.0005	0.0007	0.2319	0.999999
3	0.1259	0.9250	-0.0015	0.0099	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
...	...	...	...	...	...	...	...	...	...	...
198	0.1264	0.9246	-0.0014	0.0100	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
199	0.1258	0.9250	-0.0014	0.0099	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
200	0.1276	0.9236	-0.0015	0.0102	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
$\tilde{a}_{0,t}$	$\tilde{a}_{1,t}$	$\tilde{a}_{2,t}$	$\tilde{a}_{3,t}$	$\tilde{a}_{4,t}$	$\tilde{a}_{5,t}$	$\tilde{a}_{6,t}$	$\tilde{a}_{7,t}$	G values	R2	
1	-0.0735	0.0448	0.0036	-0.0058	-0.0000	-0.0000	-0.0013	0.9973	0.2319	0.999998
2	-0.0778	0.0482	0.0038	-0.0065	-0.0000	-0.0000	-0.0014	0.9973	0.2319	0.999997
3	-0.0772	0.0478	0.0037	-0.0064	-0.0000	0.0000	-0.0013	0.9974	0.2319	0.999998
...	...	...	...	...	...	...	...	...	...	...
198	-0.0722	0.0436	0.0035	-0.0055	-0.0000	0.0000	-0.0013	0.9976	0.2319	0.999998
199	-0.0718	0.0433	0.0035	-0.0055	-0.0000	0.0000	-0.0012	0.9975	0.2319	0.999998
200	-0.0753	0.0462	0.0035	-0.0061	-0.0000	0.0000	-0.0013	0.9975	0.2319	0.999998
$b_{0,t}$	$b_{1,t}$	$b_{2,t}$	$b_{3,t}$	$b_{4,t}$	$b_{5,t}$	$b_{6,t}$	$b_{7,t}$	G values	R2	
1	0.2888	-0.1940	0.0063	0.0718	-0.0003	-0.0000	0.0064	-0.0064	0.2319	0.999984
2	0.2859	-0.1916	0.0062	0.0713	-0.0003	-0.0000	0.0064	-0.0065	0.2319	0.999985
3	0.2871	-0.1925	0.0062	0.0715	-0.0003	-0.0000	0.0065	-0.0065	0.2319	0.999984
...	...	...	...	...	...	...	...	...	...	...
198	0.3019	-0.2045	0.0061	0.0739	-0.0003	-0.0000	0.0065	-0.0067	0.2319	0.999986
199	0.3017	-0.2043	0.0062	0.0739	-0.0003	-0.0000	0.0065	-0.0067	0.2319	0.999986
200	0.3017	-0.2044	0.0063	0.0739	-0.0003	-0.0000	0.0064	-0.0067	0.2319	0.999986

Table 14: Transition-path equilibrium: starting from  $G_1 = G_m$ ,  $z_t = z_b$

t	$a_{0,t}$	$a_{1,t}$	$a_{2,t}$	$a_{3,t}$	$a_{4,t}$	$a_{5,t}$	$a_{6,t}$	$a_{7,t}$	G values	R2
1	0.1009	0.9378	-0.0015	0.0079	0.0000	0.0000	0.0005	0.0010	0.2319	0.999999
2	0.1022	0.9368	-0.0015	0.0081	0.0000	0.0000	0.0005	0.0010	0.2319	0.999999
3	0.1008	0.9379	-0.0015	0.0079	0.0000	0.0000	0.0005	0.0010	0.2319	0.999999
...	...	...	...	...	...	...	...	...	...	...
198	0.1037	0.9355	-0.0015	0.0083	0.0000	0.0000	0.0005	0.0010	0.2319	0.999999
199	0.1044	0.9350	-0.0015	0.0085	0.0000	0.0000	0.0005	0.0010	0.2319	0.999999
200	0.1024	0.9366	-0.0015	0.0081	0.0000	-0.0000	0.0005	0.0010	0.2319	0.999999
$\tilde{a}_{0,t}$	$\tilde{a}_{1,t}$	$\tilde{a}_{2,t}$	$\tilde{a}_{3,t}$	$\tilde{a}_{4,t}$	$\tilde{a}_{5,t}$	$\tilde{a}_{6,t}$	$\tilde{a}_{7,t}$	G values	R2	
1	-0.1258	0.0895	0.0040	-0.0153	-0.0000	-0.0000	-0.0015	0.9989	0.2319	0.999993
2	-0.1116	0.0779	0.0037	-0.0129	-0.0000	-0.0000	-0.0014	0.9989	0.2319	0.999993
3	-0.1149	0.0805	0.0038	-0.0134	-0.0000	-0.0000	-0.0014	0.9990	0.2319	0.999993
...	...	...	...	...	...	...	...	...	...	...
198	-0.1260	0.0895	0.0040	-0.0152	-0.0000	-0.0000	-0.0015	0.9992	0.2319	0.999991
199	-0.1233	0.0873	0.0038	-0.0148	-0.0000	-0.0000	-0.0014	0.9992	0.2319	0.999991
200	-0.1286	0.0917	0.0039	-0.0157	-0.0000	-0.0000	-0.0015	0.9992	0.2319	0.999991
$b_{0,t}$	$b_{1,t}$	$b_{2,t}$	$b_{3,t}$	$b_{4,t}$	$b_{5,t}$	$b_{6,t}$	$b_{7,t}$	G values	R2	
1	0.3134	-0.2213	0.0076	0.0776	-0.0003	-0.0000	0.0073	-0.0074	0.2319	0.999985
2	0.3033	-0.2130	0.0080	0.0759	-0.0003	-0.0000	0.0071	-0.0074	0.2319	0.999984
3	0.3080	-0.2168	0.0077	0.0766	-0.0003	-0.0000	0.0072	-0.0074	0.2319	0.999984
...	...	...	...	...	...	...	...	...	...	...
198	0.3394	-0.2422	0.0073	0.0818	-0.0003	-0.0000	0.0074	-0.0078	0.2319	0.999984
199	0.3372	-0.2405	0.0074	0.0815	-0.0003	-0.0000	0.0073	-0.0078	0.2319	0.999984
200	0.3380	-0.2411	0.0073	0.0816	-0.0003	-0.0000	0.0074	-0.0078	0.2319	0.999985

Table 15: Transition-path equilibrium: starting from  $G_1 = G_h, z_t = z_g$

t	$a_{0,t}$	$a_{1,t}$	$a_{2,t}$	$a_{3,t}$	$a_{4,t}$	$a_{5,t}$	$a_{6,t}$	$a_{7,t}$	G values	R2
1	0.1234	0.9259	-0.0016	0.0098	0.0000	-0.0000	0.0005	0.0007	0.2433	0.999999
2	0.1269	0.9231	-0.0017	0.0104	0.0000	-0.0000	0.0006	0.0007	0.2429	0.999999
3	0.1216	0.9275	-0.0016	0.0095	0.0000	-0.0000	0.0005	0.0007	0.2424	0.999999
...	...	...	...	...	...	...	...	...	...	...
398	0.1254	0.9254	-0.0015	0.0098	0.0000	-0.0000	0.0005	0.0007	0.2319	0.999999
399	0.1262	0.9248	-0.0015	0.0099	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
400	0.1227	0.9276	-0.0015	0.0094	0.0000	0.0000	0.0005	0.0007	0.2319	0.999999
$\tilde{a}_{0,t}$	$\tilde{a}_{1,t}$	$\tilde{a}_{2,t}$	$\tilde{a}_{3,t}$	$\tilde{a}_{4,t}$	$\tilde{a}_{5,t}$	$\tilde{a}_{6,t}$	$\tilde{a}_{7,t}$	G values	R2	
1	-0.0704	0.0422	0.0035	-0.0052	-0.0000	0.0000	-0.0012	0.9973	0.2433	0.999998
2	-0.0639	0.0369	0.0033	-0.0042	-0.0000	-0.0000	-0.0012	0.9974	0.2429	0.999998
3	-0.0753	0.0463	0.0034	-0.0061	-0.0000	0.0000	-0.0012	0.9973	0.2424	0.999998
...	...	...	...	...	...	...	...	...	...	...
398	-0.0634	0.0364	0.0032	-0.0041	-0.0000	0.0000	-0.0012	0.9975	0.2319	0.999998
399	-0.0662	0.0389	0.0032	-0.0046	-0.0000	0.0000	-0.0011	0.9974	0.2319	0.999998
400	-0.0669	0.0393	0.0033	-0.0047	-0.0000	-0.0000	-0.0012	0.9975	0.2319	0.999998
$b_{0,t}$	$b_{1,t}$	$b_{2,t}$	$b_{3,t}$	$b_{4,t}$	$b_{5,t}$	$b_{6,t}$	$b_{7,t}$	G values	R2	
1	0.3271	-0.2157	0.0044	0.0759	-0.0003	-0.0000	0.0071	-0.0069	0.2433	0.999987
2	0.3180	-0.2085	0.0043	0.0744	-0.0003	-0.0000	0.0072	-0.0069	0.2429	0.999986
3	0.3017	-0.1954	0.0047	0.0717	-0.0003	-0.0000	0.0070	-0.0069	0.2424	0.999987
...	...	...	...	...	...	...	...	...	...	...
398	0.2713	-0.1792	0.0062	0.0687	-0.0003	-0.0000	0.0065	-0.0068	0.2319	0.999988
399	0.2854	-0.1906	0.0058	0.0710	-0.0003	-0.0000	0.0066	-0.0068	0.2319	0.999987
400	0.2826	-0.1883	0.0058	0.0705	-0.0003	-0.0000	0.0066	-0.0068	0.2319	0.999987

Table 16: Transition-path equilibrium: starting from  $G_1 = G_h, z_t = z_b$

t	$a_{0,t}$	$a_{1,t}$	$a_{2,t}$	$a_{3,t}$	$a_{4,t}$	$a_{5,t}$	$a_{6,t}$	$a_{7,t}$	G values	R2
1	0.0959	0.9408	-0.0014	0.0074	0.0000	-0.0000	0.0005	0.0009	0.2433	0.999999
2	0.0958	0.9409	-0.0014	0.0074	0.0000	-0.0000	0.0005	0.0009	0.2429	0.999999
3	0.0975	0.9396	-0.0014	0.0076	0.0000	-0.0000	0.0005	0.0009	0.2424	0.999999
...	...	...	...	...	...	...	...	...	...	...
398	0.1056	0.9341	-0.0016	0.0086	0.0000	-0.0000	0.0005	0.0009	0.2319	0.999999
399	0.1063	0.9335	-0.0016	0.0088	0.0000	-0.0000	0.0006	0.0010	0.2319	0.999999
400	0.1089	0.9313	-0.0017	0.0092	0.0000	-0.0000	0.0006	0.0010	0.2319	0.999999
$\tilde{a}_{0,t}$	$\tilde{a}_{1,t}$	$\tilde{a}_{2,t}$	$\tilde{a}_{3,t}$	$\tilde{a}_{4,t}$	$\tilde{a}_{5,t}$	$\tilde{a}_{6,t}$	$\tilde{a}_{7,t}$	G values	R2	
1	-0.1045	0.0719	0.0035	-0.0117	-0.0000	-0.0000	-0.0013	0.9990	0.2433	0.999993
2	-0.1206	0.0853	0.0039	-0.0144	-0.0000	-0.0000	-0.0015	0.9989	0.2429	0.999993
3	-0.1250	0.0887	0.0041	-0.0151	-0.0000	-0.0000	-0.0016	0.9990	0.2424	0.999993
...	...	...	...	...	...	...	...	...	...	...
398	-0.1359	0.0978	0.0039	-0.0170	-0.0000	-0.0000	-0.0015	0.9992	0.2319	0.999992
399	-0.1321	0.0946	0.0036	-0.0164	-0.0000	-0.0000	-0.0013	0.9993	0.2319	0.999991
400	-0.1343	0.0964	0.0036	-0.0167	-0.0000	-0.0000	-0.0013	0.9993	0.2319	0.999992
$b_{0,t}$	$b_{1,t}$	$b_{2,t}$	$b_{3,t}$	$b_{4,t}$	$b_{5,t}$	$b_{6,t}$	$b_{7,t}$	G values	R2	
1	0.3326	-0.2265	0.0062	0.0783	-0.0003	-0.0000	0.0078	-0.0081	0.2433	0.999985
2	0.3516	-0.2426	0.0060	0.0816	-0.0003	-0.0000	0.0079	-0.0081	0.2429	0.999985
3	0.3729	-0.2604	0.0055	0.0853	-0.0003	-0.0000	0.0081	-0.0081	0.2424	0.999984
...	...	...	...	...	...	...	...	...	...	...
398	0.3322	-0.2360	0.0073	0.0805	-0.0003	-0.0000	0.0074	-0.0079	0.2319	0.999985
399	0.3306	-0.2349	0.0077	0.0803	-0.0003	-0.0000	0.0072	-0.0079	0.2319	0.999984
400	0.3388	-0.2416	0.0075	0.0817	-0.0003	-0.0000	0.0073	-0.0079	0.2319	0.999985

## B.5 Calculating the welfare gain

In this appendix, we show how to use the value functions from the recursive decision problems in the transition-path equilibrium and the two-shock equilibrium to conduct the welfare cost calculation implicitly defined in equation (5.1), which we restate here for convenience:

$$E_1\left[\sum_{t=1}^{\infty} \beta_t u((1+\lambda)c_t, G_t)\right] = E_1\left[\sum_{t=1}^{\infty} \beta_t u(\tilde{c}_t, \tilde{G}_t)\right]. \quad (5.1)$$

We denote the value functions from the transition-path equilibrium and the two-shock equilibrium by  $\tilde{V}$  and  $V$ , respectively, where

$$\tilde{V} = E_1\left[\sum_{t=1}^{\infty} \beta_t u(\tilde{c}_t, \tilde{G}_t)\right],$$

and

$$V = E_1\left[\sum_{t=1}^{\infty} \beta_t u(c_t, G_t)\right].$$

Note that the right side of (5.1) is exactly  $\tilde{V}$ . Under the assumption of a log separable utility function, the left side of (5.1) can be expressed as:

$$E_1\left[\sum_{t=1}^{\infty} \beta_t u((1+\lambda)c_t, G_t)\right] = E_1\left[\sum_{t=1}^{\infty} \beta_t u(c_t, G_t)\right] + E_1\left[\sum_{t=1}^{\infty} \beta_t \theta \log(1+\lambda)\right] = \theta \log(1+\lambda) E_1\left[\sum_{t=1}^{\infty} \beta_t\right] + V.$$

This allows us to rewrite (5.1) as:

$$\theta \log(1+\lambda) E_1\left[\sum_{t=1}^{\infty} \beta_t\right] + V = \tilde{V}.$$

Thus,  $\lambda$  can be calculated as follows:

$$\lambda = \exp\left(\frac{\tilde{V} - V}{\theta E_1\left[\sum_{t=1}^{\infty} \beta_t\right]}\right) - 1.$$

Note that, since  $\beta_1$  is known at time 1, the value of the denominator in the parentheses is a function of  $\beta_1$ . The calculation of  $\lambda$  is straightforward using the transition matrix governing the Markov process for  $\tilde{\beta}$ .

Under a non-separable utility function, we solve for  $\lambda$  numerically. That is, we calculate the left side of (5.1) as a discounted sum of flow utilities under various values of  $\lambda$  by using the equilibrium policy function, and then find a value of  $\lambda$  that satisfies the equation, using a bisection search.

## C Appendix: The income risk channel illustrated

The purpose of this appendix is to illustrate the distributional implications of the income risk channel, separately for the precautionary saving effect and the rate-of-return risk effect, using a simple partial equilibrium model. We construct a stripped-down version of our linear-tax model by

keeping only elements pertaining to the income risk channel.<sup>41</sup> We first specify the infinitely-lived household's recursive problem below, followed by explanations:

$$V(a, s) = \max_{c, a'} \log(c) + \beta E[V(a', s')] \quad (\text{C.1})$$

$$s.t. \quad c + a' = (1 - \tau_w)w + (1 + r(1 - \tau_r))a \quad (\text{C.2})$$

$$a' \geq \underline{a}, \quad (\text{C.3})$$

where, with a slight abuse of notation,  $s$  is the process that is assumed to be stochastic in each of the following partial equilibrium exercises (see below), while  $\tau_w$  and  $\tau_r$  are tax rates on labor and capital income (that could be stochastic in some specifications), respectively. All the other variables are defined in the same way as in the main text of the paper.

This setup captures the essential elements in the household maximization problem of the linear-tax model, except that now we conduct exercises that only feature one relevant source of uncertainty at a time. As explained in the main text, volatilities in factor prices ( $w$  and  $r$ ) and tax rates ( $\tau_w$  and  $\tau_r$ ) all contribute to income risk. To be specific, to illustrate the precautionary saving effect, we first solve the model with and without uncertainty in  $\tau_w$  and compare welfare (exercise A). Then, we examine the effect of eliminating the volatility of the joint series  $w(1 - \tau_w)$  (exercise B). To illustrate the rate-of-return risk effect, we run analogous exercises on the capital income side: remove uncertainty in  $\tau_r$  (exercise C) and then in  $r(1 - \tau_r)$  (exercise D).

Note that the focus of those exercises is merely to illustrate the qualitative pattern of the precautionary saving and rate-of-return risk effects. Compared to the fully-fledged general equilibrium model, this partial equilibrium model lacks, for the sake of expositional clarity, a number of uncertainty sources including unemployment risk and preference shocks as well as persistence in and correlations between the after-tax factor price processes.

In all these exercises, we set the parameters based on values from the linear-tax general equilibrium model. The average values of factor prices and tax rates are calibrated to match the average values from the linear-tax two-shock model. For exercise A (C), we assume that the tax rate  $\tau_w$  ( $\tau_r$ ) follows an i.i.d. process with a standard deviation that is calibrated to the square root of the variance difference of the tax-rate series between the two-shock and the one-shock linear tax model.<sup>42</sup> For exercises B and D, we use the same approach except that now the after-tax factor prices,  $w(1 - \tau_w)$  and  $r(1 - \tau_r)$  respectively, are modeled as random variables. Lastly, the

<sup>41</sup>We chose the linear-tax model because it captures the same mechanisms at work and has similar welfare implications as the baseline case with adjusting  $\tau_1$  (which, given the U.S. tax system, is itself a result of the paper; see explanations and results in Section 6), yet it is very simple and transparent.

<sup>42</sup>Then the elimination of volatility in the partial equilibrium model can arguably be viewed as a similar thought experiment as the one considered in the main text. We specify  $1 + \tau_w$  ( $1 + \tau_r$ ) as a log-normally distributed variable, and discretize the distribution using Gaussian quadrature with three grid points.



borrowing constraint and the time discount factor are also from the linear-tax model, where for the latter we use the value of the medium grid.

Table 17: Welfare gains ( $\lambda_c$ ,  $\% \times 10,000$ ) from the four partial equilibrium exercises

Wealth (pctiles)	1%	5%	25%	50%	75%	95%	99%
$A : \tau_w$	0.5575	0.5312	0.4905	0.4599	0.4228	0.1726	0.0382
$B : w(1 - \tau_w)$	1.2420	1.1839	1.0928	1.0247	0.9419	0.3846	0.0852
$C : \tau_r$	0.0018	0.0024	0.0048	0.0077	0.0128	0.1187	0.3199
$D : r(1 - \tau_r)$	0.0041	0.0056	0.0110	0.0178	0.0297	0.2748	0.7404

Table 17 reports the welfare gains across wealth percentiles from the elimination of the volatility of  $\tau_w$ ,  $w(1 - \tau_w)$ ,  $\tau_r$ , and  $r(1 - \tau_r)$ . The slope of the welfare gains from the precautionary saving effect across wealth is negative (exercises A and B). This confirms our intuition that the wealth-poor households are more exposed to the after-tax labor income uncertainty. The effect is more than twice as large (as that in exercise A) when we consider the uncertainty jointly in the tax rate and the before-tax labor income (exercise B).

The slope of the welfare gains from the rate-of-return effect across wealth is positive (exercises C and D). This shows that the rate-of-return risk effect favors the wealth-rich households. This result is again intuitive. Wealthy households, to finance their consumption, rely more on returns to saving, which are subject to the rate-of-return risk due to uncertain tax and interest rates. Hence they gain more from the elimination of this risk. We want to emphasize that this is not an artifact of our assumption that there is only one financial asset. Even if we allowed a portfolio choice among multiple financial assets (including a bond for which the before-tax-return was fixed), as long as the returns to all the financial assets were subject to after-tax-rate-of-return uncertainty, the same result would hold. In short, wealth-rich households are more exposed to the rate-of-return risk in a realistic incomplete asset market model, so they gain more from the elimination of this risk.

These results are also robust to other details of the model. For example, changing the level of the borrowing constraint or allowing a certain degree of persistence in the capital-tax rate process does not affect the qualitative patterns of the result.

## D Appendix: Alternative specifications and additional experiments

### D.1 $\lambda$ under different model specifications

Table 18 reports the  $\lambda$ -measure of welfare gains under different model specifications.

Table 18: Expected welfare gains,  $\lambda$  (%), under different model specifications

	Wealth Group								
	All	<1%	1-5%	5-25%	25-50%	50-75%	75-95%	95-99%	>99%
Baseline	0.0293	0.0289	0.0295	0.0296	0.0293	0.0290	0.0287	0.0313	0.0371
Different Tax Function Adjustment									
Adjusting $\tau_0$	0.0295	0.0291	0.0296	0.0298	0.0295	0.0293	0.0288	0.0303	0.0347
Adjusting $\tau_2$	0.0299	0.0300	0.0305	0.0306	0.0304	0.0301	0.0291	0.0263	0.0277
Adjusting $\tau_3$	0.0298	0.0303	0.0307	0.0307	0.0304	0.0301	0.0290	0.0240	0.0242
Other Fiscal Regimes									
Balanced Budget	0.0323	0.0318	0.0319	0.0320	0.0319	0.0318	0.0322	0.0371	0.0455
Linear Tax	0.0284	0.0277	0.0279	0.0282	0.0282	0.0282	0.0283	0.0315	0.0375
Lump-sum Tax	0.0280	0.0276	0.0276	0.0277	0.0276	0.0275	0.0279	0.0336	0.0412
Non-separable Utility Function									
Substitute ( $\rho = 0.5$ )	0.0079	0.0083	0.0093	0.0091	0.0073	0.0086	0.0066	0.0074	0.0087
Complement ( $\rho = 1.5$ )	0.1231	0.2076	0.1493	0.1205	0.1125	0.1214	0.1260	0.1464	0.1435
Alternative TFP and labor income processes									
Rich income dynamics	0.0261	0.0263	0.0264	0.0265	0.0263	0.0259	0.0253	0.0259	0.0320
Constant TFP	0.0299	0.0292	0.0299	0.0300	0.0298	0.0295	0.0295	0.0331	0.0403
Additional Experiments									
Double Volatility of $G$	-0.0281	-0.0278	-0.0284	-0.0285	-0.0281	-0.0278	-0.0275	-0.0301	-0.0360
Sudden change in $G$	0.0337	0.0348	0.0351	0.0347	0.0339	0.0333	0.0323	0.0336	0.0397

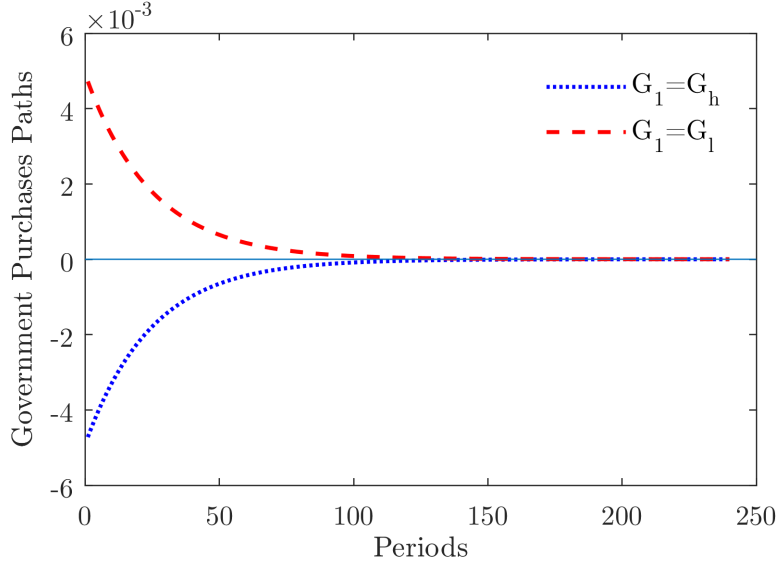
## D.2 Doubling fiscal volatility

To implement the experiment of doubling fiscal volatility, we start by solving a new two-shock equilibrium with a government purchases variance twice that in the baseline model, while keeping the other parameter values the same as in the baseline calibration. We use the Rouwenhorst method to discretize the new AR(1) process and to obtain a new grid for  $G$  ( $G_l^{new}, G_m^{new}, G_h^{new}$ )  $= ((1 - m_{new})G_m, G_m, (1 + m_{new})G_m)$ , with the same transition probability matrix as in the baseline model. We then start from the ergodic distribution of the original two-shock equilibrium and let the economy gradually transit to the new two-shock equilibrium as follows: at  $t = 1$ , after a particular  $G$ -state is realized from the old grid,  $(G_l, G_m, G_h)$ , the households in the economy learn that, from the next period on ( $t \geq 2$ ), the  $G$ -states will evolve according to a different process, with the same transition probabilities, but with new period- $t$  grid values that are conditional on the period-1 state,  $G_1$ , as  $(G_l^{new}, G_m^{new}, G_h^{new}) + G_{t,G_1}^{adj}$ .  $G_{t,G_1}^{adj}$  is an adjustment term that makes the period- $t$  conditional mean as of  $t = 1$  equal to those of the original process.<sup>43</sup> Mechanically,  $G_{t,G_1}^{adj}$  is zero for all  $t$  when  $G_1 = G_m$ , and positive (negative) and decreasing (increasing) to zero when  $G_1 = G_l$  ( $G_1 = G_h$ ). We plot  $G_{t,G_1}^{adj}$  in Figure 7.

We follow similar steps as in the baseline case to solve the model. Note that, unlike in the baseline case, we now have an uncertain government purchases level along the transition path in addition to the aggregate productivity shocks. However, we do not condition on  $G_t$  in the coefficients of transition-equilibrium laws of motions. Instead, we incorporate  $G_t$  as a regressor in  $H_{\Gamma_{t+1}}$  and  $\Theta_{t+1}$ , and pool the regressions for the laws of motion for  $t = 1, 2, \dots, 30$ . Note that we do condition the laws of motion on the period-1 value of government purchases ( $G_1$ ). We find

<sup>43</sup>Note that this adjustment term isolates the effect of a change in fiscal volatility from a sudden level adjustment.

Figure 7: Government purchases adjustment ( $G_{t,G_1}^{adj}$ )



that the following (relatively parsimonious) functional forms perform well:

$$\begin{aligned} \log(K'_{t+1}) = & a_{0,t}(z_t, G_1) + a_{1,t}(z_t, G_1)\log(K_t) + a_{2,t}(z_t, G_1)B_t + a_{3,t}(z_t, G_1)Gini(a_t) \\ & + a_{4,t}(z_t, G_1)B_t^5 + a_{5,t}(z_t, G_1)G_t^2 + a_{6,t}(z_t, G_1)B_t^5G_t^2, \end{aligned}$$

$$\begin{aligned} Gini(a'_{t+1}) = & \tilde{a}_{0,t}(z_t, G_1) + \tilde{a}_{1,t}(z_t, G_1)\log(K_t) + \tilde{a}_{2,t}(z_t, G_1)B_t + \tilde{a}_{3,t}(z_t, G_1)Gini(a_t) \\ & + \tilde{a}_{4,t}(z_t, G_1)B_t^5 + \tilde{a}_{5,t}(z_t, G_1)G_t^2 + \tilde{a}_{6,t}(z_t, G_1)B_t^5G_t^2, \end{aligned}$$

$$\begin{aligned} \tau_{1,t} = & b_{0,t}(z_t, G_1) + b_{1,t}(z_t, G_1)\log(K_t) + b_{2,t}(z_t, G_1)B_t + b_{3,t}(z_t, G_1)Gini(a_t) \\ & + b_{4,t}(z_t, G_1)B_t^2 + b_{5,t}(z_t, G_1)G_t^2 + b_{6,t}(z_t, G_1)B_t^5G_t^2. \end{aligned}$$