ESSAYS ON THE DYNAMIC EFFECTS OF GOVERNMENT SPENDING

BY

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CHAPTER 1

INTRODUCTION

This dissertation consists of three self-contained essays that investigate the effects of government spending and their determinants. Whilst increased attention has been given to the role of fiscal policy as a stabilization tool after the financial crisis of 2007–08, less theoretical and empirical works has been developed on fiscal policy than those on monetary policy. The past several years have witnessed a rapid advancement of the literature, however, there still remain many questions to be addressed. This dissertation aims to contribute to the literature by providing new empirical evidence and explanation on several major issues related to the effects of government spending. The three essays analyze the issues independently of each other, but they all employ Bayesian inference via Markov Chain Monte Carlo (MCMC) methods that has become an important tool in empirical macroeconomics. MCMC methods belong to a class of sampling-based numerical approximation techniques, which enable us to make inference when the likelihood function is either analytically intractable or computationally difficult to evaluate. In the first two essays (Chapters 2 and 3), we estimate medium-scale New Keynesian dynamic stochastic general equilibrium (DSGE) models of the Japanese economy for fiscal policy analysis. For this class of DSGE models considered in practice, the likelihood functions tend to be high-dimensional and can have nearly flat surfaces. Bayesian inference is therefore attractive because prior restrictions help researchers to evaluate the likelihood of a DSGE model taking advantage of prior information.[1] Once we obtain posterior distributions of parameters using Bayes' theorem, we can examine the empirical properties of the DSGE model taking into account uncertainty related to parameter values. In the first essay, we introduce three distortionary tax rules and non-Ricardian households to an otherwise standard closed economy DSGE model of Smets and Wouters (2003). Whereas the importance of financing rules in determining the effects of fiscal stimulus has been highlighted recently, the existing literature does not sufficiently explore the consequences of tax-financed fiscal stimulus. Motivated by Japan's experience of fiscal consolidation during the 1980s, the first essay complement the literature by examining how debt-stabilizing tax rules affect the size of government spending multiplier. The second essay turns to examining the effects of government spending in open economies. In contrast to the first essay, non-wasteful aspects of government spending are incorporated into the model of Adolfson et al. (2007), which is a small open economy version of the canonical Smets and Wouters (2003) model. Although interest in Bayesian estimation of DSGE models for the Japanese economy has been heightened since the work of Iiboshi et

[1] It is a common practice to judge identification of parameters by comparing their prior and posterior distributions because their difference is considered as evidence that the data used are informative. However, it is worth noting that identification problems in Bayesian DSGE models are more pervasive than generally thought. The priors and posteriors may differ when parameters are not identified and an improper use of prior restrictions can even hide identification problems. For a detailed discussion, see Canova and Sala (2009) and Koop et al. (2013).

al. (2006), the second essay is the first attempt to estimate a medium-scale open economy DSGE model on the Japanese data to the best of our knowledge. The third essay (Chapter 4) estimates time-varying parameter vector autoregressive (TVP-VAR) model on the post-war U.S. data. While a growing number of studies have examined nonlinear effects of government spending in the U.S. relying on regime switching models, we take a different avenue and investigate possible changes in transmission. Because the stochastic volatility assumption along the lines of Primiceri (2005) makes the likelihood function of the model intractable, we resort to the Bayesian technique described in Nakajima et al. (2011). The three essays all point to the importance of fiscal behavior with regard to determinants of the effects of government spending. In what follows, I briefly summarize the content and results of each essay.

Chapter 2 "The Government Spending Multiplier and Fiscal Financing": This chapter examines the importance of debt-stabilizing tax rules in determining the size of the government spending multiplier by using an estimated New Keynesian dynamic stochastic general equilibrium (DSGE) model of the Japanese economy featuring three distortionary tax rules and non-Ricardian households. The estimated model exhibits positive responses of consumption and output to a government spending shock regardless of its low share of non-Ricardian households. To examine the influence of tax rules on the size of government spending multiplier, we first compare the simulation results under the estimated tax rules for Japan with those under parameters that are adjusted to replicate tax rules estimated for the euro area. The coefficients of the tax rules suggest that debt in Japan is financed largely through capital income taxation, whereas financing in the euro area is instead allocated rather heavily to labour income taxation. The output multipliers of the estimated model are larger in the initial periods than those when the adjusted tax rules for the euro area are employed. To follow, impulse responses to a government spending shock under five alternative financing schemes (consumption tax-financing, labour tax-financing, capital tax-financing, spending reversal, and balanced budget) are considered. It is shown that capital tax financed spending leads to the strongest initial increases in output. Furthermore, we consider the sensitivity of the multipliers to changes in monetary policy parameters to illustrate the role of monetary policy in the estimated model. Under the monetary policy parameters that are adjusted to replicate the estimates for the euro area, interest rates are raised more aggressively, thereby weakening intertemporal substitution in consumption after a government spending shock. The increase in investment is also hampered by the higher interest rate. As a result, the short-run multipliers of capital tax financed spending are lowered until they become almost equal to those of consumption and of labour income tax financed spending. Finally, the chapter touches on medium- and long-run consequences under different financing schemes. A capital tax financed spending shock induces an investment boom in the initial periods if the speed of fiscal adjustment is slow.

However, as debt is repaid over time, the initial stimulative effects are dominated by the distortionary effects of capital taxation. Because capital taxation creates intertemporal wedges, the distortionary effects become excessively greater with longer horizons. In summary, our sensitivity analysis shows that the government spending multiplier becomes greater in the short term if the spending increase is initially financed by debt and that debt is largely repaid via a gradual increase in capital income tax under an accommodative monetary policy. Capital taxation has the smallest dampening effect on labour input, and the increase in labour input is the key factor contributing to the effectiveness of fiscal stimulus in a general equilibrium framework. Although capital income taxation has a dampening effect on investment, it is possible to have an investment boom in the initial periods after fiscal stimulus if the timing of capital taxation is sufficiently delayed. This chapter suggests that, overall, distortionary tax policy rules play a critical role in determining the size of the multiplier in the short term.

Chapter 3 "Two Fiscal Policy Puzzles Revisited: New Evidence and an Explanation": This chapter investigates the two fiscal policy puzzles, the anomaly between the standard model predictions and the VAR evidence, and proposes a new but simple approach. First, we present new VAR evidence from Japan on the responses of consumption and the real exchange rate to government consumption and government investment shocks by employing the sign-restrictions approach. In accordance with the results of previous studies on

Anglo-Saxon countries, the VAR analysis shows evidence against standard model predictions; consumption increases and the real exchange rate depreciates after both government spending shocks. Although the twin deficits phenomenon appears on impact, the trade balance is likely to improve as the real exchange rate depreciates. Second, we estimate a medium-scale open economy DSGE model introducing (i) non-separability between private and public consumption and (ii) productive public capital, to explain the two puzzles. Using the recently flourishing Bayesian method, we estimate four specifications of the model with and without zero restrictions on the key structural parameters that govern Edgeworth complementarity between private and public consumption, and productive public capital. The posterior odds favor inclusion of non-wasteful nature of government spending, especially the Edgeworth complementarity. Third, we show that the estimated model delivers a crowding-in of consumption and a real exchange rate depreciation after government spending shocks, in line with the empirical evidence obtained from the VAR analysis. The model also replicates the trade balance improvement in later periods due to the real exchange rate depreciation. While the empirical relevance of spending reversals in government investment is confirmed, their presence does not allow the model to account for the two fiscal policy puzzles. Edgeworth complementarity and productive public capital are shown to be the main contributory sources for generating responses of consumption and the real exchange rate in the empirically-plausible directions following government consumption and government investment shocks, respectively. Furthermore, it should be worth noting that the Edgeworth complementarity also does a good job in explaining the timing of the responses of consumption and the real exchange rate to a government consumption shock with the estimated model. The existing studies have implicitly relied on the tight link between consumption and the real exchange rate to solve the two fiscal policy puzzles. Therefore timing of the responses has not yet been well addressed in these studies. This chapter also shows that the combination of Edgeworth complementarity, home bias, and debt elastic risk premium allows the model to explain the timing of responses of consumption and the real exchange rate to a government consumption shock.

Chapter 4 "Public Debt, Ricardian Fiscal Policy, and Time-Varying Government Spending Multipliers"(joint work with Hirokuni Iiboshi of Tokyo Metropolitan University): In this chapter, we provide new empirical evidence on the evolution of government spending multipliers in the post-war U.S. From a methodological point of view, we present time profile of the changes in multipliers by exploiting a time-varying parameter vector autoregressive (TVP-VAR) framework, instead of relying on sub-sample analysis and regime switching models. Drawing on the findings of previous studies, monetary policy and public debt are considered as promising candidates for the possible driving forces behind the changes in the size of government spending multipliers. Therefore, we work with a medium scale TVP-VAR model that considers monetary variables and public debt. The identification of government spending shocks are achieved by means of sign restrictions in addition to the traditional recursive method. Irrespective of the use of alternative identification schemes, the results document that government spending multipliers have declined substantially since the late 1970s. Furthermore, time profiles of output and consumption responses suggest that the decline in output multiplier is mostly led by that in consumption multiplier. The medium scale TVP-VAR allows us to investigate the possible driving forces behind the changes in the effects of government spending with a help of sign restrictions identification. Considering that a growing body of literature focuses on the size of multipliers across different state of business cycles, we calculate those by imposing additional identification restrictions in the spirit of Canova and Pappa (2011). Although these multipliers are essentially hypothetical in the TVP-VAR framework, we find larger multipliers in recession and smaller ones in expansion in line with existing literature. The time profiles of output responses in recession and expansion indicate that those can be viewed as extreme bounds, and that the state of business cycle plays little role in the time-variation in government spending multipliers. Calculating the time profiles of price level and interest rate responses to government spending shocks under different monetary policy scenario, on the other hand, we find a stable relationship between them, which indicates that monetary policy response to government spending shocks does not change much throughout the estimation period. It is also shown that the inflationary effects of government spending shocks become larger since the late 1970s in accordance with the accumulation of public debt. Finally, the prevalence of either Ricardian or non-Ricardian fiscal regimes is examined applying the methodology of Canzoneri et al. (2001) and Canzoneri et al. (2010) to our TVP-VAR framework. The results show that the degree of Ricardian behavior of the government has been strengthened since the late 1970s, which corresponds to the period when government spending multipliers declined. The results lead us to conjecture that the accumulation of government debt during the period may play an important role in changing the fiscal policy stance, and thus serve as the major driving force for the observed decline in government spending multipliers. While empirical evidence on the negative correlation between debt and multipliers has been established for cross-country data, this chapter provides it by analyzing the U.S. time series data.

CHAPTER 2

THE GOVERNMENT SPENDING MULTIPLIER AND FISCAL FINANCING

2.1 Introduction

The recent global financial crisis has increased attention on the effects of fiscal stimulus. With limited room for further monetary easing, governments around the world responded by announcing massive fiscal stimulus packages. Although fiscal stimulus has helped to generate a more rapid global recovery than previously anticipated, fiscal sustainability has become an issue of growing concern. In the Toronto Summit Declaration of 2010, the G-20 leaders announced that they are "recognizing the circumstances of Japan." Japan's current headline debt-to-output ratio is much higher than that of Greece, which is in the midst of a debt crisis. However, Japan did make progress with fiscal consolidation in the 1980s. Responding to the rapid accumulation of public debt following the prolonged recession after the oil crisis in 1973, the Japanese Government started its consolidation effort at the end of 1970s. Figure 1 plots the time series for aggregate effective tax rates on capital in major countries as well as the debt-to-output ratio in Japan.[1] Although the 1980s was a time of decreasing capital taxation in many major countries, Figure 1 shows an upward trend in Japan. Japan's fiscal consolidation during the 1980s emphasizes more on spending cuts rather than taxation. Nevertheless, there was a general movement toward tax relief for individuals because of a perception among policymakers that increases in the inflation rate had raised the tax burden on middle-income workers and thus negatively affecting economic activity. In order to deal with the revenue decline caused by individual income tax reform during that period, several measures designed to increase corporate tax revenues were introduced aside from spending-cut efforts. Once progress was made in fiscal consolidation in the late 1980s, however, the Japanese Government started to follow the international trend of reducing corporate tax rates. Consequently, Japan's effective capital tax rate is largely correlated with its debt-to-output ratio throughout the 1980s and 1990s as seen in Figure 1.[2]

Unlike monetary policy, fiscal policy cannot be implemented without affecting government budgets. An increase in government spending must eventually be repaid through taxes, even if the spending increase is initially financed by debt. Under the rational expectations framework, households' behaviors are affected by their expectations regarding future fiscal adjustments to achieve government debt

[1] The aggregate effective tax rates are calculated using the method proposed in Mendoza et al. (1994). The method is intended to construct measures of tax rates that are consistent with the concept of aggregate tax rates at the macro-level. The calculation is based on macroeconomic data, such as tax revenue and national accounts. Their relatively simple methodology is found to be useful in approximating the tax rates faced by the representative agent in DSGE models (e.g., Jones (2002); Forni et al. (2009); Leeper et al. (2010a)).

[2] The movements in the effective tax rate on capital broadly reflect the changes in Japan's statutory corporate tax rate, which was raised in 1981 and 1984, and reduced in 1987, 1989, and 1990.

sustainability. Therefore, the macroeconomic effects of fiscal stimulus critically depend on how it is financed. Recently, Corsetti et al. (2010) and Corsetti et al. (2012a) suggested that the stimulative effects of fiscal expansion could be amplified by a "spending reversal" policy that would offset the initial expansion via future spending reductions below trend level.[3] Corsetti et al. (2012a) have also shown that the dynamics underlying the spending reversal fit the U.S. time series data. In contrast, the debt stabilization that occurred in Japan in the 1980s owed much to capital taxation, as seen in Figure 1. Financing debt via future taxation sounds straightforward, but the existing literature does not sufficiently explore the consequences of tax-financed fiscal stimulus, especially in the case of distortionary taxes. Once we introduce distortionary taxation instead of lump-sum taxation, a temporary substitution of debt for taxation increases economic variables, such as consumption, labor hours, investment, and output (Trostel (1993)).[4] Therefore delaying the timing of taxation to repay debt issued to finance an increase in government spending has a positive effect on the increases in economic variables after the fiscal expansion. Furthermore, when different tax instruments are available, a choice of distortionary taxes to repay the debt affects the time paths of economic variables because each tax has different distortionary effects.

Motivated by Japan's distinct experience of fiscal consolidation efforts during the 1980s and 1990s, this chapter examines how debt-stabilizing tax rules affect

[3] Similar expenditure rules can be found in Leeper and Yang (2008) and Forni et al. (2010).

[4] Ludvigson (1996) also finds that a debt-financed government spending increase is expansionary, whereas a distortionary tax-financed increase is contractionary.

dynamic responses to fiscal stimulus within a New Keynesian framework, focusing very much on its short-run effects. For this purpose, a dynamic stochastic general equilibrium (DSGE) model of the Japanese economy was estimated, featuring non-Ricardian households[5] with three distortionary tax rules, and the models were simulated under different tax rules.

The method of "new normative macroeconomics" has taken center stage in macroeconomic policy analysis (Taylor (2000)); it has become popular to assume that fiscal rules are analogous to monetary policy. The literature on fiscal policy analysis in this vein is growing rapidly, although most studies are based on neoclassical models. Leeper and Yang (2008) have examined the consequences of tax cuts under different fiscal financing rules in the context of *dynamic scoring*. More recently, Leeper et al. (2010a) and Leeper et al. (2010b) have shown that fiscal financing rules and the speed of fiscal adjustment or debt repayment have an important impact on the effects of fiscal expansion. Drautzburg and Uhlig (2011) have also examined the effect of changing the speed of fiscal adjustment and show that a slower adjustment raises the short-run government spending multiplier. Of the studies conducted within the New Keynesian framework, Forni et

[5] The non-Ricardian households are usually assumed as liquidity-constrained and hence cannot smooth consumption intertemporally. A government spending shock typically generates a negative wealth effect, which induces forward-looking households to decrease consumption in a general equilibrium framework. On the contrary, empirical studies using a standard VAR approach tend to find that private consumption rises after a government spending shock (e.g., Fatás and Mihov (2001); Blanchard and Perotti (2002a); Perotti (2007)). Galí et al. (2007) first introduced the non-Ricardian households to a simple DSGE model and have shown that it is possible to have the crowding-in effect on consumption. Introduction of non-Ricardian households is quite popular among the current workhorse DSGE models at policy institutions (e.g., Coenen et al. (2012)).

al. (2009) (FMS, hereafter) was the first to attempt to examine the effects of fiscal policy using an estimated DSGE model augmented by distortionary tax rules and non-Ricardian households.

To follow, three distortionary tax rules will be introduced into an otherwise standard Smets and Wouters (2003) New Keynesian model.[6] In addition, we will also allow for the coexistence of non-Ricardian and Ricardian households in our extended version. The estimated model of the Japanese economy exhibits rather strong positive responses to a government spending shock regardless of its low share of non-Ricardian households. Simulating the model under different tax rules showed that the debt-stabilizing tax rules employed in Japan during the 1980s and 1990s have helped to make the short-run multipliers large. The results of our analysis suggest that fiscal stimulus becomes more effective if the increase in government spending is initially financed by debt and if that debt is repaid largely via a gradual increase in capital income tax under an accommodative monetary policy. An increase in government spending leads to an increase in labor input which, in turn, increases investment. While the debt issued to finance the spending increase must eventually be repaid through tax increases, the increase in labor input resulting from the fiscal stimulus is dampened least when only the

[6] We estimate a small open economy version of the Smets and Wouters (2003) model in Chapter 3, while restricting our focus to a closed economy setup in this chapter. A wide range of theoretical and empirical studies suggests smaller multipliers in more open economies (e.g., Ilzetzki et al. (2013); Cardi and Müller (2011)). Nevertheless, we believe that our closed economy setup does not affect the size of multiplier considerably because Japanese economy is characterized by relatively low degree of openness. Japan's ratio of trade (imports plus exports) to GDP and import to GDP during the estimation period of the DSGE models are 15% and 7%, respectively. The size of multiplier for the closed economy model developed in this chapter is not so different from that for the open economy model in Chapter 3.

capital tax rate is raised to repay the debt. Although capital income taxation has a dampening effect on investment, it is therefore possible to have an investment boom in the initial periods after fiscal stimulus if the timing of capital taxation is sufficiently delayed. this chapter suggests that, overall, distortionary tax policy rules play a critical role in determining the size of the multiplier in the short term.

Whereas most of the current workhorse DSGE models employed by policy institutions use non-Ricardian households to amplify the effects of fiscal stimulus, particular tax policy rules can be of even greater importance. In addition, this present chapter considers three distortionary taxes as financing instruments and examines how the government spending multiplier can change under different tax rules, instead of relying on the recently suggested concept of a spending reversal. Therefore, this chapter complements and adds a new dimension to the recent debate regarding the government spending multiplier.

The remainder of this chapter is organized as follows. In the next section, the model is introduced in detail. Section 2.3 presents the estimation results and Section 2.4 presents the results of the simulations under alternative tax rules. Lastly, conclusions and new directions for future research are suggested in Section 2.5.

2.2 The Model

2.2.1 Households

There is a continuum of households indexed by $n \in [0,1]$. A fraction $1-\omega$ of this households indexed by $i \in [0, 1-\omega)$ has access to financial market and acts as *Ricardian*. I.e., each member of Ricardian households i maximizes its lifetime utility by choosing consumption, $C_t^R(i)$, investment, $I_t^R(i)$, government bonds, $B_t^R(i)$, next period's capital stock, $K_t^R(i)$, and intensity of the capital stock utilization, $z_t(i)$, given the following lifetime utility function:

$$E_t \sum_{t=0}^{\infty} \beta^t \varepsilon_t^b \left(\frac{1}{1-\sigma_c} \left(C_t^R(i) - hC_{t-1}^R \right)^{1-\sigma_c} - \frac{\varepsilon_t^l}{1+\sigma_l} L_t^R(i)^{1+\sigma_l} \right),$$

where, β is the discount factor, σ_c denotes the inverse of the intertemporal elasticity of substitution, σ_l is the inverse of the elasticity of work effort with respect to real wages, and $L_t^R(i)$ represents the labor supply. h measures the degree of external habit formation in consumption. C_{t-1}^R is lagged aggregate per capita Ricardian consumption.[7] Two serially correlated shocks, a preference shock, ε_t^b, and a labor supply shock, ε_t^l, are considered and are assumed to follow a first-order autoregressive process with an i.i.d.-normal error term: $\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b$ and $\varepsilon_t^l = \rho_l \varepsilon_{t-1}^l + \eta_t^l$.

The Ricardian household faces a flow budget constraint:

$$(1+\tau_t^c) C_t^R(i) + I_t^R(i) + \Psi(z_t(i)) K_{t-1}^R(i) + \frac{B_t^R(i)}{R_t P_t}$$

[7] A habit is called *external* if it is affected by the average consumption level of the economy, which is exogenous for each agent. On the other hand, it is called *internal* if the agent's habit is directly affected by its past consumption.

$$= (1-\tau_t^l)w_t(i)L_t^R(i) + (1-\tau_t^k)r_t^k z_t(i)K_{t-1}^R(i) + (1-\tau_t^k)\frac{D_t^R(i)}{P_t} + \frac{B_{t-1}^R(i)}{P_t}, \quad (2.1)$$

where $\Psi(z_t(i))$ is the cost associated with variations in the degree of capital utilization $z_t(i)$. τ_t^c, τ_t^l, and τ_t^k denote consumption, labor, and capital income tax rates, respectively. $D_t^R(i)$ denotes dividends distributed by firms to the Ricardian household i. P_t is aggregate price level, R_t is riskless return on government bonds, $w_t(i)$ is real wage income, and r_t^k is real rental rate of capital.

The physical capital accumulation law for the Ricardian household is expressed as follows:

$$K_t^R(i) = (1-\delta)K_{t-1}^R(i) + \left[1 - S\left(\frac{\varepsilon_t^i I_t^R(i)}{I_{t-1}^R(i)}\right)\right] I_t^R(i), \quad (2.2)$$

where δ is the depreciation rate, $S(\cdot)$ represents the adjustment cost function in investment. ε_t^i is a shock to investment cost function and is assumed to follow a process: $\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i$. The steady-state value of the capital utilization rate is set at $\bar{z} = 1$ and the corresponding cost function is assumed to satisfy $\Psi(\bar{z}) = 0$. Moreover, the investment adjustment cost function is assumed to satisfy $S(1) = S'(1) = 0$.

Letting Λ_t and $\Lambda_t Q_t$ denote the Lagrange multipliers, the first-order conditions with respect to $C_t^R(i)$, $B_t^R(i)$, $I_t^R(i)$, $K_t^R(i)$, and $z_t(i)$ are expressed as follows:

$$(1+\tau_t^c)\Lambda_t = \varepsilon_t^b \left(C_t^R(i) - hC_{t-1}^R\right)^{-\sigma_c}, \quad (2.3)$$

$$\beta R_t E_t\left[\frac{\Lambda_{t+1}}{\Lambda_t}\frac{P_t}{P_{t+1}}\right] = 1, \quad (2.4)$$

$$Q_t\left[1 - S\left(\frac{\varepsilon_t^i I_t^R(i)}{I_{t-1}^R(i)}\right)\right] - Q_t S'\left(\frac{\varepsilon_t^i I_t^R(i)}{I_{t-1}^R(i)}\right)\frac{\varepsilon_t^i}{I_{t-1}^R(i)} I_t^R(i)$$

$$= -\beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} Q_{t+1} S' \left(\frac{\varepsilon^i_{t+1} I^R_{t+1}(i)}{I^R_t(i)} \right) \frac{\varepsilon^i_{t+1} I^R_{t+1}(i)}{I^R_t(i)^2} I^R_{t+1}(i) \right] + 1, \tag{2.5}$$

$$Q_t = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \left((1-\delta) Q_{t+1} + (1-\tau^k_{t+1}) r^k_{t+1} z_{t+1}(i) - \Psi(z_{t+1}(i)) \right) \right] + \eta^q_t, \tag{2.6}$$

$$\left(1-\tau^k_t\right) r^k_t = \Psi'(z_t(i)). \tag{2.7}$$

Here, Q_t represents the shadow price of additional unit of capital. η^q_t is introduced to capture an equity premium shock. Letting an over-bar denote a steady-state value, it can be shown that $1/\beta = \bar{R} = 1 - \delta + \left(1 - \bar{\tau}^k\right) \bar{r}^k$ and $\bar{Q} = 1$.

The remaining households, indexed by $j \in [1-\omega, 1]$ have the same preferences as Ricardian households, however, they do not have access to financial markets and are dubbed *non-Ricardian.* Non-Ricardian households simply consume all of their current disposal income. Denoting consumption and labor input of non-Ricardian households as $C^{NR}_t(j)$ and $L^{NR}_t(j)$, the period-by-period budget constraint they face is given by:

$$(1+\tau^c_t) C^{NR}_t(j) = (1-\tau^l_t) w_t(j) L^{NR}_t(j). \tag{2.8}$$

The members of Ricardian households act as wage setters for their differentiated labor services, $L^R_t(i)$, in monopolistically competitive markets. The nominal wages for differentiated labor services, $W^R_t(i)$, are determined by staggered contracts á la Calvo (1983). On the other hand, the members of non-Ricardian households are assumed to set their wages, $W^{NR}_t(j)$, for their differentiated labor services, $L^{NR}_t(j)$, to be equal to the average wage of Ricardian households. Because all households face the same labor demand schedule, both wages and labor hours will be equal for every household, i.e., $W_t^R(i) = W_t^{NR}(j) = W_t(n)$ and $L_t^R(i) = L_t^{NR}(j) = L_t(n)$.

An independent and perfectly competitive employment agency bundles differentiated labor, $L_t(n)$, into a single type of effective labor input, L_t, using the following technology:

$$L_t = \left[\int_0^1 L_t(n)^{\frac{1}{1+\lambda_{w,t}}} dn\right]^{1+\lambda_{w,t}},$$

where an i.i.d.-normal shock, η_t^w, is assumed for the wage markup: $\lambda_{w,t} = \lambda_w + \eta_t^w$. The employment agency solves:

$$\max_{L_t(n)} W_t \left[\int_0^1 L_t(n)^{\frac{1}{1+\lambda_{w,t}}} dn\right]^{1+\lambda_{w,t}} - \int_0^1 W_t(n) L_t(n) dn,$$

where $W_t \equiv w_t P_t$ is aggregate nominal wage index.

With probability $1-\xi_w$, each Ricardian household i is assumed to be allowed to reset its wage optimally, unless otherwise it adjusts its wage partially according to the following indexation scheme:

$$W_t^R(i) = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1}^R(i),$$

where γ_w measures the degree of indexation. The Ricardian household i, which is allowed to optimally reset its wage, is assumed to maximize its lifetime utility taking aggregate nominal wage, W_t, and effective labor input, L_t, as given. Since the household knows the probability ξ_w^s that the wage it chooses in this period will still be in effect s periods in the future, the optimal wage, $W_t^{R*}(i)$, is obtained by solving the following problem:

$$\max_{W^R(i)} E_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \varepsilon^b_{t+s} \left[\begin{array}{c} \frac{1}{1-\sigma_c}\left(C^R_{t+s}(i) - hC^R_{t+s-1}\right)^{1-\sigma_c} \\ -\frac{\varepsilon^l_{t+s}}{1+\sigma_l}\left(\left(\frac{W^R_{t+s}(i)}{W_{t+s}}\right)^{-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}} L_{t+s}\right)^{1+\sigma_l} \end{array} \right],$$

subject to

$$\begin{aligned} & (1+\tau^c_{t+s})C^R_{t+s}(i) + I^R_{t+s}(i) + \Psi(z_{t+s}(i))K^R_{t+s-1}(i) + \frac{B^R_{t+s}(i)}{R_{t+s}P_{t+s}} \\ = \; & (1-\tau^l_{t+s})\frac{W^R_{t+s}(i)}{P_{t+s}}\left(\frac{W^R_{t+s}(i)}{W_{t+s}}\right)^{-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}} L_{t+s} \\ & +(1-\tau^k_{t+s})r^k_{t+s}z_{t+s}(i)K^R_{t+s-1}(i) + (1-\tau^k_{t+s})\frac{D^R_{t+s}(i)}{P_{t+s}} + \frac{B^R_{t+s-1}(i)}{P_{t+s}}. \end{aligned}$$

Since we know that $W^R_t(i) = W^{NR}_t(j) = W_t(n)$, aggregate nominal wage law of motion is then expressed as follows:

$$W_t = \left[(1-\xi_w)\left(W^*_t(n)\right)^{-\frac{1}{\lambda_{w,t}}} + \xi_w \left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1}(n) \right)^{-\frac{1}{\lambda_{w,t}}} \right]^{-\lambda_{w,t}}, \quad (2.9)$$

where $W^*_t(n) = W^{R*}_t(i)$.

2.2.2 Firms

There are two types of firms: perfectly competitive final-good firms and monopolistically competitive intermediate-good firms indexed by $f \in [0,1]$. The final-good firm produces the good, Y_t, combining the differentiated intermediate goods, $y_t(f)$, produced by the firm f.

The final-good producing firm combines intermediate goods using the following bundler technology:

$$Y_t = \left[\int_0^1 y_t(f)^{\frac{1}{1+\lambda_{p,t}}} df \right]^{1+\lambda_{p,t}},$$

where an i.i.d.-normal shock η_t^p is assumed for the price markup: $\lambda_{p,t} = \lambda_p + \eta_t^p$. The final-good firm solves:

$$\max_{y(f)} P_t \left[\int_0^1 y_t(f)^{\frac{1}{1+\lambda_{p,t}}} df \right]^{1+\lambda_{p,t}} - \int_0^1 p_t(f) y_t(f) df,$$

where $p_t(f)$ is the price of the intermediate good $y_t(f)$.

Each intermediate-good firm f produces its differentiated output using an increasing-returns-to-scale Cobb-Douglas technology:

$$y_t(f) = \varepsilon_t^a \tilde{k}_{t-1}(f)^\alpha l_t(f)^{1-\alpha} - \Phi,$$

where $\tilde{k}_{t-1}(f)$ is the effective capital stock at time t given by $\tilde{k}_{t-1}(f) = z_t k_{t-1}(f)$. $l_t(f)$ is the effective labor input bundled by the employment agency, and Φ represents a fixed cost. ε_t^a is a technology shock assumed to follow a process: $\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a$.

Taking the real rental cost of capital, r_t^k, and aggregate real wage, w_t, as given, cost minimization subject to the production technology yields marginal cost:

$$mc_t = \frac{w_t^{1-\alpha} \left(r_t^k \right)^\alpha}{\varepsilon_t^a \alpha^\alpha (1-\alpha)^{1-\alpha}}, \tag{2.10}$$

and the labor demand function at the aggregate level is given by:

$$L_t = \frac{1-\alpha}{\alpha} \frac{r_t^k}{w_t} z_t K_{t-1}. \tag{2.11}$$

Nominal profits, $d_t(f)$, of the intermediate-good firm are expressed as follows:

$$d_t(f) = p_t(f)y_t(f) - P_t mc_t(y_t(f) + \Phi),$$

which are distributed to Ricardian households as dividends. Aggregation gives:

$$D_t = P_t Y_t - P_t mc_t(Y_t + \Phi). \tag{2.12}$$

As in the case of wage setting, sluggish price adjustment due to the staggered price contracts á la Calvo (1983) is assumed. A fraction $1 - \xi_p$ of intermediate-good firms can re-optimize their prices, unless otherwise they follow the price indexation scheme:

$$p_t(f) = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p} p_{t-1}(f),$$

where γ_p measures the degree of indexation.

An intermediate-good firm f, which is allowed to re-optimize, knows the probability ξ_p^s that the price it chooses in this period will still be in effect s periods in the future. Taking aggregate nominal price index, P_t, and output, Y_t, as given, the optimal price, $p_t^*(f)$, is obtained by solving:

$$\max_{p(f)} E_t \sum_{s=0}^{\infty} (\beta\xi_p)^s \left[(p_{t+s}(f) - P_{t+s}mc_{t+s}) \left(\frac{p_{t+s}(f)}{P_{t+s}}\right)^{-\frac{1+\lambda_{p,t+s}}{\lambda_{p,t+s}}} Y_{t+s} - P_{t+s}mc_{t+s}\Phi \right].$$

Aggregate price law of motion is then expressed as follows:

$$P_t = \left[\left(1 - \xi_p\right) \left(p_t^*(f)\right)^{-\frac{1}{\lambda_{p,t}}} + \xi_p \left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p} p_{t-1}(f) \right)^{-\frac{1}{\lambda_{p,t}}} \right]^{-\lambda_{p,t}}. \tag{2.13}$$

2.2.3 Fiscal and Monetary Authorities

The fiscal authority purchases final goods, G_t, issues bonds, B_t, and levies taxes on consumption, labor income, and capital income at rates, τ_t^c, τ_t^l, and τ_t^k, respectively. The real flow budget constraint for the fiscal authority is expressed as follows:

$$G_t + \frac{B_{t-1}}{P_t} = \tau_t^c C_t + \tau_t^l w_t L_t + \tau_t^k r_t^k z_t K_{t-1} + \tau_t^k \frac{D_t}{P_t} + \frac{1}{R_t}\frac{B_t}{P_t}. \tag{2.14}$$

We consider three feedback rules for each tax and a government spending rule in log-linearized form. The aggregate tax rates are assumed to positively respond to a predetermined debt-to-output ratio following FMS:

$$\hat{\tau}_t^c = \rho_{tc}\hat{\tau}_{t-1}^c + (1-\rho_{tc})\,\phi_{tcb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^{tc}, \tag{2.15}$$

$$\hat{\tau}_t^l = \rho_{tl}\hat{\tau}_{t-1}^l + (1-\rho_{tl})\,\phi_{tlb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^{tl}, \tag{2.16}$$

$$\hat{\tau}_t^k = \rho_{tk}\hat{\tau}_{t-1}^k + (1-\rho_{tk})\,\phi_{tkb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^{tk}, \tag{2.17}$$

where the hats above variables denote log-deviations from the steady state. $b_t \equiv B_t/P_t$ denotes government bonds in real terms. η_t^g, η_t^{tc}, η_t^{tl}, and η_t^{tk} are i.i.d.-normal errors. It should be noted that the government budget constraint and the tax policy rules described here allow partial debt finance after a government spending increase, while the debt is to be repaid through tax revenue over time. The speed of fiscal adjustment is determined by the coefficient of the debt-to-output ratio. Government spending is assumed to follow a feedback rule that responds to output gap in log-linearized form:

$$\hat{G}_t = \rho_g \hat{G}_{t-1} + \left(1 - \rho_g\right) \phi_{gy} \hat{Y}_{t-1} + \eta_t^g. \tag{2.18}$$

The monetary authority sets the nominal interest rate according to a simple feedback rule:

$$\hat{R}_t = \rho_r \hat{R}_{t-1} + (1 - \rho_r)\, \phi_{r\pi} \hat{\pi}_{t-1} + (1 - \rho_r)\, \phi_{ry} \hat{Y}_t + \eta_t^R, \tag{2.19}$$

where $\pi_{t-1} \equiv \log(P_{t-1}/P_{t-2})$ denotes inflation rate. An i.i.d.-normal shock, η_t^R, to the interest rate is assumed.

2.2.4 Aggregation and Market Clearing

Aggregate consumption, C_t, and labor input, L_t, in per-capita term are given by a weighted average of the corresponding variables for each consumer type:

$$C_t = (1 - \omega) C_t^R(i) + \omega C_t^{NR}(j), \tag{2.20}$$

$$L_t = (1 - \omega) L_t^R(i) + \omega L^{NR}(j),$$

and again, since all households supply the same amount of labor by assumption, aggregate labor input is given by:

$$L_t = L_t^R(i) = L_t^{NR}(j).$$

Because only Ricardian households have access to financial markets, aggregate government bonds, B_t, investment, I_t, physical capital, K_t, and dividends, D_t, distributed by firms are expressed as follows:

$$B_t = (1-\omega)B_t^R(i),$$

$$I_t = (1-\omega)I_t^R(i),$$

$$K_t = (1-\omega)K_t^R(i),$$

$$D_t = (1-\omega)D_t^R(i).$$

Finally, aggregate production equation and the final-goods market equilibrium condition are given by:

$$Y_t = \varepsilon_t^a \left(z_t K_{t-1}\right)^\alpha L_t{}^{1-\alpha} - \Phi, \tag{2.21}$$

$$Y_t = C_t + I_t + G_t + \Psi\left(z_t\right) K_{t-1}. \tag{2.22}$$

2.3 Bayesian Estimation of the Model

2.3.1 Preliminary Setting

In estimating the model parameters, we first log-linearize the model around the deterministic steady state and conduct Bayesian inference using the Markov Chain Monte Carlo (MCMC) method. A MCMC method is a simulation technique that aims to produce posterior distribution using Markov chains. It is standard practice to use the Random Walk Metropolis-Hastings (RWMH) algorithm for the estimation of DSGE models. The RWMH algorithm is a special case of Metropolis–Hastings algorithm in which candidates are sampled by drawing a proposal from a random walk process.[8] The log-linearized version of the model is presented in Appendix B. The parameters are estimated for the Japanese data covering the period from 1980:Q1 to 1998:Q4. We utilize fiscal data on government spending (calculated as the sum of government consumption and investment) and aggregate effective tax rates on consumption and labor income. We also use the ordinary seven-part series typically employed in the literature, which includes output, private consumption and investment, labor hours, wages, the inflation rate, and the interest rate. The aggregate effective tax rates are calculated following Mendoza et al. (1994). See appendix A for details of how to calculate the effective tax rates.[9] All of the variables are detrended using the Hodrick-Prescott filter.

The end of the estimation period is determined for both computational and empirical reasons. As discussed in Braun and Waki (2006), the zero lower bound on interest rates requires us to deal with two difficult problems in a DSGE framework: non-linearity and indeterminacy. Mainly because of the technical limitation, most of the existing empirical New Keynesian DSGE literature on the Japanese economy does not include data during the zero-interest-rate period in the estimation and we follow the strategy.[10] Moreover, it is worth noting that Japan's

[8] The proposal is accepted or rejected according to the ratio of posterior distribution evaluated at the proposal and the previously accepted candidate. See An and Schorfheide (2007) for a succinct description of the algorithm. The application of the RWMH algorithm for the estimation of DSGE models is first proposed by Schorfheide (2000). The algorithm is useful when we have little information on the posterior distribution because we need not find a proposal distribution that is required to implement a more general class of Metropolis-Hastings algorithm.

[9] The series of effective tax rates on capital income is also calculated. The obtained data series is too volatile, however; it is therefore treated as a latent variable whose value cannot be observed directly in the MCMC estimation.

[10] See, for exapmle, Iiboshi et al. (2006), Sugo and Ueda (2008), Ichiue et al. (2008), and Hirose (2008).

fiscal policy regime seems to have changed around 1999 from an empirical point of view. The severe economic downturn in the aftermath of the Asian financial crisis in 1997-1998 forced the government to suspend its fiscal consolidation efforts temporarily. After that, the government started to increase its focus on spending cuts as opposed to taxation as the dominant mode of fiscal consolidation.[11]

To illustrate the changes in the fiscal policy regime in Japan, we estimate the following single-equation fiscal rules using the Ordinary Least Squares (OLS) method for different fiscal instruments for the subsamples 1980:Q1-1998:Q4 and 1999:Q1-2008:Q1:

$$(\text{fiscal instrument})_j = (\text{constant term})_j + \alpha_j \, (\text{debt-to-output ratio}) \, .$$

Table 1 reports the estimated values of the coefficients α_j of debt-to-output ratio for different fiscal instruments j and the results of a Chow test in which the breakpoint is set equal to 1999:Q1. It appears that aggregate effective tax rates on consumption and capital income increased in response to debt-to-output ratios during the 1980-1998 period in Japan and that capital income tax played a greater role in stabilizing debt. It would also seem that government spending during the period responded *positively* to debt-to-output ratios. This contradicts the idea of a spending reversal. A spending reversal policy is weakly observed during the period 1999-2008 but not for 1980-1998. Also, note that the results of the Chow

[11] The Japanese Government adopted the *Resolution on Fiscal Consolidation* in December 1979 and started its consolidation efforts. To push ahead with the efforts, the *Fiscal Structural Reform Act* was enacted in 1997, however, the Act was amended and suspended in 1998 to cope with the unanticipated sharp economic downturn.

breakpoint test provide strong support for Japan's fiscal policy regime change around 1999.

Because the model is an extended variant of Smets and Wouters (2003) and based on its use as a tool for analyzing the Japanese economy in Iiboshi et al. (2006) and Sugo and Ueda (2008), we largely follow these studies in choosing prior distributions and in fixing several parameters that are difficult to identify. Specifically, we set the capital share at $\alpha = 0.3$, the discount rate at $\beta = 0.99$, the depreciation rate at $\delta = 0.06$, the wage markup at $\lambda_w = 0.5$, and the parameter for the elasticity of investment to the price of capital adjustment cost at $\varsigma \equiv 1/\bar{S}'' = 6.32$. The steady-state capital-output ratio and debt-to-output ratio are set at $\bar{K}/\bar{Y} = 2.2$ and $\bar{B}/\bar{P}\bar{Y} = 0.6$, following Iiboshi et al. (2006) and Broda and Weinstein (2004), respectively. We assume that $\bar{C}^R/\bar{Y} = \bar{C}^{NR}/\bar{Y} = \bar{C}/\bar{Y}$ following Galí et al. (2007) and take sample period averages for the steady-state values for the government spending-to-output ratio and consumption, labor, and capital income tax rates.

2.3.2 Estimation Results

The estimation results are reported in Table 2 along with prior distributions of the parameters. Tables 3-4 compare the estimated mean parameter values with those of previous DSGE studies: Smets and Wouters (2003) (SW), Coenen and Straub (2005) (CS), and FMS for the euro area, Levin et al. (2006) (LOWW) for the United States, and Iiboshi et al. (2006) (INW) and Sugo and Ueda (2008) (SU) for Japan. The studies listed here, with the exception of FMS, are all variants of the Smets and Wouters (2003) model. Although FMS employs adjustment cost functions for sticky price and wage mechanism, FMS's other features, such as real rigidities, shocks, and functional forms, share much in common with the studies listed here.

Overall, the values of posterior mean estimates are not very different from those reported in previous studies. From the viewpoint of fiscal policy effectiveness, structural parameters for the non-Ricardian share, price and wage stickiness, habit persistency, and labor supply elasticity are of particular interest. The estimated mean value of the non-Ricardian share, 0.25, is very much consistent with the Kalman filter estimates of Hatano (2004). Hatano (2004), using a Kalman filter technique, determines that this figure remains between 0.2 and 0.3 throughout the 1980s and the 1990s in Japan.[12] Compared with other DSGE-based estimates for the euro area and the U.S., the value is somewhat smaller.[13] The Calvo parameter for wage stickiness is higher, whereas that for price is lower than the INW and SU estimates. They are, however, largely in line with the results of Koga and Nishizaki (2005).[14] Our estimate of the inverse elasticity of the labor supply is

[12] The estimation period ranges 1955-1998. Ogawa (1990) is the first paper to adopt a Kalman filter technique to estimate Japan's non-Ricardian share for the period 1970-1983. It reports that the share stays in the range of 0.4-0.5 in the first half of the 1980s.

[13] As for the euro area, FMS report 0.34 for a case without unions. They also report 0.37 for a case with unions, which are assumed to act as wage setters representing both types of households. Coenen and Straub (2005) report 0.246, 0.249, and 0.370 for different tax specifications. Ratto et al. (2009) report 0.35. As regards the U.S., Bilbiie et al. (2008) report 0.35 and 0.51 for different sample periods.

[14] They estimate Japanese Calvo parameters for wage and price are in the range of 0.7-0.75

close to those of INW and SU. The parameter value for habit persistency is much smaller than that reported by INW but much larger than that reported by SU. SU conjecture that their small value for habit persistence is due to their assumption of *internal* habit. This chapter assumes that habit is *external*, as does INW. On the other hand, that our value is smaller than that of INW may be attributable to the inclusion of non-Ricardian households. As Coenen and Straub (2005) note, this has the effect of lowering the estimate of the parameter for habit persistency and raising that for the intertemporal elasticity of substitution. In fact, the value of the estimated intertemporal elasticity of substitution $1/\sigma_c$ is larger than that of INW. Overall, posterior means for structural parameters do not suggest that the government spending multiplier is large in this model.

Turning to the policy parameters, we note that relative to those of INW, the estimated response of monetary policy to inflation is weak, and the estimated response to the output gap is strong. The less aggressive stance of monetary policy towards inflation may reflect the difference in the sample periods.[15] The posterior mean estimates of tax rule parameters that govern responses of tax instruments to debt-to-output ratio are all positive, although those of consumption and labor income tax rules are not reliably different from zero. The results are quite consistent with those of the OLS estimates of single-equation fiscal rules

and 0.5-0.55 respectively, based on the method of Galí and Gertler (1999).

[15] The estimation period of INW is 1970:Q1 to 1998:Q4, while that is 1980:Q1 to 1998:Q4 in this paper. Ichiue et al. (2008) obtain mean estimates closer to those of this paper ($\rho_r = 0.85$, $\phi_{r\pi} = 1.49$, and $\phi_{ry} = 0.16$) for a sample period 1981:Q1 to 1995:Q4.

reported in Table 1, which suggests that capital income taxation contributed to debt stabilization to the largest extent during the 1980s and 1990s in Japan. Although the series of aggregate effective tax rates on capital is treated as a latent variable in the MCMC estimation, we reach the same conclusion as that suggested by the OLS estimation in which capital tax data series is utilized.

2.4 Assessing the Role of Tax Policy Rules

The size of a coefficient on the debt-to-output ratio of a tax policy rule determines the speed of fiscal adjustment or debt repayment and accordingly affects the time paths of economic variables such as output, consumption, and investment after a government spending increase. Even more importantly, when one analyzes an economy with different kinds of taxes, the size of the coefficient compared with those of other tax rules also affects the time paths because different distortionary taxes differ in their disincentive effects on household decisions. To assess the role of tax rules in determining the size of government spending multiplier, we consider the sensitivity of the multiplier to changes in financing schemes. For the sake of clarity, parameter values are calibrated to the estimated means of the posterior distributions for the parameters unless otherwise noted. Therefore the government spending multipliers are to be calculated in a deterministic way. The purpose of this section is to investigate the transmission mechanism of a government spending shock in the standard New Keynesian model and not to address the size of actual multiplier that is inherently non-deterministic.

2.4.1 The Impact of Tax Rule Change: Japan 1980-1998 vs. Euro Area 1980-2005

We begin by comparing the simulation results under the estimated tax rules for Japan 1980:Q1-1998:Q4 with those under parameters that replicate tax rules estimated for the euro area 1980:Q1-2005:Q4 in FMS. Setting the smoothing parameter values to those estimated for Japan, we adjust the policy parameters ϕ_{tcb}, ϕ_{tlb}, and ϕ_{tkb} for each tax rule so that the coefficients of the debt-to-output ratio become equal to those of the FMS estimates. The adjusted policy parameters and the coefficients are reported in Table 5 with those of our estimates and those of FMS's original estimates. The coefficients suggest that debt in Japan is financed largely through capital income taxation, whereas financing in the euro area is instead allocated rather heavily to labor income taxes.

Figure 2 illustrates the dynamic responses of output, consumption, investment, and labor input to a government spending shock equal to one percent of the steady-state output under the estimated tax rules and those under the adjusted FMS tax rules for the euro area. Each dynamic response is depicted as a percentage deviation from the steady state and hence corresponds to the *impact multiplier* of Mountford and Uhlig (2009). The impact multiplier for output in period k is defined as follows:

$$\text{Impact Multiplier } (k) = \frac{\Delta Y_{t+k}}{\Delta G_t}.$$

The output multipliers of the estimated model are larger in the initial periods than those when the adjusted FMS tax rules are employed; greater declines are shown in later periods. The upper right-hand and lower left-hand panels reveal that the greater output multipliers of the estimated model in the initial periods can be attributable both to the dynamic responses of consumption and to those of investment. A closer look at the patterns of output, consumption, and investment responses indicates that investment serves as a major driving force for the stronger output response under the estimated tax rule. The strong increase in investment reflects the increase in the labor supply, which has a positive impact on the marginal product of capital. It is also traceable to a moderate increase in the interest rate due to the less aggressive monetary policy. In later periods, however, the estimated model exhibits large decreases in consumption, in investment, and thus in output. The decreases are brought about by delayed tax increases in response to debt accumulation. Because the main financing source for the estimated tax rules is capital income taxation, the decline in later periods is significant for investment. Note that the estimated model delivers a slight but positive consumption response in the initial periods. This is somewhat surprising because none of the estimated values of key structural parameters for fiscal policy effectiveness—such as the non-Ricardian share, price and wage stickiness, habit persistency, or labor supply elasticity—seem to generate the crowding-in effect. In particular, the estimated share of non-Ricardian households in Japan seems to be too small to have precipitated the crowding-in effect as suggested in previous studies (e.g., Coenen and Straub (2005)[16]). It is worth emphasizing that the difference in the coefficients of tax rules is solely responsible for the observed difference in the size of multipliers. Although a variable capital utilization rate plays an important role to smooth the response of investment to a government spending shock in our model, the overall results here does not change if a capital utilization rate is assumed to be invariable.

2.4.2 Policy Experiments

In the following, we examine how different financing schemes affect the effectiveness of fiscal stimulus. We consider three alternative tax-financing schemes: (a) one in which the consumption tax alone adjusts to stabilize debt (a consumption tax-financing scheme), (b) one in which the labor income tax alone adjusts (a labor tax-financing scheme), and (c) one in which the capital income tax alone adjusts (a capital tax-financing scheme). The parameter values for the three tax-financing schemes are set as follows: (a) $\rho_{tc} = 0.6$, $\phi_{tcb} = 0.2/\bar{\tau}^c$, $\bar{\tau}^c = 0.08$, $\phi_{tlb} = \phi_{tkb} = 0$; (b) $\rho_{tl} = 0.6$, $\phi_{tlb} = 0.2/\bar{\tau}^l$, $\bar{\tau}^l = 0.31$, $\phi_{tcb} = \phi_{tkb} = 0$; (c) $\rho_{tk} = 0.6$, $\phi_{tkb} = 0.2/\bar{\tau}^k$, $\bar{\tau}^k = 0.45$, $\phi_{tcb} = \phi_{tlb} = 0$. The responsiveness parameters of three

[16] They argue that the value of non-Ricardian share needs to exceed 0.35 to obtain the crowding-in effect in their estimated medium-scale DSGE model of the euro area.

tax rules, ϕ_{tcb}, ϕ_{tlb}, and ϕ_{tkb}, are normalized by their respective steady-state values because $\hat{\tau}_t^c$, $\hat{\tau}_t^l$, and $\hat{\tau}_t^k$ are defined as deviations from their steady-state values. For the sake of simplicity, we assume that government spending does not respond to the output gap ($\phi_{gy} = 0$) in the exercise below. We also consider the following two alternative financing schemes for comparative purposes: (d) a spending reversal and (e) a balanced budget. In the case of a spending reversal, the government spending rule is assumed to take the following form:

$$\hat{G}_t = \rho_g \hat{G}_{t-1} - \left(1 - \rho_g\right) \phi_{gb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^g. \tag{2.23}$$

where ϕ_{gb} captures the degree of future spending cuts based on the debt-to-output ratio. We set $\rho_g = 0.6$ and $\phi_{gb} = 0.2 \times \left(\bar{C}/\bar{G}\right)$, where $\bar{C}/\bar{G} = 2.5$. For a balanced budget, we assume that the current labor income tax alone adjusts to meet the following period-by-period budget constraint:

$$G_t = \bar{\tau}^c C_t + \tau_t^l w_t L_t + \bar{\tau}^k r_t^k z_t K_{t-1} + \bar{\tau}^k \frac{D_t}{P_t}. \tag{2.24}$$

Figure 3 displays the impulse responses to a government spending shock under the five alternative financing schemes formulated above. We put the responses under the labor tax-financing scheme in both the right and left panels for comparative purposes. As in Figure 2, the responses correspond to the impact multipliers. The top two panels show that the stimulative effects of capital tax-financed spending exceed those under other financing schemes in the short term. Fiscal stimulus under the balanced budget scheme shows the smallest output response on impact.

Because the balanced budget scheme does not allow any debt finance, the negative wealth effect on consumption becomes quite large. The initial rise in consumption is the largest under the capital tax-financing scheme. It should be noted that the hump-shaped rise in Ricardian consumption caused by the spending reversal occurs from the sixth quarter onward in the model. That is, the observed initial increases in total consumption are brought about by non-Ricardian households. The capital tax-financed spending leads to the strongest initial increases in investment as well, but a large decline occurs as the capital tax increases in later periods. Labor input also shows the strongest increase under the capital tax-financing scheme. Recall that the coefficients of the estimated tax rules for Japan suggest that debt is repaid largely through capital income taxation, whereas its financing in the euro area is allocated rather heavily to labor income tax. In comparing the responses shown in the left panels of Figure 3 with those in Figure 2, we notice that the response patterns of output, consumption, investment, and labor input under the capital tax-financing scheme all show similar patterns to those under the estimated tax rules for Japan. On the other hand, the response patterns under the labor tax-financing scheme show similar patterns to those under the adjusted FMS tax rules for the euro area.

To assess the quantitative importance of changes in the multipliers brought by alternative tax-financing schemes, we compare the first-year average responses for different tax-financing schemes in Table 6. The responses for different non-

Ricardian shares are also presented for capital tax-financed spending. As expected, the introduction of non-Ricardian households contributes toward a crowding-in effect on consumption. The crowding-in effect decreases as the share of non-Ricardian households declines. On the other hand, the investment multipliers become larger as the non-Ricardian share declines because non-Ricardian households do not own capital, and hence, the total investment in the economy increases as the share declines. Note that decreases in Ricardian consumption also become smaller as investment responds strongly. Both consumption and labor tax-financed spending cannot generate the crowding-in effect on consumption with a relatively high non-Ricardian share ($\omega = 0.4$) in this model. In contrast, the stimulative effects of capital tax-financed spending are larger than those of consumption and labor tax-financed spending with a high non-Ricardian share, even when non-Ricardian households do not exist ($\omega = 0.0$). The results here indicate that a choice of tax rules can alter the consequences of a fiscal stimulus program anticipated by the given non-Ricardian share.

In a general equilibrium framework, an (irreversible) increase in government spending needs to eventually be financed through a corresponding increase in taxation, even if it is financed by debt initially. Taxation creates a negative wealth effect on consumption and leisure. The decrease in leisure is result of increased labor hours. The increases in labor hours induce capital accumulation because they have a positive impact on the marginal product of capital, making investment more attractive. Therefore, investment tends to rise after a *permanent* government spending increase in neoclassical models (e.g., Aiyagari et al. (1992); Baxter and King (1993)[17]). The same basic forces apply in the face of a *persistent* increase in government spending (e.g., Burnside et al. (2004)). In New Keynesian models, however, investment tends to decline because strong monetary policy reactions lead to a rise in the real interest rate (e.g., Linnemann and Schabert (2003); Cogan et al. (2010)).

In our estimated model, fiscal stimulus has persistent effects, and monetary policy does not respond aggressively to inflation. Therefore, investment increases through the above-mentioned neoclassical channel without being hampered by a real rate rise. Because the model allows partial debt finance and three distortionary taxes, debt repayment is to be financed via a split among consumption, labor, and capital income taxes. Regarding the role of different taxes, note that both consumption and labor income taxes have dampening effects on labor hours because the labor supply schedule is related to the utility-maximizing choice between consumption and leisure on an after-tax basis. Hence, debt stabilization via either a consumption tax or a labor income tax limits the initial increase in labor input after fiscal stimulus more than debt stabilization via a capital income tax. Labor input increases greatly under the capital tax-financing scheme, and so does investment. Although capital income taxation is harmful to investment, the

[17] Baxter and King (1993) also consider the case in which public capital has productive effects on private output. They show that endogenous responses of private investment and labor to changes in public investment play important roles in making output multiplier large. Productive public capital will be introduced to an open economy DSGE model in Chapter 3.

speed of fiscal adjustment or debt repayment is slow, and the increase in investment is strong enough to outweigh the distortionary effects of capital taxation in the initial periods. The results here are closely related to the findings presented by Jones (2002), which indicate that labor income taxation has a greater downward effect on labor input—and, accordingly, on output—than capital income taxation does in a neoclassical framework.

Furthermore, in our New Keynesian model, the investment boom pushes up the rental rate on capital, but monetary policy does not react very aggressively to inflation; it allows negative real interest rates, at least for a while. The negative real rate not only further increases investment but also induces Ricardian consumption to rise initially through the intertemporal substitution effect. Hence, both investment and consumption respond positively to the capital tax-financed spending increase. Notice also that as we have seen in Table 6, increases in investment have positive effects on Ricardian consumption.

To illustrate the role of monetary policy in the estimated model, we consider the sensitivity of the multipliers to changes in parameter values as we did for the tax rules earlier. Setting the interest rate smoothing coefficient to the estimated value for Japan ($\rho_r = 0.93$), we adjust the policy parameters $\phi_{r\pi}$ and ϕ_{ry} of the monetary policy rule so that the coefficients of inflation and the output gap become equal to the corresponding FMS estimates for the euro area. Again, the adjusted policy parameters and the coefficients are reported in Table 5 with our estimates and the FMS's original monetary policy estimates. The adjusted parameter values indicate that the estimated monetary policy for Japan is less aggressive towards inflation than that for the euro area. Figure 4 shows the impact multipliers for different tax-financing schemes under the adjusted FMS monetary policy rule for the euro area. The responses under the capital tax-financing scheme and the estimated monetary policy for Japan are also shown for comparative purposes. As we have previously seen, consumption rises initially under the capital tax-financing scheme and estimated monetary policy. Under the adjusted FMS monetary policy, however, interest rates are raised more aggressively, thereby weakening intertemporal substitution in consumption. The increase in investment is also hampered by the higher interest rate. As a result, the short-run impact multipliers of capital tax-financed spending are lowered until they become almost equal to those of consumption and of labor income tax-financed spending under the relatively aggressive monetary policy rule.

Although this chapter aims to address the effect of short-run fiscal stimulus under alternative financing schemes, it is important to remember their medium- and long-run consequences. Mountford and Uhlig (2009) suggest the *present-value multiplier* as a summary measure intended to capture the cumulative effects of a fiscal shock along an entire path up to a particular time. The present-value multiplier for output over a k-period horizon is defined as follows:

$$\text{Present-Value Multiplier } (k) = \frac{E_t \sum_{s=0}^{k} \bar{R}^{-s} \Delta Y_{t+s}}{E_t \sum_{s=0}^{k} \bar{R}^{-s} \Delta G_{t+s}}.$$

Figure 5 depicts the present-value multipliers for output, consumption, and investment under alternative tax-financing schemes. When capital income tax alone is adjusted to stabilize debt, the present-value multipliers for output are the largest up to a three-year horizon. Over longer horizons, higher capital taxes lower investment, and thereby, the present-value multipliers for investment decrease below those under the consumption and labor tax-financing schemes. The present-value multipliers for consumption become negative within a two-year period, but the decline is smaller than under the consumption and labor tax-financing schemes up to a seven-year horizon.

Table 7 reports the cumulative (horizon=∞) present-value multipliers under alternative tax-financing schemes and under the balanced budget scheme. The capital income tax-financed spending increase has the largest adverse effect on investment, consumption, and output. The cumulative present-value multiplier is slightly positive when the spending increase is consumption tax-financed and slightly negative when it is labor tax-financed. As can be seen in Figure 3, taxation on labor causes a larger decline in labor input than does consumption tax in later periods. Accordingly, the decline in investment is rather prolonged when the spending is financed by labor taxes. These long-run consequences are in line with the widespread consensus: taxes on capital are harmful to growth,[18] and taxes on consumption are the least distortionary. The cumulative present-value multipliers under the labor-tax financed balanced budget scheme are larger than those when labor income tax is adjusted to stabilize debt through the feedback rule, although the short-run impact multipliers are smaller, as shown in Figure 3. The reason is that the labor tax feedback rule allows partial debt finance initially, thereby making taxation partly delayed. Delaying the timing of taxation increases output in the short term; however, the output decrease caused by the delayed taxation may be larger than the initial increase (Trostel (1993)).

Table 7 also reports the welfare effects of a government spending shock under alternative financing schemes, including a spending reversal. Following Levine et al. (2008b), we use a quadratic approximation of the representative household's utility as the welfare criterion.[19] The change in welfare is expressed as the percentage of steady-state consumption equivalence. Because the utility function is assumed not to be affected by government spending, the overall results are quite similar to those suggested by the cumulative present-value multipliers. The amount of welfare loss is the greatest if spending is financed by capital income taxes. A labor tax-financed spending shock has a larger negative impact on wel-

[18] Leeper et al. (2010a) obtain the same results by conducting similar exercises to this paper in a neoclassical framework.

[19] Recall that we assume non-Ricardian households have the same utility function as Ricardian households. In conducting welfare analysis, we employ a linear-quadratic (LQ) framework because it is easily applicable to our medium-scale DSGE model in log-linearized form. Regarding the accuracy of the LQ approximation, see Benigno and Woodford (2006) and Levine et al. (2008a).

fare than a consumption tax-financed spending shock does. Welfare loss is the smallest when a future spending reversal is prospected because it does not require an additional tax increase to stabilize debt. The results seem to indicate that a spending reversal policy is the most desirable. However, it should be noted that the results depend critically on the simplifying assumption that government spending is completely wasteful in our model.[20]

The results of this study suggest that output decline and welfare loss are, in the long term, greatest under the capital tax-financing scheme. As previously discussed, a capital tax-financed spending shock induces an investment boom in the initial periods if the speed of fiscal adjustment is slow. This is because capital taxation has the smallest adverse effect on the increase in the labor supply. An accommodative monetary policy plays a critical role in allowing the real interest rate to decline in the short term. However, as debt is repaid over time, the initial stimulative effects are dominated, in the long term, by the distortionary effects of capital taxation. Because capital taxation creates intertemporal wedges, the distortionary effects become excessively greater with longer horizons,[21] especially in the presence of imperfect competition (e.g., Judd (2002); Schmitt-Grohé and Uribe (2006)). Thus, it is important when designing fiscal stimulus packages and financing schemes to take into account the long-run costs that arise from future

[20] Therefore, most of the literature on welfare effects of fiscal policy assumes utility-enhancing government expenditure (e.g. Pappa and Vassilatos (2007); Forni et al. (2010)).

[21] The growing distortions in intertemporal allocations created by capital income taxes constitute the underlying mechanism behind the famous Chamley-Judd result. Using a neoclassical growth model with infinitely-lived agents, Chamley (1986) and Judd (1985) show that the optimal capital income tax is zero in the long-run.

tax burdens.

2.5 Conclusion

This chapter used an estimated DSGE model of the Japanese economy to study changes in the government spending multiplier under alternative fiscal financing schemes. The results have shown that the government spending multiplier becomes greater in the short term if the spending increase is initially financed by debt and that debt is largely repaid via a gradual increase in capital income tax under an accommodative monetary policy. Capital taxation has the smallest dampening effect on labor input, and the increase in labor input is the key factor contributing to the effectiveness of fiscal stimulus in a general equilibrium framework, as shown by Aiyagari et al. (1992) and Baxter and King (1993). Therefore, to improve the effectiveness of the stimulus, future taxation for debt repayment is better allocated to capital tax instead of labor-dampening taxes, such as consumption and labor income taxes. In light of this chapter's finding that a prospective future financing scheme considerably affects the size of the short-run multiplier, governments are advised to announce both stimulus plans and financing schemes at the same time to ensure the effects are predictable.

There are some further points regarding the possible extension of this model that should be noted. First, this chapter restricts its analysis to the case in which both fiscal and monetary policy rules are stable and linear. However, policy rules are likely to change over time (e.g., Davig and Leeper (2007); Chung et al. (2007); Davig and Leeper (2011)). Embedding the possibility of a policy regime change in the model is therefore an important avenue to be explored. In addition, the recent crisis highlights the importance of fiscal stimulus when nominal interest rates are at zero, the lower bound (e.g., Woodford (2011); Christiano et al. (2011b); Erceg and Lindé (2014)). It would be interesting to extend our analysis to a "liquidity trap" scenario, in which monetary policy rule cannot be approximated by a linear function. Second, further research could entail incorporating non-wasteful feature of government spending into the model because it is commonly believed that government spending can have a direct effect on the production and utility function (e.g., Kamps (2004); Linnemann and Schabert (2006); Bouakez and Rebei (2007)). The incorporation of these features may increase the size of the government spending multiplier and provide broader implications to welfare analysis, and therefore deserves high priority in future research.

2.6 Tables and Figures

Table 1: Responses of fiscal instruments to debt-to-output ratio

	(1) 1980:Q1-1998:Q4	(2) 1999:Q1-2008:Q1	Chow test: F-statistic (Breakpoint = 1999:Q1)
Consumption tax rate	0.0814***	-0.0039	26.302***
	(3.748)	(-1.380)	[0.000]
Labor income tax rate	0.0894	0.0122*	3.6374***
	(1.384)	(1.869)	[0.030]
Capital income tax rate	0.2777**	0.0360	2.5196*
	(2.143)	(1.134)	[0.085]
Gov. spending-to-output ratio	0.0007*	-0.0005***	23.642***
	(1.884)	(-14.42)	[0.000]

Notes: A triple asterisk (***) denotes significant at the 1 percent level; a double asterisk (**) denotes significant at the 5 percent level; a single asterisk (*) denotes significant at the 10 percent level. Values in parentheses are t-statistics. Probabilities of the Chow's breakpoint test are shown in square brackets. Aggregate effective tax rates on consumption, labor and capital income are calculated following the method of Mendoza et al. (1994). Government spending is the sum of government consumption and investment. In calculating debt-to-output ratio, debt held by the government is excluded.

Table 2: Estimation results

Parameters	Prior			Posterior	
	Distribution	Mean	S. D.	Mean	90% interval
h	beta	0.7	0.1	0.465	[0.313 0.622]
σ_c	gamma	1.5	0.2	1.620	[1.283 1.954]
σ_l	gamma	2	0.375	2.113	[1.472 2.736]
φ	gamma	1.45	0.25	1.904	[1.529 2.312]
ψ	gamma	0.2	0.075	0.416	[0.290 0.536]
ξ_w	beta	0.75	0.15	0.824	[0.762 0.887]
ξ_p	beta	0.75	0.15	0.432	[0.323 0.543]
γ_w	beta	0.75	0.15	0.211	[0.096 0.325]
γ_p	beta	0.75	0.15	0.595	[0.308 0.887]
ω	beta	0.35	0.05	0.248	[0.183 0.310]
ρ_r	beta	0.8	0.1	0.934	[0.904 0.959]
$\phi_{r\pi}$	normal	1.7	0.1	1.533	[1.363 1.705]
ϕ_{ry}	normal	0.125	0.05	0.254	[0.189 0.318]
ρ_g	beta	0.8	0.1	0.736	[0.644 0.832]
ϕ_{gy}	normal	0.1	0.05	0.068	[-0.016 0.152]
ρ_{tc}	beta	0.8	0.1	0.507	[0.350 0.668]
ϕ_{tcb}	normal	0.1	0.05	0.013	[-0.016 0.041]
ρ_{td}	beta	0.8	0.1	0.568	[0.417 0.718]
ϕ_{tdb}	normal	0.1	0.05	0.005	[-0.029 0.044]
ρ_{tk}	beta	0.8	0.1	0.655	[0.547 0.761]
ϕ_{tkb}	normal	0.1	0.05	0.123	[0.055 0.190]
ρ_a	beta	0.8	0.1	0.518	[0.383 0.654]
ρ_b	beta	0.8	0.1	0.431	[0.250 0.619]
ρ_l	beta	0.8	0.1	0.257	[0.157 0.353]
ρ_i	beta	0.8	0.1	0.800	[0.652 0.960]
η^a	inv. gamma	0.4	2	0.788	[0.679 0.892]
η^b	inv. gamma	0.2	2	4.652	[3.128 6.116]
η^i	inv. gamma	0.1	2	0.078	[0.023 0.139]
η^l	inv. gamma	1	2	169.6	[54.19 282.4]
η^q	inv. gamma	0.4	2	1.968	[1.653 2.280]
η^w	inv. gamma	0.25	2	0.231	[0.056 0.432]
η^p	inv. gamma	0.15	2	2.215	[1.436 2.979]
η^r	inv. gamma	0.1	2	0.224	[0.180 0.267]
η^g	inv. gamma	0.3	2	1.220	[1.057 1.379]
η^{tc}	inv. gamma	0.1	2	0.643	[0.551 0.732]
η^{td}	inv. gamma	0.1	2	0.676	[0.581 0.767]
η^{tk}	inv. gamma	0.4	2	4.805	[3.625 5.969]

Notes: This table reports prior distributions, posterior means, and 90% credible intervals (or Bayesian confidence intervals) of the parameters. In conducting Bayesian MCMC estimation, the draws from the posterior distribution have been obtained by taking two parallel chains of 1000,000 replications for Metropolis-Hastings algorithm.

Table 3: Mean estimates of structural parameters compared with those of previous studies

	Euro Area			U.S.	Japan		
	SW	CS[†]	FMS[††]	LOWW	INW	SU	This chapter
h	0.592	0.412	0.73	0.29	0.795	0.102	0.465
σ_c	1.391	1.101	(1.00)[‡]	2.19	1.912	1.249	1.620
σ_l	2.503	2.343	2.00	1.49	2.077	2.149	2.113
$1/\varsigma$	6.962	7.386	5.30	1.79	24.39	6.319	(6.319)[‡]
φ	1.417	1.602	n.a.	1.09	1.588	1.084	1.904
ψ	0.201	0.219	0.22	0.21	0.288	0.422	0.416
ξ_w	0.742	0.747	n.a.	0.79	0.275	0.516	0.824
ξ_p	0.905	0.914	n.a.	0.83	0.791	0.875	0.432
γ_w	0.728	0.724	n.a.	0.79	0.581	0.246	0.211
γ_p	0.477	0.456	n.a.	0.08	0.579	0.862	0.595
ω	n.a.	0.370	0.34	n.a.	n.a.	n.a.	0.248

[†] Estimates for a case in which time-invariant distortionary taxes are considered.
[††] Baseline estimates (without unions).
[‡] Values in parentheses are calibrated.

Table 4: Mean estimates of policy parameters compared with those of previous studies

	Euro Area			U.S.	Japan		
	SW	CS†	FMS††	LOWW	INW	SU	this chapter
Monetary policy parameters							
ρ_r	0.956	0.964	0.92	0.839	0.687	0.842	0.934
$\phi_{r\pi}$	1.688	1.692	1.72	2.695	1.628	0.606	1.533
ϕ_{ry}	0.098	0.103	0.13	0.097	0.097	0.110	0.254
(coeff. on $\Delta\hat{Y}$)	0.151	0.160	0.23	0.264	n.a.	0.250	n.a.
(coeff. on $\Delta\hat{\pi}$)	0.158	0.153	0.07	0.509	n.a.	0.647	n.a.
Fiscal policy parameters							
ρ_g	0.943	0.944	n.a.	0.944	0.793	0.960	0.736
ϕ_{gy}	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.068
ρ_{tc}	n.a.	n.a.	0.96	n.a.	n.a.	n.a.	0.507
ϕ_{tcb}	n.a.	n.a.	0.50	n.a.	n.a.	n.a.	0.013
ρ_{tl}	n.a.	n.a.	0.91	n.a.	n.a.	n.a.	0.568
ϕ_{tlb}	n.a.	n.a.	0.28	n.a.	n.a.	n.a.	0.005
ρ_{tk}	n.a.	n.a.	0.97	n.a.	n.a.	n.a.	0.655
ϕ_{tkb}	n.a.	n.a.	0.57	n.a.	n.a.	n.a.	0.123

† Estimates for a case in which time-invariant distortionary taxes are considered.
†† Baseline estimates (without unions).

Table 5: Tax and monetary policy rules for Japan and the euro area

	Japan (1980:Q1-1998:Q4)	Euro Area (1980:Q1-2005:Q4)	
	this chapter	FMS estimates	Adjusted FMS
$\hat{\tau}^c$ rule			
$1-\rho_{tc}$	0.493	0.04	0.493
ϕ_{tcb}	0.013	0.50	0.041
coeff.	0.006	0.020	0.020
$\hat{\tau}^l$ rule			
$1-\rho_{tl}$	0.432	0.09	0.432
ϕ_{tlb}	0.005	0.28	0.058
coeff.	0.002	0.025	0.025
$\hat{\tau}^k$ rule			
$1-\rho_{tk}$	0.345	0.03	0.345
ϕ_{tkb}	0.123	0.57	0.050
coeff.	0.043	0.017	0.017
monetary policy rule			
$1-\rho_r$	0.066	0.08	0.066
$\phi_{r\pi}$	1.533	1.72	2.072
coeff.	0.102	0.138	0.138
ϕ_{ry}	0.254	0.13	0.157
coeff.	0.017	0.010	0.010

Table 6: First-year average responses to government spending shocks for different tax-financing schemes and non-Ricardian shares

	τ^k financing			τ^l financing	τ^c financing
	$\omega = 0.4$	$\omega = 0.2$	$\omega = 0.0$	$\omega = 0.4$	$\omega = 0.4$
$\frac{\Delta Y}{\Delta G}$	0.779	0.767	0.757	0.558	0.481
$\frac{\Delta C}{\Delta G}$	0.091	0.039	-0.004	-0.062	-0.046
$\frac{\Delta C^R}{\Delta G}$	-0.074	-0.034	-0.004	-0.191	-0.144
$\frac{\Delta C^{NR}}{\Delta G}$	0.337	0.333	-	0.131	0.102
$\frac{\Delta I}{\Delta G}$	0.369	0.505	0.619	-0.702	-1.357

Table 7: Cumulative present-value multipliers and welfare effects of a government spending shock

	τ^k financing	τ^l financing	τ^c financing	Balanced bdg.	Spending rev.
$\frac{PV(\Delta Y)}{PV(\Delta G)}$ (horizon=∞)	-1.903	-0.020	0.095	0.093	-
$\frac{PV(\Delta C)}{PV(\Delta G)}$ (horizon=∞)	-2.470	-1.446	-1.424	-1.274	-
$\frac{PV(\Delta I)}{PV(\Delta G)}$ (horizon=∞)	-8.601	-2.423	-1.344	-2.247	-
Welfare loss†	-1.686	-0.374	-0.293	-0.326	-0.156

† Expressed by the change in certainty-equivalent consumption in percentage of its steady state level.

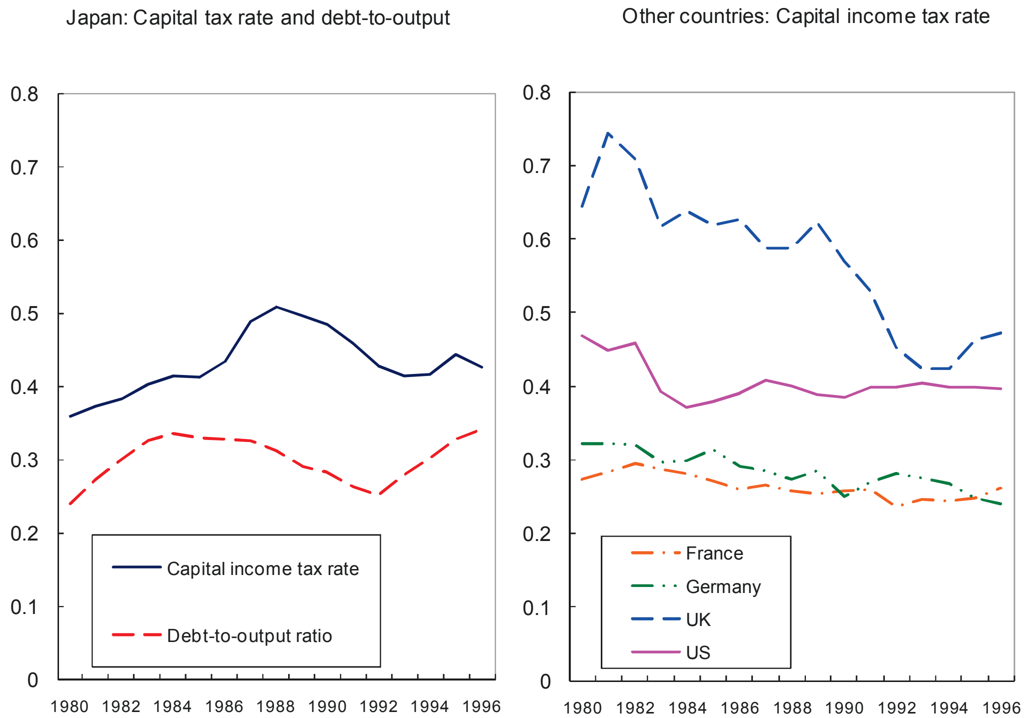


Figure 1: Cross-country comparison of aggregate effective tax rates on capital income

Notes: Capital income tax rates are taken from "Mendoza-Razin-Tesar effective tax rates updated through 1996," which is available at http://econ-server.umd.edu/~mendoza/. In calculating Japan's debt-to-output ratio, debt held by the government is excluded.

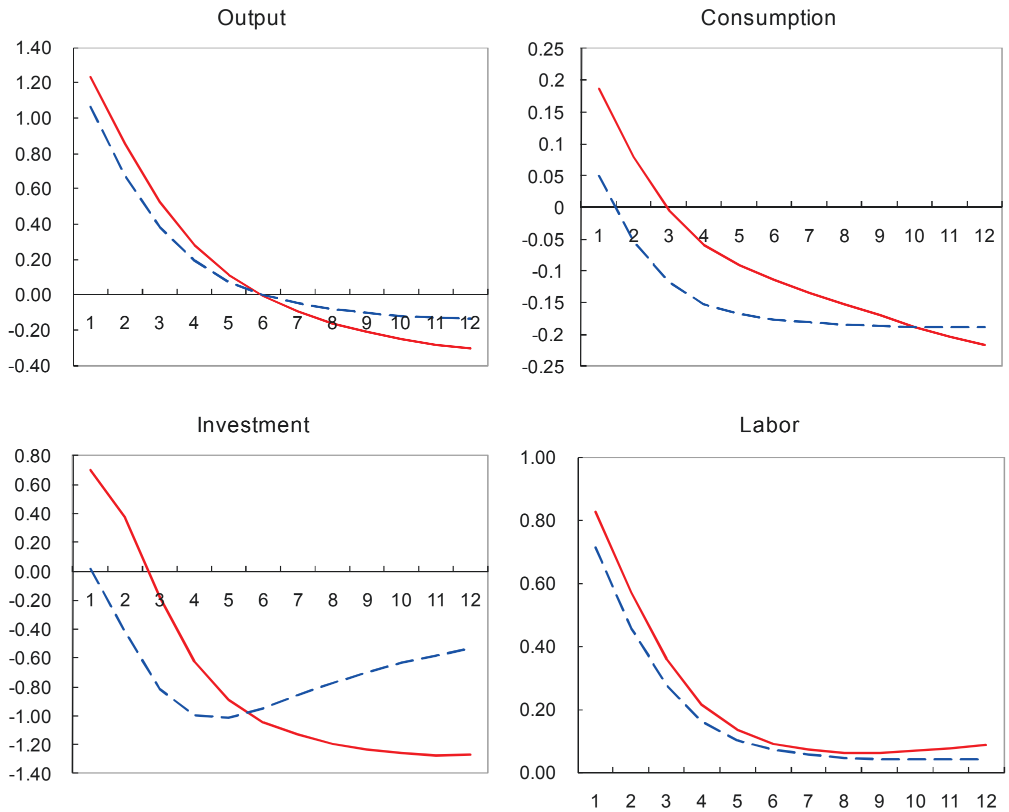


Figure 2: Impact multipliers for different tax rules

Notes: Solid lines—estimated tax rules for Japan 1980-1998; dashed lines—adjusted FMS tax rules for the euro area 1980-2005.

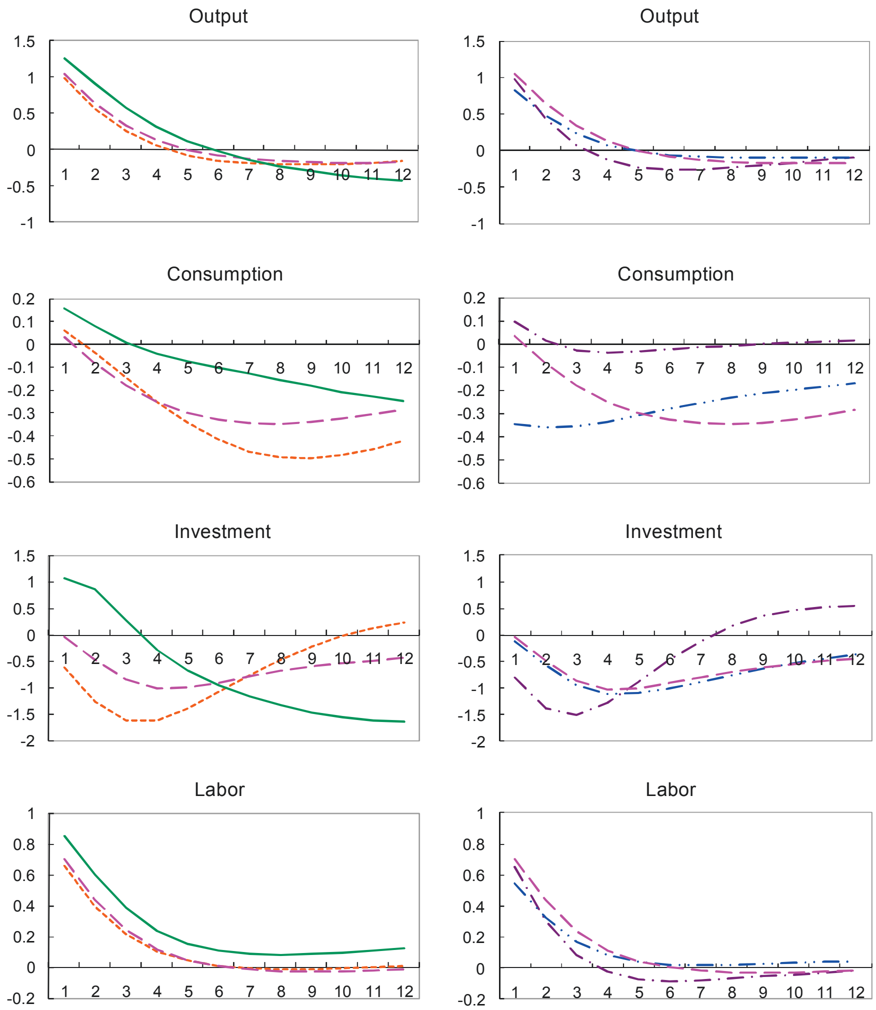


Figure 3: Impact multipliers for different financing schemes

Notes: Solid lines—capital tax-financing; dashed lines—labor tax-financing; dotted lines—consumption tax-financing; dash- dotted lines—spending reversal; dash- double dotted lines—balanced budget.

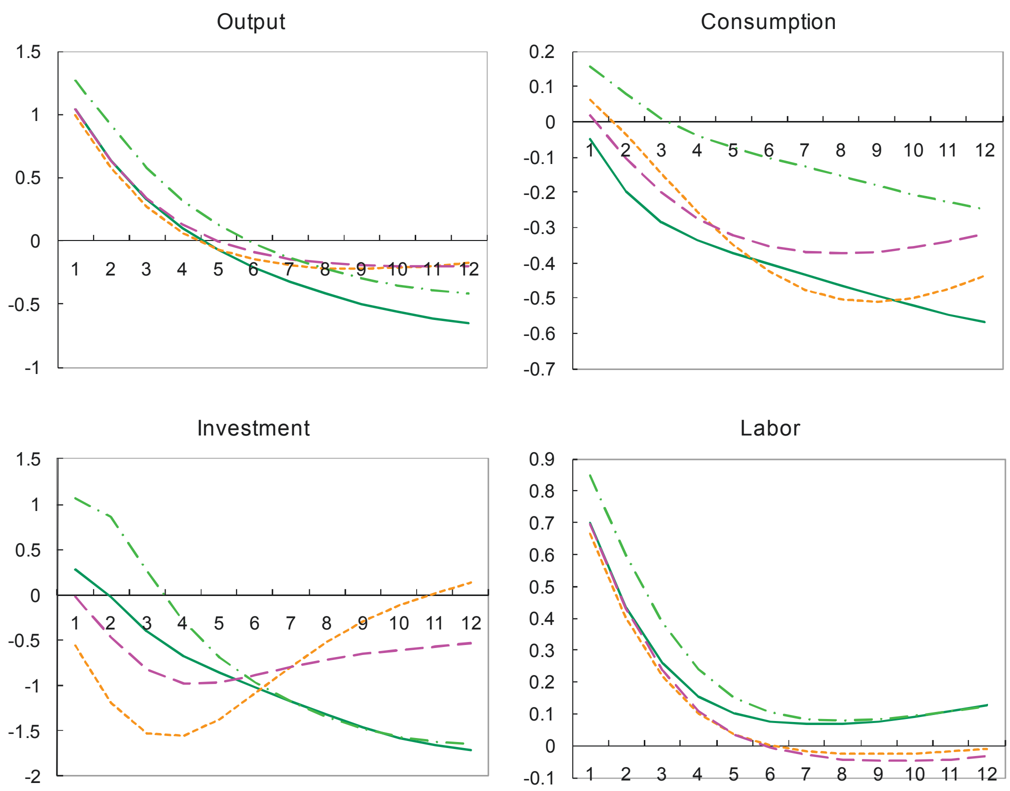


Figure 4: Impact multipliers for different tax-financing schemes under the adjusted FMS monetary policy for the euro area

Notes: Solid lines—capital tax-financing; dashed lines—labor tax-financing; dotted lines—consumption tax-financing; dash- dotted lines—capital tax-financing under the estimated monetary policy in Japan.

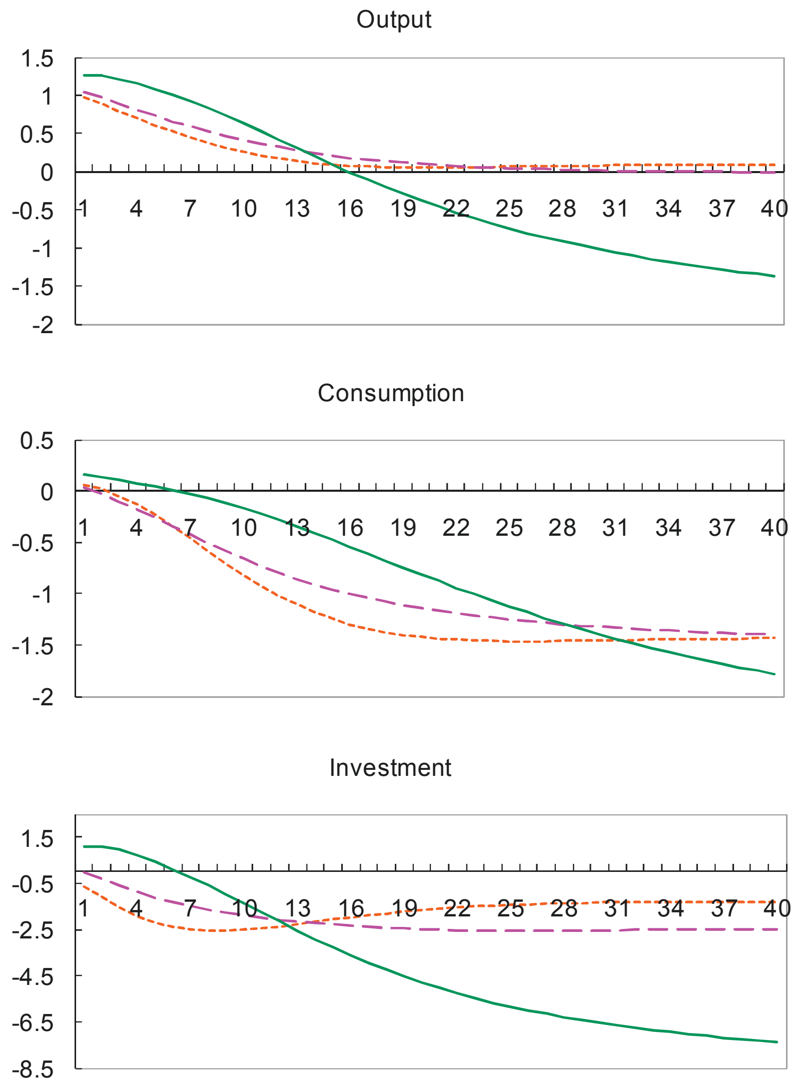


Figure 5: Present-value multipliers for different tax-financing schemes

Notes: Solid lines—capital tax-financing; dashed lines—labor tax-financing; dotted lines—consumption tax-financing.

CHAPTER 3

TWO FISCAL POLICY PUZZLES REVISITED: NEW EVIDENCE AND AN EXPLANATION

3.1 Introduction

Fiscal policy has been gaining renewed attention as a stabilization tool after the Lehman shock, since the zero bound on nominal interest rate has become a binding constraint for monetary policy in major industrial countries. With regard to the consequences of fiscal policy, however, there are two major disagreements between theoretical predictions and empirical evidence on the responses of private consumption and the real exchange rate to a government spending shock. A structural vector autoregressive (VAR) analysis tends to find a *crowding-in* of consumption and a *depreciation* of the real exchange rate after an increase in government spending. However, standard dynamic general equilibrium models predict *crowding-out* of consumption in response to a government spending increase, while the textbook IS–LM models predict a positive response of consumption. In addition, both the international real business cycle (IRBC) models and the new open economy macroeconomics (NOEM) models, as well as traditional Mundell–Fleming IS–LM models, predict an *appreciation* of the real exchange rate.

Whereas the first puzzle concerning the response of consumption to a government spending shock has been well recognized and several theoretical attempts have been made to account for the anomalies in a closed-economy setting,[1] the second puzzle, which concerns the response of the real exchange rate, has received less attention, at least until recently. Kim and Roubini (2008), Monacelli and Perotti (2010), Corsetti et al. (2012a), and Ravn et al. (2012) have documented that government spending shocks in one country depreciate its real exchange rate, based on empirical evidence from VAR models. Since their work has been published, reconciliation between the empirical evidence and theoretical predictions has become an important challenge for fiscal policy analysis in an open economy. Several theoretical approaches have been developed; Monacelli and Perotti (2010), Corsetti et al. (2012a), and Ravn et al. (2012) suggest that models augmented with non-separable preferences over consumption and leisure, "spending reversals," and "deep habits" can generate a depreciation of the real exchange rate in response to a government spending shock, respectively. With regard to empirical testing, however, Ravn et al. (2012) is the only study that estimates the key structural parameters of their models. It is worth noting that these approaches solve the first puzzle and the second puzzle simultaneously. In standard IRBC and NOEM models, the household's optimization problem yields tight link between consump-

[1] It has been shown that positive response of consumption to a government spending increase can be generated in a dynamic general equilibrium model by introducing either of the following: (a) non-Ricardian households (Galí et al. (2007)), (b) non-separable preferences over consumption and leisure (Linnemann (2006); Bilbiie (2009); Bilbiie (2011)), (c) "deep habits" (Ravn et al. (2006)), (d) "spending reversals" (Corsetti et al. (2010)), (e) productive public capital (Linnemann and Schabert (2006)), and (f) Edgeworth complementarity between private consumption and government spending (Bouakez and Rebei (2007)).

tion and the exchange rate. The above-mentioned approaches that study the two fiscal policy puzzles have focused on generating proper directions of the responses of consumption and the exchange rate to a government spending shock relying on the tight link. Thus, timing of the responses has not yet been well considered in the literature so far.

Although the effects of government spending have always been at the center of the policy debate, government spending has been typically modeled as wasteful in most macroeconomic models. In particular, surprisingly very few papers have considered its non-wasteful nature in the context of two fiscal policy puzzles. Linnemann and Schabert (2006) and Bouakez and Rebei (2007) are the early attempts that account for the first puzzle by incorporating productive public capital and Edgeworth complementarity between private consumption and government spending, respectively. While Basu and Kollmann (2013) recently incorporate productive public capital into a two-country model in order to solve the second puzzle, Edgeworth complementarity has not yet been examined in the literature. In this regard, the composition of government spending has also received less attention. The necessity of modeling two different roles of government spending that enters in the utility and production functions has long been recognized (e.g., Barro (1981); Aschauer (1985); Aschauer (1989)). However, there are only few exceptions that distinguish between the roles of government consumption and government investment in a general equilibrium framework (Turnovsky and Fisher

(1995); Finn (1998); Pappa (2009)).

Another limitation of the existing contributions on the two fiscal policy puzzles is that they have focused only on data for Anglo-Saxon countries.[2] It is, however, worth exploring the effects of fiscal expansion on the real exchange rate in the context of Japanese fiscal policy. Japan's current account surplus position is considered to have helped maintain stability in the Japanese Government Bond market, despite the extraordinary high level of government debt. If expansionary fiscal policy appreciates the real exchange rate and leads to a current-account deterioration, its use as a stabilization tool needs to be restrained in light of Japan's current fiscal position. Nonetheless, time-series evidence on the effect of government spending on the real exchange rate has not yet been established for the Japanese data. On the other hand, recent empirical studies based on the Japanese data tend to suggest a non-wasteful nature of government spending. Kawaguchi et al. (2009) find a slight but positive externality of public capital in Japan. Okubo (2003) concludes that the relationship between private and government consumption in Japan is not a substitute, which is consistent with the early findings by Karras (1994).

Against this background, the present chapter seeks to solve the two fiscal policy puzzles in a medium-scale open economy DSGE model estimating parameters governing non-wasteful nature of government spending by using the Japanese

[2] Kim and Roubini (2008), Corsetti et al. (2012a), and Enders et al. (2011) examine the effects of government spending on the real exchange rate using VAR models estimated on data for the U.S., while Monacelli and Perotti (2010) and Ravn et al. (2012) consider data for Australia, Canada, the U.K., and the U.S.

data. In the following, we first estimate a structural VAR model using the same Japanese data as those used to estimate the DSGE model. Then we extend a standard medium-scale open economy model by incorporating non-separability between private and government consumption, and productive public capital. The model is based on the work of Adolfson et al. (2007), which features home bias and debt elastic risk premium. We also incorporate "spending reversals" to the model to examine whether they work with the Japanese data. Following Christiano et al. (2011a), investment-specific technological progress (IST) of Greenwood et al. (1997) is also considered in addition to neutral technological progress for the purpose of facilitating parameter identification.

The impulse responses from the structural VAR model show that the empirical anomalies found in data for Anglo-Saxon countries can be observed in the Japanese data: consumption increases and the real exchange rate depreciates after both government consumption and government investment shocks. The directions of empirical responses can be well replicated by the estimated DSGE model. While the empirical relevance of spending reversals in government investment is confirmed, Edgeworth complementarity and productive public capital are shown to be the main contributory sources for generating responses of consumption and the real exchange rate in the empirically-plausible directions following government consumption and government investment shocks, respectively. In addition, the timing of empirical responses to a government consumption shock is also well addressed. The simulation results reveal that the combination of Edgeworth complementarity, home bias, and debt elastic risk premium allows the model to account for an immediate increase in consumption and for a hump-shaped depreciation of the real exchange rate after a government consumption shock. This result matches the response patterns generated by the structural VAR model.

The chapter is organized as follows: Section 3.2 presents the results of the VAR analysis. Section 3.3 describes the model to be estimated and Section 3.4 reports the estimation results. Section 3.5 investigates the transmission mechanism and Section 3.6 concludes.

3.2 Time-Series Evidence

3.2.1 Data and the Identification Framework

We start our analysis by presenting time-series evidence from the Japanese data. We consider a VAR model that consists of nine variables: government spending, gross domestic product, private consumption, private investment, budget balance, trade balance (all on a per-capita basis), GDP deflator, real effective exchange rate, and short-term interest rates. We use the logarithm for all variables except for interest rates. Two categories of government spending—government consumption and government investment—are considered. Because the VAR analysis aims to provide dynamic properties of the time-series data to assess the empirical performance of the DSGE model to be developed in the next section, the sample period is chosen so as to cover the estimation period of the DSGE model, which starts in 1980:Q1 and ends in 1998:Q4. Nonetheless, because the estimation period of the DSGE model is relatively short, we have conducted the estimation for the period from 1980:Q1 to 2005:Q4 in order to have sufficient length to identify government spending shocks.

Regarding shock identification, we employ the sign restrictions approach proposed by Uhlig (2005).[3] The idea is to require impulse responses to have certain signs, so that the signs are consistent with the principles of macroeconomic theory. Given that the main focus of this chapter is to account for empirical responses to government spending shocks with a DSGE model, this approach is attractive because it is more agnostic than other identification approaches and is firmly grounded in macroeconomic theory. The sign restrictions approach has been applied to identifying fiscal shocks (e.g., Mountford and Uhlig (2009); Pappa (2009)). Among others, Enders et al. (2011) recently provide evidence that government spending depreciates the real exchange rate when this methodology is employed for the U.S. data. Thus, we impose restrictions along the lines of Enders et al. (2011).

Table 1 reports the set of sign restrictions used. The responses of consumption and the real exchange rate to a government spending shock are our main interest, and are therefore unrestricted. In addition, because responses of investment and

[3] An application of the relatively new identification method to Japanese monetary policy can be found in Braun and Shioji (2006).

trade balance depend on the specifications of DSGE models, we also leave the signs of these variables unrestricted. On the other hand, we impose restrictions that a government spending shock increases output, inflation, and interest rate, which are consistent with predictions of a large class of DSGE models. The restriction that an increase in government spending has a negative impact on budget balance is the key identifying restriction that distinguishes a government spending shock from other shocks, such as productivity, or monetary policy shocks. The sign restrictions are imposed for a year after the shock (i.e., $K = 3$), following Mountford and Uhlig (2009). Since our data sets are relatively short, the lag length of the VAR model is limited to three. We employ the same restrictions on responses to a government consumption shock and a government investment shocks. Following Uhlig (2005), we do not include a constant and a time trend in the VAR model where variables are expressed in levels. As a robustness check, we also estimate the model using variables detrended with a linear and quadratic time trend. This is particularly important for the identification of government consumption shocks because government consumption during the estimation period has upward trend reflecting population aging and therefore it could be difficult to identify permanent and transitory shocks separately.

3.2.2 VAR Evidence on Government Spending Shocks with Sign Restrictions

The estimated impulse responses to a one-standard-deviation expansionary government consumption shock are shown in Figures 1.a and 1.b in which variables are expressed in levels and as deviations from a linear and quadratic trend, respectively. Except for the responses of government consumption, Figures 1.a and 1.b show very similar results, indicating that the dynamic effects of permanent and transitory shocks in government consumption on each of the variables do not differ substantially.[4] Both figures suggest that a government consumption shock generates a crowding-in of consumption and a depreciation of the real exchange rate. Note that an increase in the real exchange rate is conventionally expressed as a *depreciation* throughout this chapter. While private consumption increases immediately after the shock contributing to output rise, the real exchange rate shows a hump-shaped pattern of depreciation. Private investment, on the other hand, shows large decline in later periods. Trade balance deteriorates on impact, but the real exchange rate depreciation induces improvement with some delay. The hump-shaped pattern of trade balance improvement is consistent with

[4] Iwata (2012) also obtained similar results to those shown in Figure 1.a by using two different data sets in which the effect of population aging on government consumption is considered to some extent. The first data set is based on 1968 System of National Accounts (SNA) for the period 1973:Q1-1998:Q4 and the second data set is based on 1993 SNA for the period 1980:Q1-2005:Q4. In the former, government consumption that does not include social security benefits in kind as defined in the 1968 SNA is used. In the latter, on the other hand, *actual final consumption* (i.e.,collective consumption expenditure, such as national defense etc.) is used as government consumption because 1993 SNA defines government consumption as that includes social security benefits in kind.

Corsetti et al. (2012a).

Figures 2.a and 2.b show responses to a one-standard-deviation expansionary government investment shock. Very similar results to those of a government consumption shock are obtained. All in all, regardless of the type of government spending, it is confirmed that the empirical anomalies regarding responses of consumption and the real exchange rate to government spending shocks can be observed within the Japanese data. The results suggest that the downside risk of expansionary fiscal policy to Japan's external position may not as big as standard open economy models predict.

3.3 The Model

The structure of the model closely follows Adolfson et al. (2007). Following Barro (1981), we consider two different roles of government spending. Drawing from Finn (1998), government consumption and government investment are assumed to have direct impact on individual utility and production, respectively.

3.3.1 Firms

The competitive domestic final-good firm combines the differentiated goods, $Y_{i,t}$, produced by monopolistically competitive intermediate-good firms $i \in [0, 1]$, using the following bundler technology:

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{1}{\lambda_t^d}} di \right]^{\lambda_t^d}, \quad 1 \leq \lambda_t^d < \infty, \tag{3.1}$$

where λ_t^d is the price markup that follows an exogenous stochastic process. The stochastic process governing the markup shock is presented at the end of this section together with those of other structural shocks that appear below. The production function of each intermediate-good firm is given by:

$$Y_{i,t} = z_t^{1-\alpha} \epsilon_t \tilde{K}_{i,t-1}{}^{\alpha} L_{i,t}{}^{1-\alpha} \left(K_{t-1}^G\right)^{\alpha_g} - z_t^+ \Theta, \tag{3.2}$$

where $\alpha > 0$, $\alpha_g > 0$ and $\alpha + \alpha_g < 1$.[5] $\tilde{K}_{i,t-1}$ is the effective private capital stock at time t given by $\tilde{K}_{i,t-1} = u_{i,t} K_{i,t-1}$. $u_{i,t}$ is the degree of capital utilization. $L_{i,t}$ is the effective labor input bundled by the employment agency (discussed below). Θ represents a fixed cost. ϵ_t is a stationary neutral technology shock. The economy has two sources of growth: a neutral (or equivalently, labor-augmenting) technological progress, represented by a scaling variable, z_t, and a investment-specific technological (IST) progress in the private sector, represented by Ψ_t. The fixed cost is included to ensure that profits of the intermediate-good firms are zero in the steady state, and thus it needs to grow at the same rate as output. Assuming that public capital, K_{t-1}^G, grows at the same rate as output on a balanced growth path, the growth of output can then be represented by a scaling variable:

$$z_t^+ = \Psi_t^{\frac{\alpha}{1-\alpha-\alpha_g}} z_t^{\frac{1-\alpha}{1-\alpha-\alpha_g}}. \tag{3.3}$$

With the exception of labor, L_t, private capital, K_t, and investment, I_t, all the other real variables at the aggregate level grow at the same rate as output, $\mu_{z^+,t} \equiv$

[5] As customary in the literature, the firm is assumed to face constant returns to scale in the two private factors and increasing returns to scale in all three factors of production due to the positive externality of public capital (e.g., Baxter and King (1993); Glomm and Ravikumar (1997); Finn (1998); Turnovsky (2004); Pappa (2009); Leeper et al. (2010b)). The condition, $\alpha + \alpha_g < 1$, is necessary to ensure a stable balanced growth path (Turnovsky (2004)).

z_t^+/z_{t-1}^+. $\mu_{z^+,t}$ follows an exogenous stochastic process. On the other hand, K_t and I_t grow at the same rate, $\mu_{z^+,t}\mu_{\Psi,t}$, where $\mu_{\Psi,t} \equiv \Psi_t/\Psi_{t-1}$. $\mu_{\Psi,t}$ also follows an exogenous stochastic process. With regard to the price setting problem, the staggered price contracts á la Calvo (1983) is assumed. A fraction $1-\xi_d$ of intermediate-good firms can re-optimize their prices, unless otherwise they follow the price indexation scheme: $P_{i,t}^d = \left(\pi_{t-1}^d\right)^{\kappa_d} P_{i,t-1}^d$, where $\pi_{t-1}^d \equiv P_{t-1}^d/P_{t-2}^d$, and κ_d measures the degree of indexation. An intermediate-good firm, which is allowed to re-optimize, knows the probability ξ_d^s that the price it chooses in this period will still be in effect s periods in the future. The optimal price, $P_{i,t}^{d,opt}$, is obtained by maximizing the present discounted value of future profits:

$$\max_{P_{i,t}^d} E_t \sum_{s=0}^{\infty} (\beta\xi_d)^s \left[\begin{array}{c} \left(P_{i,t+s}^d - P_{t+s}^d mc_{t+s}^d\right) \left(\frac{P_{t+s}^d}{P_{i,t+s}^d}\right)^{\frac{\lambda_{t+s}^d}{\lambda_{t+s}^d - 1}} Y_{t+s} \\ -z_{t+s}^+ P_{t+s}^d mc_{t+s}^d \Theta \end{array} \right], \tag{3.4}$$

where β is the discount factor, mc_t^d stands for the real marginal cost that can be obtained from the cost minimization problem subject to the production technology.

There are three types of monopolistically competitive firms other than domestic intermediate-good producing firms: consumption-good importing, investment-good importing, and exporting firms. The importing [exporting] firms buy foreign [domestic] goods at price P_t^* [P_t^d] and convert them into differentiated goods, through a brand naming technology. The differentiated goods are sold to competitive domestic wholesalers of imported consumption goods, imported investment goods, and export goods, respectively. The production functions of the wholesalers are given by:

$$C_t^m = \left[\int_0^1 C_{i,t}^{m\,\frac{1}{\lambda_t^{m,c}}} di\right]^{\lambda_t^{m,c}}, \; I_t^m = \left[\int_0^1 I_{i,t}^{m\,\frac{1}{\lambda_t^{m,i}}} di\right]^{\lambda_t^{m,i}}, \; X_t = \left[\int_0^1 X_{i,t}^{\frac{1}{\lambda_t^x}} di\right]^{\lambda_t^x}, \tag{3.5}$$

where the price markups follow exogenous stochastic processes. The importing and exporting firms are subject to price setting frictions á la Calvo (1983) in an analogous manner to domestic intermediate-good firms. The real marginal cost for these firms are given by $mc_t^{m,c} = S_t P_t^* / P_t^{m,c}$, $mc_t^{m,i} = S_t P_t^* / P_t^{m,i}$, and $mc_t^x = P_t^d / S_t P_t^x$, where S_t denotes the nominal exchange rate. $P_t^{m,c}$, $P_t^{m,i}$, and P_t^x stand for output prices of the wholesalers. Domestic final consumption and investment goods are produced by the competitive retailer combining domestic final goods and imported goods. The production function of the consumption-good retailer is given by:

$$C_t = \left[(1-\omega_c)^{\frac{1}{\eta_c}} \left(C_t^d\right)^{\frac{\eta_c - 1}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}} \left(C_t^m\right)^{\frac{\eta_c - 1}{\eta_c}}\right]^{\frac{\eta_c}{\eta_c - 1}}, \tag{3.6}$$

where C_t^d is domestically produced consumption good and $\omega_c \in [0, 0.5]$ measures the home bias. Following Christiano et al. (2011a), final investment goods, $\tilde{I}_t$ are defined as the sum of investment goods and those used in capital maintenance: $\tilde{I}_t = I_t + a(u_t) K_{t-1}$, where $a(u_t)$ is the cost associated with variations in the degree of capital utilization, u_t. The cost function is assumed to satisfy $a(u) = 0$. $\sigma_a \equiv a^{''}(u)/a^{'}(u)$ is defined for the steady-state rate of capital utilization, $u = 1$.

The production function of the investment-good retailer is given by:

$$\tilde{I}_t = \Psi_t \left[(1-\omega_i)^{\frac{1}{\eta_i}} \left(I_t^d\right)^{\frac{\eta_i - 1}{\eta_i}} + \omega_i^{\frac{1}{\eta_i}} \left(I_t^m\right)^{\frac{\eta_i - 1}{\eta_i}} \right]^{\frac{\eta_i}{\eta i - 1}}. \tag{3.7}$$

where I_t^d is domestically produced investment good and $\omega_i \in [0, 0.5]$ measures the home bias. Foreign demand for exported goods is assumed to satisfy:

$$X_t = \left[\frac{P_t^x}{P_t^*} \right]^{-\eta_f} Y_t^*, \tag{3.8}$$

where Y_t^* is foreign output. It is assumed that an asymmetric technology shock, $\tilde{z}_t^* \equiv z_t^* / z_t^+$, follows an exogenous stochastic process, where z_t^* represents a technological progress in foreign economy.

3.3.2 Households

The utility function of household $j \in [0, 1]$ is given by:

$$E_t \sum_{t=0}^{\infty} \beta^t \left(\begin{array}{c} \zeta_t^c \ln \left(\tilde{C}_{j,t} - h\tilde{C}_{j,t-1} \right) \\ -\zeta_t^l A_L \frac{{L_{j,t}}^{1+\sigma_l}}{1+\sigma_l} + V(G_t^C) \end{array} \right), \tag{3.9}$$

where ζ_t^c and ζ_t^l are preference shocks to consumption and labor supply, respectively. h measures the degree of habit formation in consumption. $\tilde{C}_{j,t}$ is effective consumption defined as $\tilde{C}_t = C_t + \upsilon G_t^C$, where G_t^C is government consumption.[6] Negative [positive] υ indicates that an increase in G_t^C increases [decreases] the

[6] The linear specification employed here is the most commonly used and proposed by Bailey (1971). Examples include, among others, Aschauer (1985), Barro (1989), and Christiano and Eichenbaum (1992). Alternatively, Cobb–Douglas and CES specifications have been employed. Note that the linear and the Cobb–Douglas specifications are special cases of the CES specification (Ni (1995); Fiorito and Kollintzas (2004)).

marginal utility of C_t, implying complementarity [substitutability] between C_t and G_t^C. A function $V(G_t^C)$ which satisfies $V^{'}(\cdot) > 0$ is added to ensure positive marginal utility with respect to G_t^C even when υ takes a negative value, following Karras (1994) and Ganelli and Tervala (2009). The household faces a flow budget constraint:

$$\begin{aligned}&(1+\tau^c) P_t^c C_{j,t} + P_t^i \tilde{I}_{j,t} + B_{j,t} + S_t B_{j,t}^* \\ &= \left(1-\tau^l\right) W_{j,t} L_{j,t} + \left(1-\tau^k\right) R_t^k u_{j,t} K_{j,t-1} + \tau^k P_t^i a\left(u_{j,t}\right) K_{j,t-1} \\ &+ \left(1-\tau^k\right) D_{j,t} + R_{t-1} B_{j,t-1} + \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) R_{t-1}^* S_t B_{j,t-1}^*, \end{aligned} \tag{3.10}$$

where P_t^c and P_t^i are output prices of final consumption and investment goods. $B_{j,t}$ and $B_{j,t}^*$ denote domestic government bonds denominated in domestic currency and international bonds denominated in foreign currency, respectively. R_{t-1} and R_{t-1}^* represent each riskless return. $D_{j,t}$ denotes the sum of nominal dividends distributed by domestic intermediate-good producing, consumption-good importing, investment-good importing, and exporting firms to the household. $W_{j,t}$ and R_t^k are nominal wage income and rental rate of capital. τ^c, τ^l, and τ^k represent tax rates on consumption, labor income, and capital income, respectively. $\Phi(\cdot)$ represents a risk premium on international bond holdings, which is assumed to have the following functional form:

$$\Phi\left(a_t, \tilde{\phi}_t\right) = \exp\left(-\tilde{\phi}_a\left(a_t - a\right) + \tilde{\phi}_t\right), \tag{3.11}$$

where $\tilde{\phi}_a$ is a positive parameter and $\tilde{\phi}_t$ is a risk premium shock. $a_t = A_t/z_t^+$ stands for a real aggregate net foreign asset position in scaled form, where $A_t \equiv S_t B_t^* / P_t^d$. It is assumed that $a = 0$, $\Phi(0,0) = 1$ in the steady state. The inclusion of debt elastic risk premium ensures that the model has a unique steady state that is independent of initial conditions. Following Adolfson et al. (2007), the real exchange rate is defined as $rex_t \equiv S_t P_t^* / P_t^c$.[7] Note that transfers (i.e., social benefits other than social transfers in-kind) are not considered here, because transfers would have no effect on consumption in an infinitely-lived representative agent model (Coenen et al. (2012)). The physical capital accumulation law for the household is expressed as:

$$K_{j,t} = (1-\delta)K_{j,t-1} + \zeta_t^i \left[1 - S\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right] I_{j,t}, \tag{3.12}$$

where δ is the depreciation rate, ζ_t^i is a shock to investment cost function, and $S(\cdot)$ represents the adjustment cost function in investment. In the steady state, the cost function is assumed to satisfy $S(1) = S'(1) = 0$ and $S''(1) \equiv 1/\chi > 0$.

An independent and perfectly competitive employment agency bundles differentiated labor into a single type of effective labor input, using the following technology:

$$L_t = \left[\int_0^1 L_{j,t}^{\frac{1}{\lambda_w}} dj\right]^{\lambda_w}, \tag{3.13}$$

[7] Because our model does not make distinction between prices of imported consumption and investment goods, the definition can be interpreted as that of the CPI-based real exchange rate. It should be noted that the literature on the "second" fiscal policy puzzle finds a depreciation of the CPI-based real exchange rate in response to government spending shocks (e.g., Monacelli and Perotti (2010); Corsetti et al. (2012a); Ravn et al. (2012)). Notice also that the foreign price is exogenously given due to the small open economy assumption.

where λ_w is the wage markup. The household j sets its nominal wage according to a variant of Calvo-style sticky price mechanism. A fraction $1-\xi_w$ of households can re-optimize their wages, unless otherwise they follow the price indexation scheme: $W_{j,t} = \left(\pi^c_{t-1}\right)^{\kappa_w} W_{j,t-1}$, where $\pi^c_{t-1} \equiv P^c_{t-1}/P^c_{t-2}$. The optimal wage, $W^{opt}_{j,t}$, is obtained by solving the following problem:

$$\max_{W_{j,t}} E_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left[\begin{array}{c} \zeta^c_{t+s} \ln\left(\tilde{C}_{j,t+s} - h\tilde{C}_{j,t+s-1}\right) \\ -A_L \frac{\zeta^l_{t+s}}{1+\sigma_l} \left(\left(\frac{W_{j,t+s}}{W_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}} L_{t+s}\right)^{1+\sigma_l} \end{array} \right], \tag{3.14}$$

subject to the households' budget constraint.

3.3.3 Fiscal and Monetary Authorities

The flow budget constraint for the fiscal authority is expressed as follows:

$$\begin{aligned} & P^d_t G^C_t + P^d_t G^I_t + R_{t-1} B_{t-1} \\ & = \tau^c P^c_t C_t + \tau^l W_t L_t + \tau^k R^k_t u_t K_{t-1} - \tau^k P^i_t a\left(u_t\right) K_{t-1} + \tau^k D_t + B_t, \end{aligned} \tag{3.15}$$

where G^I_t denotes government investment. The stock of public capital, which is accumulated by government investment, evolves in a manner analogous to the law of motion of the private capital stock. Its depreciation rate, δ_g, adjustment cost function, $S^g(\cdot)$, and shock to the cost function, ζ^{gi}_t, is formulated in a similar way. The time paths of stationarized government consumption, $g^c_t = G^C_t/z^+_t$, and government investment, $g^i_t = G^I_t/z^+_t$, are described by the log-linear feedback rules below:

$$\hat{g}^c_t = \rho_{gc}\hat{g}^c_{t-1} + \left(1-\rho_{gc}\right)\phi_{gc}\hat{b}_{t-1} + \varepsilon^{gc}_t, \tag{3.16}$$

$$\hat{g}_t^i = \rho_{gi}\hat{g}_{t-1}^i + \left(1-\rho_{gi}\right)\phi_{gi}\hat{b}_{t-1} + \varepsilon_t^{gi}, \tag{3.17}$$

where i.i.d.-normal shocks $\varepsilon_t^{gc}$and ε_t^{gi} are assumed. Note that variables marked with a hat denote percent deviations from their steady states. If ϕ_{gc} $[\phi_{gi}] < 0$, government consumption [government investment] follows a debt-stabilizing spending rule called "spending reversals" (Corsetti et al. (2012a)). Because all tax rates are assumed to be time-invariant, at least one of ϕ_{gc} and ϕ_{gi} needs to be negative in order to prevent government debt from exploding.

The monetary authority sets nominal interest rates according to a simple feedback rule in log-linearized form:

$$\hat{R}_t = \rho_r\hat{R}_{t-1} + (1-\rho_r)\,\phi_{r\pi}\hat{\pi}_{t-1}^c + (1-\rho_r)\,\phi_{ry}\hat{y}_t + \varepsilon_t^R, \tag{3.18}$$

where $y_t \equiv Y_t/z_t^+$, and an i.i.d.-normal shock to the interest rate, ε_t^R, is assumed.

3.3.4 Market Clearing Conditions, Foreign Economy, and Structural Shocks

The aggregate resource constraint is given by:

$$C_t^d + I_t^d + G_t^C + G_t^I + X_t = \epsilon_t\left(u_t K_{t-1}\right)^{\alpha} {L_t}^{1-\alpha}\left(K_{t-1}^G\right)^{\alpha_g} - z_t^+\Theta. \tag{3.19}$$

The domestic economy's net foreign assets evolve according to:

$$S_t P_t^x X_t - S_t P_t^*\left(C_t^m + I_t^m\right) = S_t B_t^* - \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) R_{t-1}^* S_t B_{t-1}^*. \tag{3.20}$$

Following Adolfson et al. (2007), foreign inflation, output, and interest rate are assumed to be exogenously given. The foreign economy is modeled as a structural

VAR model:

$$F_0 X_t^* = F(L) X_{t-1}^* + \varepsilon_t^{x^*}, \tag{3.21}$$

where $X_t^* \equiv \begin{bmatrix} \ln \pi_t^* & \Delta \ln Y_t^* & \Delta R_t^* \end{bmatrix}'$, $\pi_t^* \equiv P_t^*/P_{t-1}^*$, and Δ denotes the temporal difference operator. Prior to the Bayesian estimation of the model, the structural VAR model for the foreign economy is estimated assuming that F_0 has a following structure:

$$F_0 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\gamma_\pi^* & -\gamma_y^* & 1 \end{bmatrix}. \tag{3.22}$$

The structural shocks of the model are all assumed to follow a first-order autoregressive process with an i.i.d.-normal error term: $\hat{\zeta}_t = \rho_\zeta \hat{\zeta}_{t-1} + \varepsilon_{\zeta,t}$, where $\zeta_t = \{\lambda_t^d, \lambda_t^{m,c}, \lambda_t^{m,i}, \lambda_t^x, \epsilon_t, \zeta_t^c, \zeta_t^l, \zeta_t^i, \zeta_t^{gi}, \mu_{z^+,t}, \mu_{\Psi,t}, \tilde{z}_t^*\}$.

3.4 Non-Wasteful Government Spending in Open Economies

3.4.1 Bayesian Estimation and Model Implications

In estimating the model parameters, we first log-linearize the model around the deterministic steady state and conduct Bayesian inference using the Markov Chain Monte Carlo (MCMC) method. The log-linearized version of the model is presented in Appendix C. The pre-estimated parameters of the structural VAR model for the foreign economy are kept fixed throughout the Bayesian estimation as in Adolfson et al. (2007). The parameters are estimated on the Japanese data covering the period from 1980:Q1 to 1998:Q4.[8] In the estimation, we use the following 18 variables: government consumption, government investment, gross domestic product, private consumption, private investment, imports, exports, labor hours, real wage (all on a per-capita basis), GDP deflator, consumption deflator, investment deflator, exports deflator, real effective exchange rate, short-term interest rates, foreign output, foreign inflation rate, and foreign interest rates.[9] Private consumption is defined as personal consumption expenditures on non-durables and services, while private investment is the sum of personal consumption expenditures on durables and gross private domestic investment. We take logs and first differences except for interest rates and inflation rates, respectively.[10] Calibrated parameter and steady-state values are summarized in Table 2.

Table 3 reports prior distributions, posterior means, and 90%-credible intervals (or Bayesian confidence intervals) of the parameters for the benchmark model (labeled M1). Most parameters are well identified, but some are not.[11] Overall,

[8] As in Hirose (2008), the end of the estimation period is determined so that it does not include the zero interest rate period in Japan. The zero lower bound on interest rates requires us to deal with two difficult problems in a DSGE framework: non-linearity and indeterminacy (e.g., Braun and Waki (2006)).

[9] The domestic series are obtained from the Cabinet Office and the Bank of Japan. The foreign output and prices series are calculated as a weighted average index of, respectively, the GDP and GDP deflator series for Japan's major trading partners: the U.S., Germany, Korea, Taiwan, Hong Kong, and China. Data used in the calculation are derived from Japan External Trade Organization, International Financial Statistics of the IMF, and the Taiwan Statistical Bureau. The Fed fund rate, taken from the FRED database, is used as a proxy for the foreign interest rate.

[10] Because the variables grow at substantially different rates, I remove the mean from each of the time series as in Christiano et al. (2011a). Similarly to Adolfson et al. (2007) and Christiano et al. (2011a), I allow for measurement errors, except for interest rates. The measurement equations that link the model to data are reported in Appendix C, where $\varepsilon^{me}_{V,t}$ denotes measurement errors for variables V. The standard deviations of the measurement errors are calibrated so that they correspond to 30% of the variance of each data series.

[11] Poor identifiability can be found especially in parameters related to shocks to government investment cost function and those to the asymmetry between the technological progress in domestic and foreign economies.

posterior mean estimates of structural parameters, such as habit persistency, are not very different from those reported in previous studies.[12] With regard to the parameters of our interest, the estimated mean value of ν is -0.42 in favor of Edgeworth complementarity. The results indicate that the relationship between private and government consumption may be complementary, which is consistent with the findings of Karras (1994) and Okubo (2003). The estimated mean value of α_g is 0.05, which is in between the OLS estimate by Kawaguchi et al. (2009) and the official estimate by the Cabinet Office.[13] "Spending reversals" are observed for government investment, whereas hardly observed for government consumption.

To explore the importance of non-wasteful nature of government spending in estimating DSGE models, we also estimate the model imposing restrictions on the parameters, ν and α_g. In addition to the benchmark model without restrictions ($\alpha_g \neq 0$, $\nu \neq 0$), we estimate a model in which α_g is constrained to zero ($\alpha_g = 0$, $\nu \neq 0$) (labeled M2); a model in which ν is constrained to zero ($\alpha_g \neq 0$, $\nu = 0$) (labeled M3); a "plain vanilla" model in which α_g and ν are both constrained to zero ($\alpha_g = 0$, $\nu = 0$) (labeled M4). The estimated posterior means of these model are reported in Table 4, which shows that the estimates are stable across different specifications. With regard to the evaluation and comparison of the models, Table

[12] Although the estimated mean value of the elasticity of a risk premium to net foreign asset position is quite large compared with those used in the standard calibration, Adolfson et al. (2007) also report large posterior mean estimate ($\tilde{\phi}_a = 0.252$). Christiano et al. (2011a), on the other hand, employ a different functional form, in which risk premium is assumed to depend not only on net foreign asset position but also on the relative level of the interest rate, $R_t^* - R_t$. While calibrating $\tilde{\phi}_a = 0.01$, they obtain 1.096 as the mean estimate of the elasticity of a risk premium to the relative level of the interest rate.

[13] See the *Annual Report on the Japanese Economy and Public Finance 2010.*

5 reports log-marginal data densities and posterior odds for alternative specifications. The likelihood seems to speak in favor of the models with non-wasteful government spending, especially with Edgeworth complementarity.

Before investigating the role of these parameters in response to government spending shocks, it is worth discussing the estimation results for Edgeworth complementarity. Although recent studies tend to find complementarity,[14] government spending has long been considered as a substitute for private consumption. This is partly because the most commonly used linear specification of effective consumption seems to imply that private consumption and government spending are substitutes. If an increasing function of government consumption ($V(G_t^C)$ in our model) is absent from the utility function, private and government consumption need to be substitutes to satisfy the standard assumption that they are both utility enhancing.[15] From an empirical point of view, the composition of government spending would be a more important issue to be addressed. Whereas Aschauer (1985) find substitutability between private consumption and overall government spending, Karras (1994), Evans and Karras (1996), and Okubo (2003) find complementarity by considering only government consumption.[16] Fiorito and Kollintzas

[14] See Karras (1994), Evans and Karras (1996), Okubo (2003), Fiorito and Kollintzas (2004), Bouakez and Rebei (2007), Mazraani (2010), and Fève et al. (2013).

[15] The seemingly restrictive nature of the linear specification is discussed in Karras (1994), Ni (1995), Turnovsky and Fisher (1995), and Fiorito and Kollintzas (2004). In fact, earlier works by Barro (1989) and Christiano and Eichenbaum (1992), which add an increasing function of government spending, similar to that in Karras (1994), assume substitutability between private consumption and government spending.

[16] Mazraani (2010) reports that the degree of complementarity between private and government consumption is stronger than that between private and public capital. On the other hand, Bouakez and Rebei (2007) and Fève et al. (2013) find complementarity by considering government spending that includes government investment.

(2004) further divide government consumption into two groups: "public goods" and "merit goods." The former category consists of general public service, national defense, and public order and safety. The latter contains health, education, and other social expenditures. Their estimates for 12 European countries reveal that public goods substitute while merit goods complement private consumption. Therefore, they conclude that private and government consumption are complements in aggregate because the merit goods account for two-thirds of government consumption. Their study provides a useful perspective to consider the relationship between private and government consumption in Japan. Japan's public good component for fiscal years 1980–1998 explains only 22.8% of government consumption on average, which is much lower than 32.3%, the sample average calculated from data used in Fiorito and Kollintzas (2004). One notable feature of government consumption in Japan is that its largest share goes to health care spending. The health component, which explains 30.9% of government consumption for the above mentioned period, may be an important driver of the observed complementarity between private and government consumption in Japan. For instance, the national health care system in Japan requires the insured individual to pay a certain portion of the health care costs. Therefore, health care benefits provided in-kind by the government (classified as government consumption) is always accompanied by its co-payment from households (classified as private consumption). The importance of a health component as a factor determining the relationship between private and government consumption will increase in the near future, because the aging population in Japan contributes to the growing government consumption through health care (benefits in-kind), as pointed out by McNelis and Yoshino (2012).

3.4.2 Impulse Responses to Government Spending Shocks

Figure 3 illustrates the selected dynamic responses to a government consumption shock equal to one percent of the steady-state output in M1 and M4. For comparison purposes and to quantify the importance of the parameters that govern Edgeworth complementarity (EC) and productive public capital (PPC), all parameter values are calibrated to the estimated means of the posterior distributions in the following exercise. Each dynamic response is depicted as a percentage deviation from the steady state and hence can be interpreted as the *impact multiplier*. Because the transmission mechanism of a government consumption shock is substantially affected by the parameter ν, the models with $\nu = -0.42$ (i.e., M1 and M2) show quite similar patterns in dynamic responses. For the same reason, the models with $\nu = 0$ (i.e., M3 and M4) show quite similar patterns. Therefore, the responses in M2 and M3 are omitted here. The model with EC (i.e., M1) delivers immediate increases in consumption after a government consumption shock. The output multiplier exceeds 1.2 on impact because of the sharp rise in consumption. The real exchange rate appreciates initially, but depreciates in later periods.

Regarding trade balance, the crowding-in of consumption induces increases in imports and therefore the model with EC shows the "twin deficits" phenomenon in initial periods after the shock. In later periods, however, the real exchange rate depreciation improves the trade balance. The hump-shaped responses of the real exchange rate and trade balance are consistent with the VAR evidence shown in Section 3.2. In contrast, the model without EC (i.e., M4) delivers crowding-out of consumption. The real exchange rate appreciates to a large extent initially, and goes back to its trend level showing a very slight depreciation in later periods.

Figure 4 illustrates the selected dynamic responses to a government investment shock equal to one percent of the steady-state output in M1 and M4. The models with $\alpha_g = 0.05$ (i.e., M1 and M3) and those with $\alpha_g = 0$ (i.e., M2 and M4) show quite similar patterns in dynamic responses, respectively. Therefore, the responses in M2 and M3 are omitted as in Figure 3. The model with PPC (i.e., M1) delivers declines in consumption and an appreciation of the exchange rate in initial periods after a government investment shock. However, a crowding-in of consumption and a depreciation of the real exchange rate occur in later periods as the new public capital is put in place. The positive externality of public capital increases private investment and accordingly, private consumption. The output multiplier is close to one on impact. It is smaller than that the model with EC exhibits in response to a government consumption shock, but it declines more slowly reflecting the increases in investment and consumption in later periods. Although the model with PPC delivers the crowding-in of consumption, it does not show the "twin deficits" phenomenon after a government investment shock because the crowding-in occurs only in later periods and to a small extent. The difficulty with this type of evidence is the movements in private consumption and investment. The VAR evidence shows immediate rise in consumption after a government consumption shock; however, the model with PPC predicts a crowding-in of consumption only in later periods. In addition, the model delivers a hump-shaped increase in investment, which can not be observed in the VAR evidence. Although the degree of a real exchange rate depreciation generated by PPC after a government investment shock is not so different from the one generated by EC after a government consumption shock, the trade balance does not show a clear improvement in later periods because of the hump-shaped increase in consumption and investment. The model without PPC (i.e., M4), on the other hand, delivers crowding-out of consumption. The real exchange rate appreciates to a large extent initially, and goes back to its trend level showing a very slight depreciation in later periods.

3.5 Transmission Mechanism

3.5.1 Link between Consumption and Real Exchange Rate

We now turn to investigate the transmission mechanism underlying the responses of the estimated model to government spending shocks. It can be shown that the first-order conditions for the households with respect to consumption and international bond holdings (or international financial transactions) yield an equation that illustrates a tight link between the expected growth rate in marginal utility of consumption and that of the real exchange rate. Other things being equal, the resulting equation predicts an appreciation of the real exchange rate when consumption decreases.[17] Accordingly, the real exchange rate tends to appreciate after a government spending shock in standard open economy models, because consumption is typically crowded-out in response to a rise in government spending. Intuitively, international financial markets allow households to import when its marginal utility of consumption increases following the crowding-out of consumption caused by a government spending shock. The real exchange rate adjusts to accommodate the international transaction. Therefore, crowding-out of consumption is always accompanied by an appreciation of the real exchange rate. This is why the solutions to the first puzzle basically solve the second puzzle.[18]

Consider now the transmission of government spending shocks in the benchmark model (M1). The model is augmented with three features that help cause

[17] If we assume the world economy as that made up with a continuum of small open economies with complete asset markets along the lines of Monacelli and Perotti (2010), we can obtain the *international risk sharing condition* that ensures a positive correlation between relative consumption across countries and the real exchange rate in levels using the symmetric first order conditions for domestic and foreign households. Monacelli and Perotti (2010) argue that rest-of-the world consumption is exogenous to domestic government spending shocks in their small open economy framework and that the change of their model assumption to a two-country structure with incomplete asset market does not generate quantitative differences. It has been well known that the assumption of asset market incompleteness alone cannot eliminate the tight link between relative consumption and the real exchange rate quantitatively since the work of Chari et al. (2002).

[18] The only exception is inclusion of non-Ricardian households. Because non-Ricardian households do not have access to asset markets, their consumption behaviors are irrelevant to the real exchange rate dynamics.

a crowding-in of consumption in response to a government spending shock: EC, PPC, and "spending reversals" in government investment. These features also contribute to a depreciation of the real exchange rate, in accordance with the relationship between consumption and the real exchange rate stated above. In the presence of EC, an increase in government consumption raises the marginal utility of private consumption. When the increase in marginal utility is strong enough to offset the negative wealth effects caused by an increase in government consumption, private consumption increases and accordingly the real exchange rate depreciates. In the presence of PPC, on the other hand, an increase in public capital shifts up the marginal product schedule for private investment. This leads to an increase in output, which, in turn, increases consumption in later periods. In addition, spending reversals observed in a government investment rule also help cause an increase in output, because future reduction in government spending below trend level entails positive wealth effects.

Spending reversals, however, do not play a central role in generating a crowding-in of consumption and a depreciation of the real exchange rate in the benchmark model. Recall that the "plain vanilla" model augmented with spending reversals (M4) delivers crowding-out of consumption and only a very slight depreciation of the real exchange rate in later periods in response to both types of government spending shocks. It follows that EC and PPC are the main sources for replicating the empirical responses of consumption and the real exchange rate to government spending shocks in the benchmark model.

3.5.2 The Role of Home Bias and Debt Elastic Risk Premium

A co-movements between consumption and the real exchange rate is theoretically predicted, however, the benchmark model shows an immediate increase in consumption and a hump-shaped depreciation of the real exchange rate after a government consumption shock as can be seen in Figure 3. To understand the exchange rate movements after a government consumption shock in the benchmark model, we first consider the role of *home bias*. International financial transactions cause a depreciation of the real exchange rate when the marginal utility of consumption decreases, following a crowding-in of consumption. However, home bias in private spending moves the real exchange rate in the opposite direction. In the presence of home bias, a crowding-in of consumption contributes to an increase in domestic price of domestically produced goods relative to that of foreign produced goods, leading to an appreciation of the real exchange rate. In order to obtain some intuition for the effects of home bias, we examine the sensitivity of the responses to a government consumption shock, by considering a case without home bias ($\omega_c = \omega_i = 0.5$). Figure 5 shows responses of the real exchange rate and trade balance to a government consumption shock without home bias. Without home bias, the real exchange rate depreciates in initial periods after a government consumption shock and the trade balance shows improvement with a lag. This implies that the presence of home bias prevents the initial depreciation caused by EC.

Next, we consider the role of *debt elastic risk premium* to investigate the mechanism underlying the hump-shaped depreciation of the real exchange rate. Due to the assumption of debt elastic risk premium, the uncovered interest rate parity (UIP) condition obtained from the first-order conditions for the households with respect to domestic and international bond holdings contains a risk premium term, which may hamper the co-movements between consumption and the real exchange rate. Figure 6 shows responses of the real exchange rate and trade balance to a government consumption shock for a case in which risk premium elasticity of debt is very low ($\tilde{\phi}_a = 0.001$).[19] The hump-shaped real exchange rate depreciation after a government consumption shock disappears and the trade balance does not turn into surplus in this case. While an initial sharp rise in private consumption after a government consumption shock caused by EC is not large enough to generate the real exchange rate depreciation in the presence of home bias, the consumption increase leads to deterioration in net foreign asset position, as shown in Figure 7. The deterioration in net foreign asset position, in turn, increases the risk premium over the international interest rate, thereby depreciating the real exchange rate. On the other hand, a government investment shock does not stimulate consumption on impact, and hence the net foreign asset position does not show sharp

[19] Without the debt elastic risk premium, the equilibrium dynamics would have a random walk property. See Schmitt-Grohé and Uribe (2003) for further details.

deterioration, indicating that the effects of a government investment shock on the real exchange rate through the risk premium channel are limited.

In a nutshell, EC causes an initial rise in consumption and a deterioration in the net foreign asset position in response to a government consumption shock. The presence of home bias prevents the initial depreciation of the real exchange rate, but debt elastic risk premium helps cause depreciation of the real exchange rate in later periods. The depreciation reflects a deterioration in the net foreign asset position.

3.6 Conclusion

This chapter has investigated the two fiscal policy puzzles, the anomaly between the standard model predictions and the VAR evidence, and proposes a new but simple approach. First, we present new VAR evidence from Japan on the responses of consumption and the real exchange rate to government consumption and government investment shocks by employing the sign restrictions approach. In accordance with the results of previous studies on Anglo-Saxon countries, the VAR analysis shows evidence against standard model predictions; consumption increases and the real exchange rate depreciates after both government spending shocks. Although the "twin deficits" phenomenon appears on impact, the trade balance is likely to improve as the real exchange rate depreciates. This implies that the downside risk of expansionary fiscal policy to Japan's external position may not as big as standard open economy models predict. Second, we have estimated a medium-scale open economy DSGE model introducing (i) non-separability between private and government consumption and (ii) productive public capital, to explain the two puzzles. Using the recently flourishing Bayesian method, we estimate four specifications of the model with and without zero restrictions on the key structural parameters that govern Edgeworth complementarity between private and government consumption, and productive public capital. The posterior odds favor inclusion of non-wasteful nature of government spending, especially the Edgeworth complementarity. Third, we have shown that the estimated model delivers a crowding-in of consumption and a real exchange rate depreciation after government spending shocks, in line with the empirical evidence obtained from the VAR analysis. The model also replicates the trade balance improvement in later periods due to the real exchange rate depreciation. While the empirical relevance of spending reversals in government investment is confirmed, their presence does not allow the model to account for the two fiscal policy puzzles. Edgeworth complementarity and productive public capital are shown to be the main contributory sources for generating responses of consumption and the real exchange rate in the empirically-plausible directions following government consumption and government investment shocks, respectively.

Furthermore, it should be worth noting that the Edgeworth complementarity also does a good job in explaining the timing of the responses of consumption and the real exchange rate to a government consumption shock with the estimated model. The existing studies have implicitly relied on the tight link between consumption and the real exchange rate to solve the two fiscal policy puzzles. Therefore timing of the responses has not yet been well addressed in these studies. This chapter also shows that the combination of Edgeworth complementarity, home bias, and debt elastic risk premium allows the model to explain the timing of responses of consumption and the real exchange rate to a government consumption shock. On the other hand, the model fails to explain the timing of an increase in consumption after a government investment shock. While the hump-shaped depreciation of the real exchange rate is consistent with the VAR evidence, a corresponding hump-shaped increase in consumption cannot be observed. Thus, a priority for future research should be to develop a model that replicate the empirical response of consumption to a government investment shock.

3.7 Tables and Figures

Table 1: Set of imposed sign restrictions

	Sign restrictions
Government spending	+
Output	+
Private consumption	?
Private investment	?
Budget balance	−
Trade balance	?
Inflation	+
Interest rate	+
Real exchange rate	?

Notes: This table reports signs imposed on the impulse responses of the variables to a expansionary government spending (either government consumption or government investment) shock. The question mark (?) indicates that the responses of the variables are unrestricted. A positive sign (+) [negative sign (-)] indicates the response of the variables are restricted to be positive [negative] for four quarters (including the initial quarter).

Table 2: Calibrated parameter and steady-state values

Parameter	value	Steady-state rate/ratio	value
β	0.995	μ_{z^+}	1.005
δ	0.06	μ_{Ψ}	1.003
δ_g	0.108	τ^c	0.076
θ ($\equiv 1+\Theta/y$)	1.9	τ^l	0.309
λ^w	1.05	τ^k	0.446
κ_w	0.2	g^c/c	0.283
ω_c	0.35	k^g/c	2.027
ω_i	0.33	b/y	0.6

Table 3: Estimation results

Benchmark model — M1 ($\alpha_g \neq 0, \nu \neq 0$)						
	Prior			Posterior		
Parameters	Distribution	Mean	S. D.	Mean	90% interval	
ξ_w	beta	0.6	0.1	0.387	[0.275	0.499]
ξ_d	beta	0.6	0.1	0.656	[0.578	0.736]
$\xi_{m,c}$	beta	0.6	0.1	0.827	[0.778	0.876]
$\xi_{m,i}$	beta	0.6	0.1	0.931	[0.895	0.966]
ξ_x	beta	0.6	0.1	0.780	[0.709	0.855]
κ_d	beta	0.4	0.15	0.243	[0.072	0.407]
$\kappa_{m,c}$	beta	0.4	0.15	0.201	[0.049	0.342]
$\kappa_{m,i}$	beta	0.4	0.15	0.320	[0.082	0.544]
κ_x	beta	0.4	0.15	0.209	[0.060	0.356]
h	beta	0.7	0.1	0.436	[0.306	0.566]
σ_l	gamma	2	0.75	1.060	[0.483	1.600]
ν	normal	0.1	1.5	-0.415	[-1.281	0.453]
η_c	inv. gamma	1.5	0.25	1.315	[1.071	1.558]
η_i	inv. gamma	1.5	0.25	1.561	[1.089	1.996]
η_f	inv. gamma	1.5	0.25	2.039	[1.624	2.450]
σ_a	gamma	1	0.75	2.306	[1.071	3.478]
χ	normal	0.2	0.1	0.123	[0.040	0.202]
α	beta	0.2	0.05	0.265	[0.190	0.336]
α_g	beta	0.2	0.1	0.046	[0.009	0.079]
ρ_{λ_d}	beta	0.8	0.1	0.877	[0.790	0.968]
$\rho_{\lambda^{m,c}}$	beta	0.8	0.1	0.423	[0.283	0.567]
$\rho_{\lambda^{m,i}}$	beta	0.8	0.1	0.549	[0.357	0.740]
ρ_{λ_x}	beta	0.8	0.1	0.755	[0.608	0.912]
ρ_ϵ	beta	0.8	0.1	0.877	[0.746	0.984]
ρ_{ζ^c}	beta	0.8	0.1	0.810	[0.688	0.945]
ρ_{ζ^l}	beta	0.8	0.1	0.308	[0.183	0.436]
ρ_{ζ^i}	beta	0.8	0.1	0.954	[0.922	0.987]
$\rho_{\zeta^{gi}}$	beta	0.8	0.1	0.800	[0.650	0.957]
$\rho_{\mu_{z^+}}$	beta	0.6	0.1	0.559	[0.403	0.723]
ρ_{μ_Ψ}	beta	0.6	0.1	0.436	[0.289	0.581]
$\rho_{\tilde{z}^*}$	beta	0.6	0.1	0.598	[0.438	0.764]
ρ_{gc}	beta	0.8	0.1	0.776	[0.606	0.948]
ρ_{gi}	beta	0.8	0.1	0.761	[0.579	0.947]
ρ_r	beta	0.8	0.1	0.856	[0.814	0.898]
$\tilde{\phi}_a$	normal	0.2	0.1	0.495	[0.374	0.612]
ϕ_{gc}	normal	-0.2	0.1	0.023	[-0.045	0.088]
ϕ_{gi}	normal	-0.2	0.1	-0.127	[-0.238	-0.038]
$\phi_{r\pi}$	gamma	2	0.5	1.951	[1.515	2.345]
ϕ_{ry}	gamma	0.125	0.05	0.046	[0.015	0.076]

Notes: This table reports prior distributions, posterior means, and 90% credible intervals (or Bayesian confidence intervals) of the parameters. In conducting Bayesian MCMC estimation, the draws from the posterior distribution have been obtained by taking two parallel chains of 300,000 replications for Metropolis-Hastings algorithm.

Table 4: Posterior mean estimates under different types of parameter restrictions

Parameters	M2 ($\alpha_g = 0, \nu \neq 0$)	M3 ($\alpha_g \neq 0, \nu = 0$)	M4 ($\alpha_g = 0, \nu = 0$)
		Posterior Mean	
ξ_w	0.410	0.395	0.401
ξ_d	0.661	0.655	0.660
$\xi_{m,c}$	0.827	0.828	0.826
$\xi_{m,i}$	0.930	0.931	0.930
ξ_x	0.775	0.781	0.776
κ_d	0.247	0.244	0.243
$\kappa_{m,c}$	0.205	0.204	0.199
$\kappa_{m,i}$	0.314	0.324	0.322
κ_x	0.212	0.214	0.217
h	0.442	0.470	0.468
σ_l	1.125	1.024	1.049
ν	-0.424	-	-
η_c	1.308	1.313	1.309
η_i	1.575	1.550	1.565
η_f	2.049	2.041	2.055
σ_a	2.259	2.300	2.295
χ	0.118	0.121	0.115
α	0.267	0.266	0.268
α_g	-	0.045	-
ρ_{λ_d}	0.873	0.870	0.873
$\rho_{\lambda^{m,c}}$	0.416	0.425	0.421
$\rho_{\lambda^{m,i}}$	0.550	0.555	0.553
ρ_{λ_x}	0.760	0.757	0.757
ρ_ϵ	0.876	0.869	0.869
ρ_{ζ^c}	0.793	0.811	0.804
ρ_{ζ^l}	0.301	0.316	0.316
ρ_{ζ^i}	0.957	0.954	0.954
$\rho_{\zeta^{gi}}$	0.806	0.799	0.803
$\rho_{\mu_{z+}}$	0.554	0.558	0.555
ρ_{μ_Ψ}	0.442	0.434	0.439
$\rho_{\tilde{z}^*}$	0.600	0.599	0.601
ρ_{gc}	0.770	0.776	0.775
ρ_{gi}	0.760	0.763	0.758
ρ_r	0.858	0.857	0.857
$\tilde{\phi}_a$	0.481	0.490	0.479
ϕ_{gc}	0.031	0.011	0.018
ϕ_{gi}	-0.125	-0.134	-0.135
$\phi_{r\pi}$	1.972	1.953	1.953
ϕ_{ry}	0.049	0.038	0.040

Notes: This table reports posterior mean estimates of parameters in models under different types of restriction on parameters that govern productivity of public capital (α_g) and non-separability between private and public consumption (ν) in their estimation. Parameters of these models are estimated using the same prior distributions as those used for the estimation of the benchmark model M1. Sample period is 1980:Q1-1998:Q4. In conducting Bayesian MCMC estimation, the draws from the posterior distribution have been obtained by taking two parallel chains of 300,000 replications for Metropolis-Hastings algorithm.

Table 5: Log-marginal data densities and posterior odds

Specification	Log-marginal data density	Posterior odds versus M4
M1	-2100.86	1.70
M2	-2098.78	13.60
M3	-2100.90	1.64
M4	-2101.39	1.00

Notes: The log marginal data densities are computed based on modified harmonic mean estimator.

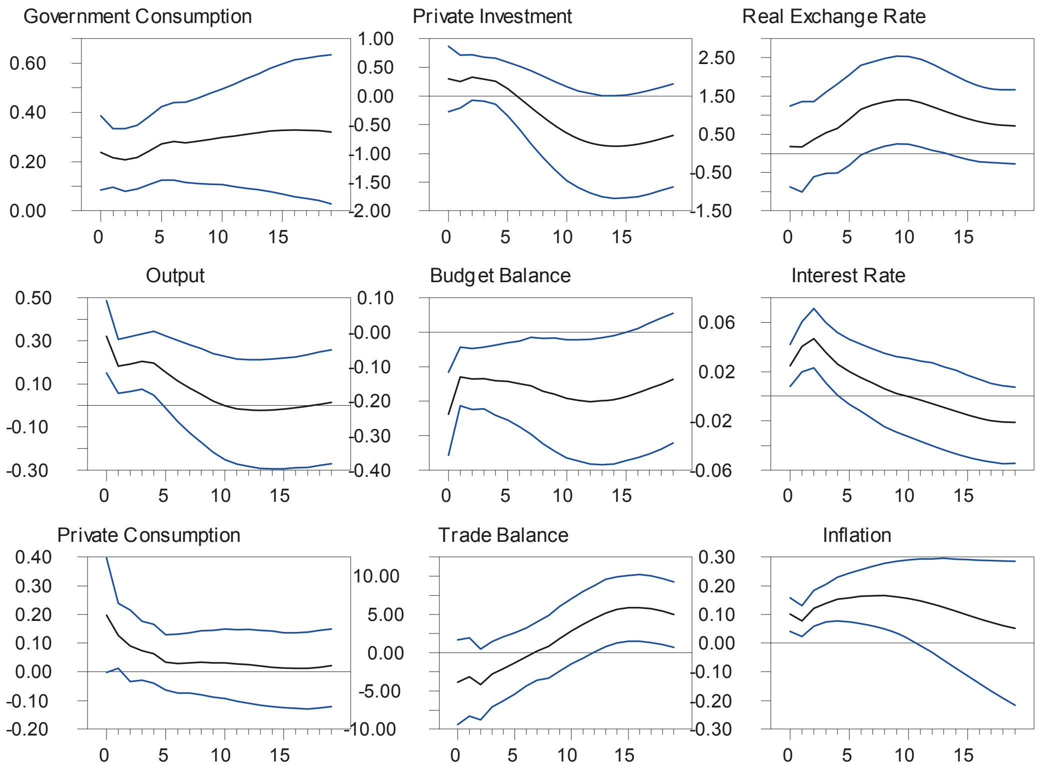


Figure 1.a: Impulse responses to an expansionary government consumption shock one standard deviation in size

Notes: Variables are expressed in levels. The median responses and the 16 and 84% quantiles are depicted.

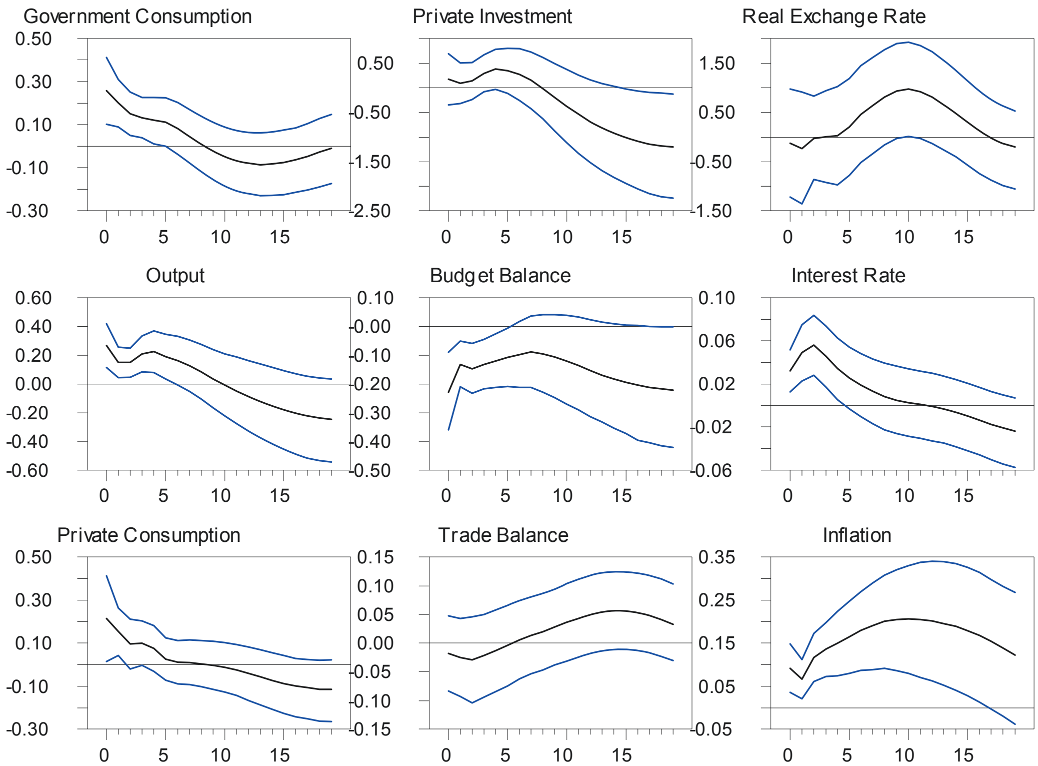


Figure 1.b: Impulse responses to an expansionary government consumption shock one standard deviation in size

Notes: Variables are expressed as deviations from a linear and quadratic trend. The median responses and the 16 and 84% quantiles are depicted.

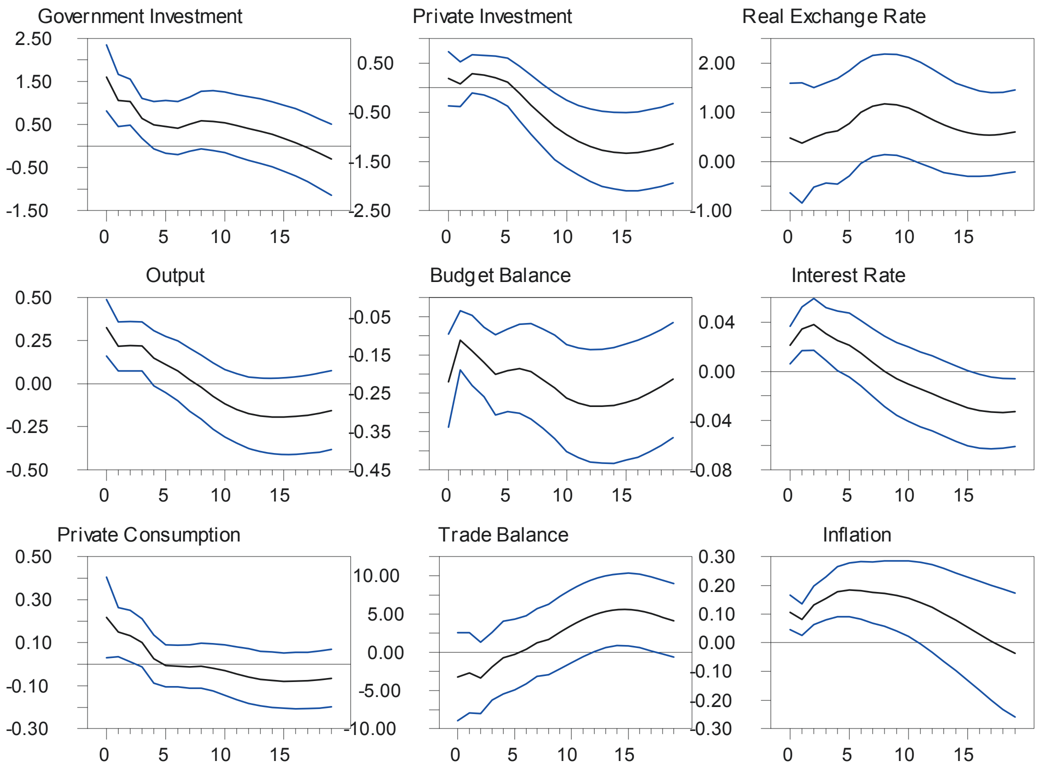


Figure 2.a: Impulse responses to an expansionary government investment shock one standard deviation in size

Notes: Variables are expressed in levels. The median responses and the 16 and 84% quantiles are depicted.

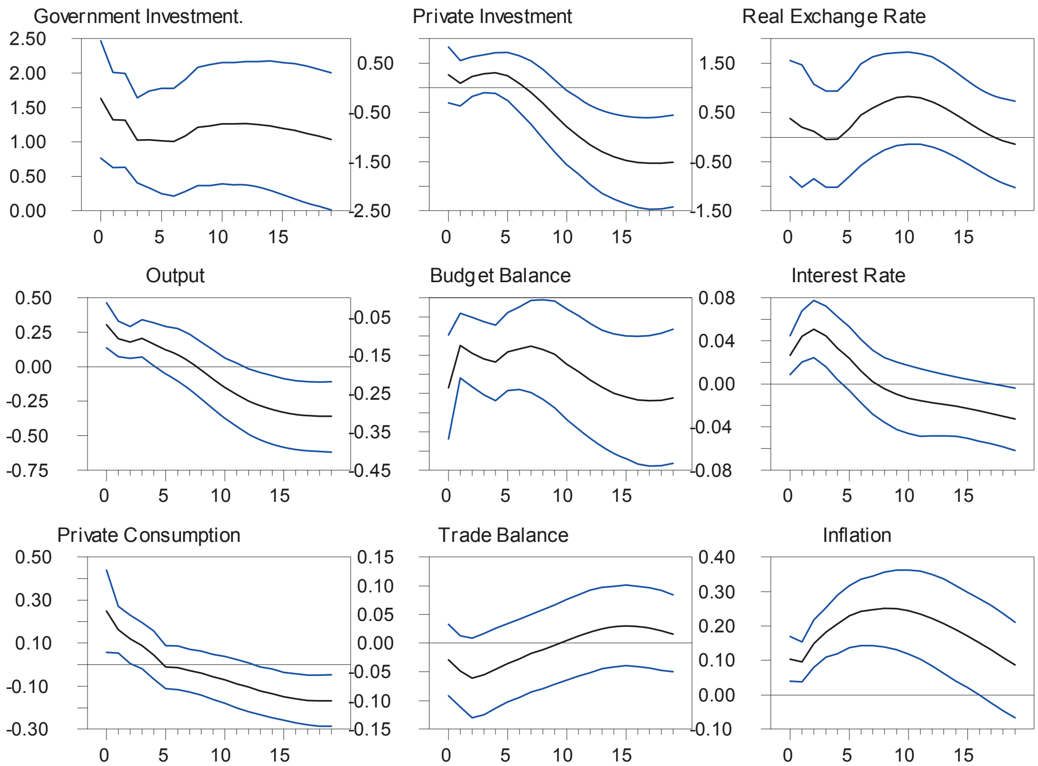


Figure 2.b: Impulse responses to an expansionary government investment shock one standard deviation in size

Notes: Variables are expressed as deviations from a linear and quadratic trend. The median responses and the 16 and 84% quantiles are depicted.

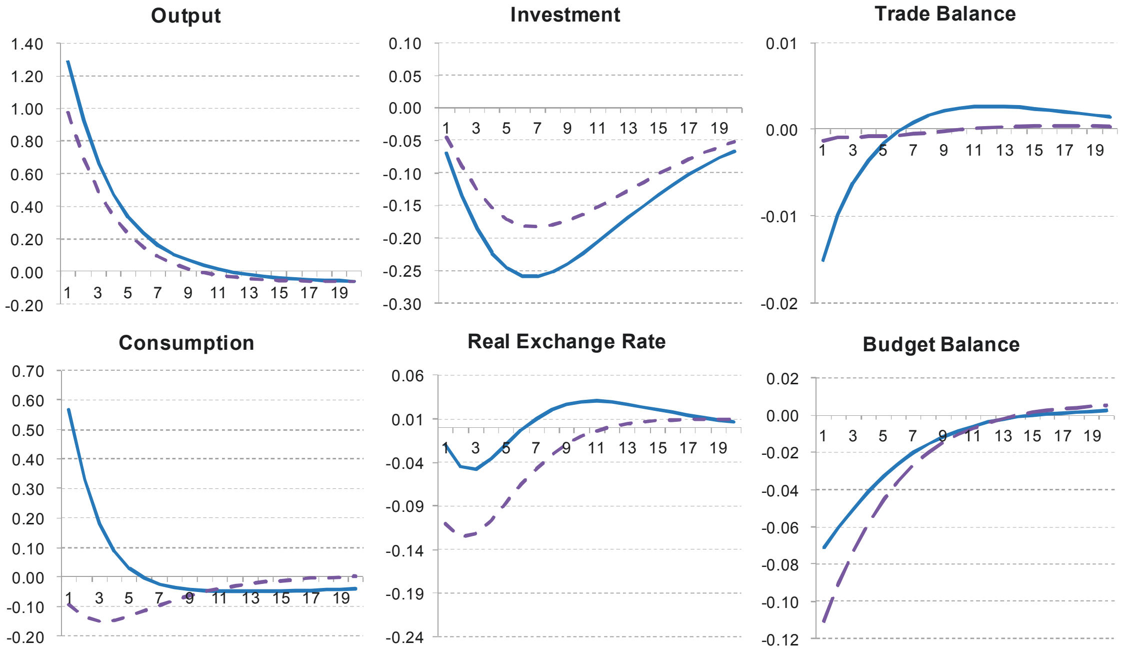


Figure 3: Model responses to a government consumption shock equal to one percent of the steady-state output

Notes: Solid lines: M1 (with Edgeworth complementarity and productive public capital); dashed lines: M4 (without Edgeworth complementarity and productive public capital).

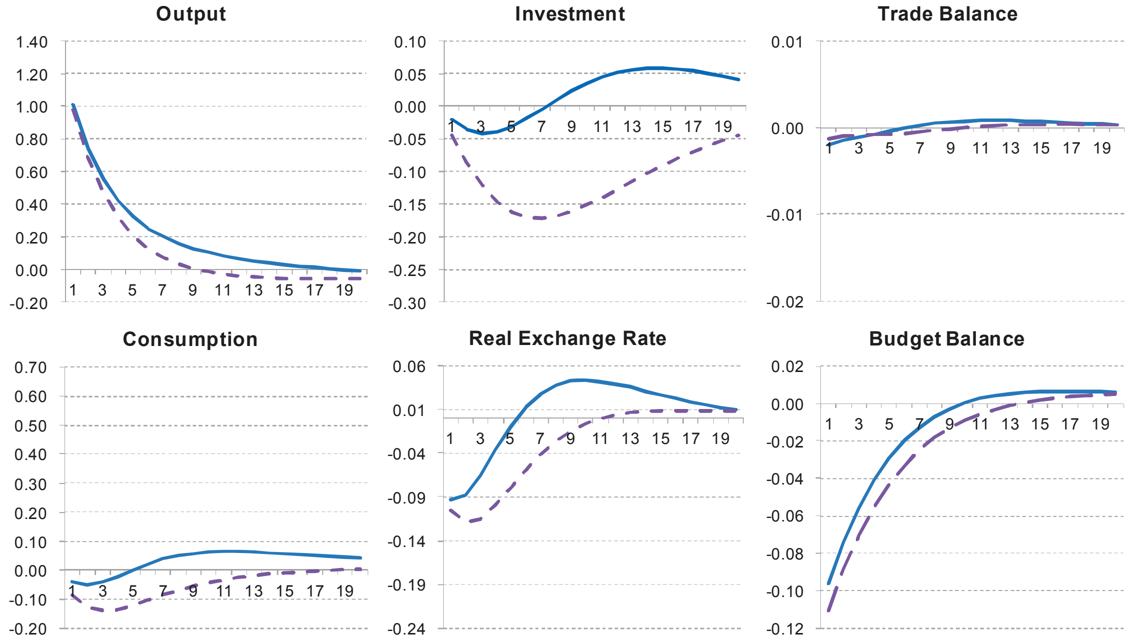


Figure 4: Model responses to a government investment shock equal to one percent of the steady-state output

Notes: Solid lines: M1 (with Edgeworth complementarity and productive public capital); dashed lines: M4 (without Edgeworth complementarity and productive public capital).

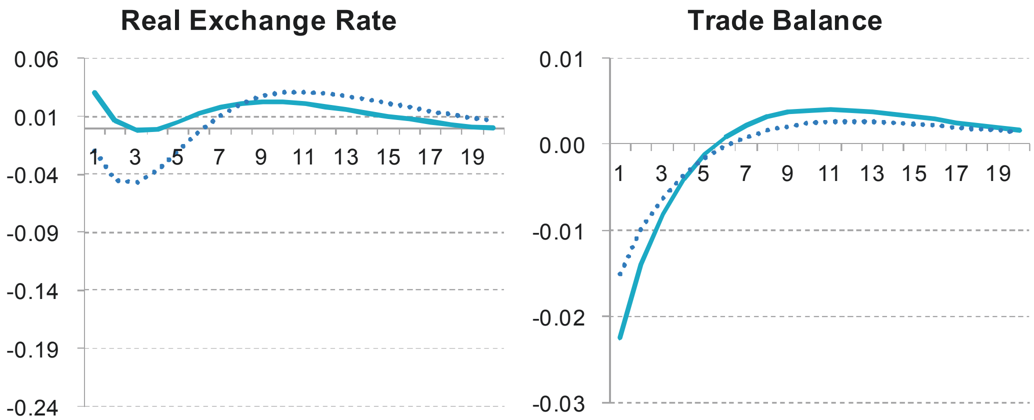


Figure 5: Sensitivity for home bias — Model responses to a government consumption shock equal to one percent of the steady-state output for a benchmark model (M1) with (dotted lines) and without home bias (solid lines).

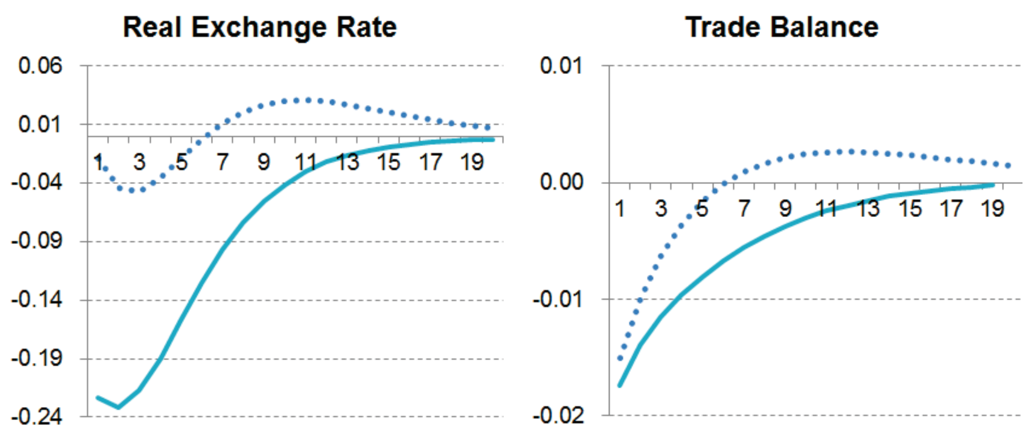


Figure 6: Sensitivity for different degree of risk premium elasticity — Model responses to a government consumption shock equal to one percent of the steady-state output for a benchmark model (M1) with high (dotted lines) and very low risk premium elasticity (solid lines).

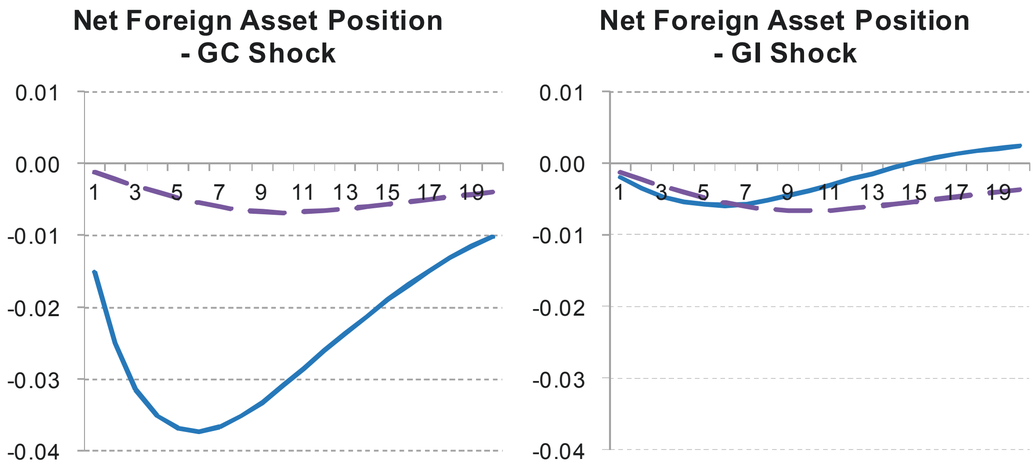


Figure 7: Model responses to government consumption (left panel) and government investment (right panel) shocks equal to one percent of the steady-state output

Notes: Solid lines: M1 (with Edgeworth complementarity and productive public capital); dashed lines: M4 (without Edgeworth complementarity and productive public capital).

CHAPTER 4

PUBLIC DEBT, RICARDIAN FISCAL POLICY, AND TIME-VARYING GOVERNMENT SPENDING MULTIPLIERS

Joint work with Hirokuni Iiboshi

4.1 Introduction

The economic impact of government spending is one of the classic theme in macroeconomics. While the size of the government spending multiplier has always been a central topic in the literature, the past several years have witnessed increased attention to its heterogeneity over time and across countries. As emphasized by Alesina and Giavazzi (2013), researchers in recent years generally agree with the view that "there is no such thing as a 'single' fiscal multiplier."[1] A growing body of literature has documented that the size of government spending multiplier may vary depending on the state and characteristics of the economy.

Recent debate on multipliers in the post-war U.S. tends to focus on their state-dependent nature across the business cycle. Table 1 gives a summary of studies

[1] See also Parker (2011), Favero et al. (2011), and Corsetti et al. (2012b). Batini et al. (2014) provide a comprehensive survey of the recent developments in the literature of fiscal multipliers.

that find nonlinear effects of government spending shocks in the U.S. Several studies provide evidences that the size of government spending multipliers is larger in recession than those in expansions (e.g., Auerbach and Gorodnichenko (2012); Bachmann and Sims (2012); Batini et al. (2012); Candelon and Lieb (2013); Caggiano et al. (2015)).[2] Similar results have also been reported in studies that consider data from OECD countries (e.g., Tagkalakis (2008); Baum et al. (2012); Auerbach and Gorodnichenko (2013); Dell'Erba et al. (2014); Riera-Crichton et al. (2014)). On the other hand, the relation between the size of government spending multipliers and characteristics of the economy has been studied mainly based on cross-country panel data. (e.g., Favero et al. (2011); Corsetti et al. (2012b); Ilzetzki et al. (2013); Nickel and Tudyka (2014)). The notable common finding is that government spending multipliers are larger in the economies where debt-to-output ratio is low (e.g., Favero et al. (2011); Corsetti et al. (2012b); Ilzetzki et al. (2013)). From the U.S. point of view, the role of public debt is worth examining because its debt-to-output ratio has been growing since the early 1980s. The relationship between public debt level and the effects of fiscal policy has also been investigated in the literature on non-Keynesian effects. Using a panel data from OECD countries, Perotti (1999) shows that government spending shocks have larger positive impact on private consumption at low levels of debt and negative one (i.e., non-Keynesian effects) in the opposite circumstances. The empirical

[2] In contrast, Owyang et al. (2013) and Ramey and Zubairy (2014) argue that they do not find evidence that multipliers differ depending on the state of the U.S. economy based on the local projection method of Jordà (2005).

evidences in the literature have been provided primarily based on cross-country panel data or specific episode in European countries. All in all, the role of public debt in the effects of government spending has not yet been examined based on the U.S. time series data.

In the context of the U.S. economy, a recent strand of the fiscal theory of the price level (FTPL) literature provide a new look at the importance of fiscal policy regime in determining the effects of government spending. Using a calibrated New Keynesian model augmented with estimated monetary and fiscal policy regimes on the U.S. data, Davig and Leeper (2011) demonstrate that output effects of government spending become smaller when monetary policy is active and fiscal policy is passive in the sense of Leeper (1991).[3] It is worth emphasizing that the active and passive policy are defined depending on its responsiveness to government debt, which gives rise to a potential role for the debt level in affecting changes in policy regimes.[4] Studies in this strand tend to find that fiscal policy has 'fluctuated' among active and passive rules. The results contrast with those based on linear models, which give support to Ricardian fiscal regime throughout the post-war period (e.g., Bohn (1998); Canzoneri et al. (2001); Canzoneri et al. (2010)).[5] Regarding the role of monetary policy, on the other hand, it has often

[3] Traum and Yang (2011) also examine the effects of government spending using New Keynesian models estimated over different sample periods with different priors centered at policy regimes of the period.

[4] Davig et al. (2010) develop a model in which probability of active fiscal policy rises with the level of public debt.

[5] By estimating Markov-switching model, Ito et al. (2011) conclude that the U.S. government follows a Ricardian fiscal policy throughout their entire sample period, 1940-2005.

been argued that multipliers became smaller because of the changes in the conduct of monetary policy after the appointment of Paul Volcker as Fed Chairman in 1979 (e.g., Perotti (2004); Bilbiie et al. (2008)).[6] Nevertheless, there is a considerable disagreement as to whether monetary policy has changed substantially or not.[7] Accordingly, little empirical evidence has been provided on the influence of monetary policy regime change on the effects of government spending.

Against this background, the present chapter provides new evidence on the changes in the effects of government spending on output in the post-war U.S., by taking different approach. Instead of relying on sub-sample analysis or regime-switching models, we employ a time-varying parameter vector autoregressive (TVP-VAR) model with stochastic volatility, where both the autoregressive coefficients and the log of variances for structural shocks are assumed to follow random walk processes, because the evolution of government debt in the post-war U.S. are better described as permanent change rather than transitory change. The framework allows us to present time profile of the changes in government spending multipliers without any *a priori* knowledge of a certain timing of structural change or regimes that are characterized by certain policy rules.

There is a large strand of literature that documents time-varying effects of

[6] Canzoneri et al. (2012) develop a New Keynesian model in which the change in monetary policy can account for the reduction in the size of government spending multipliers.

[7] While the 'good policy' explanation of the Great Moderation has been suggested by several studies (e.g., Clarida et al. (2000); Lubik and Schorfheide (2004); Boivin and Giannoni (2006)), studies based on VAR models tend to find evidences in support of the 'good luck' hypothesis (e.g., Stock and Watson (2003); Cogley and Sargent (2005); Primiceri (2005); Sims and Zha (2006); Gambetti et al. (2008)).

monetary policy within the TVP-VAR framework (e.g., Cogley and Sargent (2002); Primiceri (2005)), but only a few papers employ the methodology to investigate possible changes in the effects of fiscal policy. The notable exceptions are Pereira and Lopes (2014), Kirchner et al. (2010), and Rafiq (2012), which study the time variation in the effects of fiscal policy in the U.S., the euro area, and Japan, respectively.[8] They all report changes in the effects of fiscal policy, however, Kirchner et al. (2010) is the only study that performs exercises to investigate the driving forces behind the changes.[9] Conducting regression analysis using the estimated government spending multipliers calculated from their TVP-VAR and possible explanatory factors, they conclude that rising public debt is the main cause of the observed decline in multipliers in the euro area.

In the following, we estimate a TVP-VAR model with stochastic volatility along the lines of Primiceri (2005). In estimating the model, the Bayesian technique described in Nakajima et al. (2011) is exploited. Drawing on the findings of previous studies, monetary policy and public debt are considered as promising candidates for the possible driving forces behind the changes in the size of government spending multipliers. Therefore, we work with a medium scale TVP-VAR model that considers monetary variables and public debt. Differently from earlier

[8]Rafiq (2012) use a TVP-FAVAR model that combines a TVP-VAR model and a factor-augmented VAR (FAVAR) approach, which extracts a few latent common factors from a large set of observed macroeconomic variables.

[9]Pereira and Lopes (2014) argue that the effectiveness of fiscal policy in the U.S. has declined over the period 1965-2009, while addressing that the decline is much more evident for net taxes than government spending. Kirchner et al. (2010) find a decline in government spending multipliers at a horizon of five years over the period 1980-2008 for the euro area. Rafiq (2012) find a decline in government investment multipliers in Japan since the 1980s, while reporting a rise in those of government consumption, particulary since the start of 2000s.

TVP-VAR studies on fiscal policy, we achieve the identification of government spending shocks by means of sign restrictions in addition to the traditional recursive method. While applications of sign restrictions to TVP-VAR studies have been developed (e.g., Baumeister and Peersman (2013); Gambetti et al. (2008); Benati (2008)), this chapter is the first work that applies the method to those on fiscal policy, to the best of our knowledge. The estimated results show that the government spending multipliers have declined substantially since the late 1970s. The medium scale TVP-VAR allows us to investigate the possible driving forces behind the changes in the effects of government spending with a help of sign restrictions identification. Considering that a growing body of literature focuses on the size of multipliers across different state of business cycles, we calculate those by imposing additional identification restrictions in the spirit of Canova and Pappa (2011). In line with existing studies, we obtain larger multipliers in a hypothetical recession scenario. We then explore the role of monetary policy with the addition of restrictions and show that it plays little role in the observed decline in multipliers. Finally, the prevalence of either Ricardian or non-Ricardian fiscal regimes is examined applying the methodology of Canzoneri et al. (2001) and Canzoneri et al. (2010) to our TVP-VAR framework. The results show that the degree of Ricardian behavior of the government has been strengthened since the late 1970s. The accumulation of government debt during the period is suggested to be the major driving force behind the decline in multipliers.

The remainder of this chapter is organized as follows. Section 4.2 discusses the empirical methodology. Section 4.3 reports the results and examines the changes in the effects of government spending. Section 4.4 investigates the changes in the transmission of government spending shocks. Section 4.5 concludes.

4.2 Empirical Methodology

4.2.1 A VAR with Time-Varying Parameters and Stochastic Volatility

We consider the following VAR (p) model with time-varying parameters and stochastic volatility:

$$Y_t = B_{1,t}Y_{t-1} + \cdots + B_{p,t}Y_{t-p} + u_t, \tag{4.1}$$

where Y_t is a $k \times 1$ vector of observed variables, and $B_{i,t}$, $i = 1, ...p$, are $k \times k$ matrices of time varying coefficients. The u_t is a $k \times 1$ vector of heteroskedastic shocks that are assumed to be normally distributed with a zero mean and a time-varying covariance matrix, Ω_t. Following established practice, we decompose u_t as $u_t = A_t^{-1}\ \Sigma_t \varepsilon_t$, where

$$A_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ a_{21,t} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ a_{k1,t} & \cdots & a_{kk-1,t} & 1 \end{bmatrix}, \tag{4.2}$$

$$\Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{k,t} \end{bmatrix}, \tag{4.3}$$

and $\varepsilon_t \sim N(0, I_k)$. It follows that $A_t \Omega_t A_t' = \Sigma_t \Sigma_t'$. Let β_t be a stacked $k^2 p \times 1$ vector of the elements in the rows of the $B_{1,t \ldots p,t}$, and a_t be the vector of nonzero and nonone elements of the A_t. Following Primiceri (2005), we assume that these vectors follow a random walk process as follows:

$$\beta_{t+1} = \beta_t + u_{\beta,t}, \tag{4.4}$$

$$a_{t+1} = a_t + u_{a,t}, \tag{4.5}$$

$$h_{t+1} = h_t + u_{h,t}, \tag{4.6}$$

$$\begin{bmatrix} \varepsilon_t \\ u_{\beta,t} \\ u_{a,t} \\ u_{h,t} \end{bmatrix} \sim N\left(0, \begin{bmatrix} I & O & O & O \\ O & \Sigma_\beta & O & O \\ O & O & \Sigma_a & O \\ O & O & O & \Sigma_h \end{bmatrix}\right), \tag{4.7}$$

where $h_t = (h_{1,t}, \ldots, h_{k,t})'$ with $h_{j,t} = \ln \sigma_{j,t}^2$ for $j = 1, ..., k$, and I is a k-dimensional identity matrix. As in Nakajima et al. (2011), we further assume for simplicity that Σ_β, Σ_a, and Σ_h are all diagonal matrices.

Observe that the model allows the log of variance for the structural shocks to evolve over time as a random walk. The stochastic volatility assumption makes the likelihood function of the model to be hard to construct and requires Bayesian inference via Markov Chain Monte Carlo (MCMC) methods. In implementing the MCMC algorithm, we follow the procedure presented in Nakajima et al. (2011). Regarding the sampling of β_t and a_t, the simulation smoother of de Jong and Shephard (1995) is used, because the model can be written as a linear Gaussian state space form conditional on the rest of the parameters.[10] In sampling h_t, on the other hand, we employ the multi-move sampler of Shephard and Pitt (1997) and Watanabe and Omori (2004) for nonlinear and non-Gaussian state space models. The methodological novelty of Nakajima et al. (2011) lies in their use of the sampler,[11] as previous TVP-VAR studies rely on other methods, such as the single-move sampler of Jacquier et al. (1994) and the mixture sampler of Kim et al. (1998). The multi-move sampler is known to be more efficient than the single-move sampler used in Cogley and Sargent (2005) and Baumeister and Benati (2013).[12] Furthermore, the method enables us to draw sample from the exact conditional posterior density of the stochastic volatility, unlike the mixture sampler employed by Primiceri (2005) and Canova and Gambetti (2009).[13]

[10] We employ the simulation smoother of de Jong and Shephard (1995) instead of the multi-state sampler of Carter and Kohn (1994), which is widely used in previous TVP-VAR studies (e.g., Primiceri (2005); Canova and Gambetti (2009); Baumeister and Benati (2013)). The multi-state sampler generates the whole of the state vector at once and therefore converges more quickly than the single-state sampler that yields a strong correlation among the samples. However, the method is prone to a problem of degeneracies because the whole of the state vector is constructed recursively. The simulation smoother of de Jong and Shephard (1995) avoids the problem by drawing disturbances rather than states.

[11] The Ox and MATLAB codes to implement the MCMC algorithm incorporated with the multi-move sampler of Shephard and Pitt (1997) and Watanabe and Omori (2004) are available at Jouchi Nakajima's Web site (https://sites.google.com/site/jnakajimaweb/tvpvar).

[12] The shortcoming of using the single-move sampler is that it leads to slow convergence when state variables are highly autocorrelated. The multi-move sampler reduces the inefficiency by generating randomly selected blocks of disturbances rather than the states one at a time.

[13] The algorithm in Primiceri (2005) is recently corrected by Del Negro and Primiceri (2015).

4.2.2 Data and Identification Strategies

We use the quarterly data from the U.S. for the period 1952:Q1-2013:Q4. Although our sample period contain the period of zero interest-rate policy, we do not incorporate the zero lower bound constraint in light of the findings of Nakajima (2011).[14] The observed variables include government spending (consumption expenditures and gross investment), gross domestic product (GDP), personal consumption expenditures, debt-to-output ratio,[15] GDP deflator, and nominal interest rate. Because the level of public debt and the conduct of monetary policy are often suggested as candidates that affect the size of multipliers, we include debt-to-output ratio and monetary variables, such as price level and interest rate, in the TVP-VAR. The importance of including public debt in a VAR model is suggested by Favero and Giavazzi (2012) and Chung and Leeper (2007) who argue that the effects of its dynamics on other variables should not be overlooked. While they impose equations assuming a feedback from the level of public debt to fiscal instruments, we include debt-to-output ratio without imposing any restrictions as in Corsetti et al. (2013) because we consider plausibility of non-Ricardian behavior of the government. For the very same reason, we are interested in a price level adjustment and hence include price level rather than inflation rate in

[14] Nakajima (2011) provides evidence that a TVP-VAR model with stochastic volatility can produce almost the same result as that explicitly considers the zero lower bound based on the Japanese data from 1977 to 2010. The role of stochastic volatility in obtaining the similar impulse responses is suggested.

[15] The U.S. public debt is the sum of federal, state, and local government liabilities.

our system.[16] The first three variables are expressed in real per capita terms. We use the logarithm for all variables except the nominal interest rate and debt-to-output ratio. All variables are detrended with a linear and quadratic trend, and are seasonally adjusted except for the interest rate. The lag length is set to $p = 4$ following Blanchard and Perotti (2002b). We postulate an inverse-Gamma distribution for the i-th diagonal elements of the covariance matrices. The prior densities are specified as $(\Sigma_\beta)_i^2 \sim IG(20, 10^{-4})$, $(\Sigma_a)_i^2 \sim IG(4, 10^{-4})$, and $(\Sigma_h)_i^2 \sim IG(4, 10^{-4})$. The initial states of the time-varying parameters are set as $\beta_0 \sim N(0, 10I)$, $a_0 \sim N(0, 10I)$, and $h_0 \sim N(0, 50I)$.

The identification of structural shocks are achieved via both traditional recursive approach and sign restrictions approach for robustness reasons. We follow Corsetti and Müller (2006) in ordering real variables before monetary variables in the Cholesky decomposition. Ordering government spending first is in line with the assumption proposed by Blanchard and Perotti (2002b). In implementing the sign restrictions approach within the TVP-VAR framework, we exploit the algorithm proposed by Rubio-Ramírez et al. (2010) (RWZ algorithm, hereafter), as in Benati (2008) and Baumeister and Peersman (2013). To calculate the sign-restricted impulse responses, we proceed as follows. We draw an independent standard normal $k \times k$ matrix X_j for period j. QR decomposition of X_j gives an orthogonal matrix P_j that satisfies $P_j P_j' = I$ and an upper triangular matrix R.

[16] The following results does not change much if we use inflation rate instead of price level. The use of GDP deflator in estimating VARs can be found in Uhlig (2005), Sims and Zha (2006), and Mountford and Uhlig (2009).

Using $A_j^{-1}\Sigma_j P_j$, impulse responses are generated for each MCMC replication, and if the impulse response satisfies the restrictions, we keep the draw, and otherwise we discard it. The combination of P_j' and ε_t, $\varepsilon_t^* = P_j'\varepsilon_t$ is now regarded as a new set of structural shocks, which has the same covariance matrix as the original shock ε_t. Because P_j is orthogonal, the new shocks are orthogonal to each other by design.

The sign restrictions we employed are presented in Table 2. As argued by Canova and Pappa (2011), existing theories do not provide definitive answers to the short-run dynamics after a government spending shock. Furthermore, it is computationally burdensome to estimate impulse responses from a TVP-VAR model imposing sign restrictions for several periods. Therefore, we impose a minimum set of contemporaneous restrictions to make our identification as agnostic as possible.[17] We do not impose restrictions on output responses to fiscal and monetary policy shocks, as in Mountford and Uhlig (2009) and Uhlig (2005). The restriction that an increase in government spending has a positive impact on debt-to-output ratio is the key identifying restriction that distinguishes government spending shocks from other shocks. We also require government spending shocks to be orthogonal to monetary policy and business cycle shocks following Mountford and Uhlig (2009). The restrictions to identify the 'monetary policy shock' and the 'business cycle shock' are imposed borrowing their definition. The

[17] The choice of time periods for which the responses are restricted does not change the basic results of this chapter. Similar patterns of time-variation in government spending multipliers are found when we estimated the model imposing sign restrictions for a year after a shock.

RWZ algorithm allows us to impose orthogonality conditions only by identifying other uncorrelated shocks. The algorithm is particularly appealing in identifying several shocks within our highly parameterized medium-scale TVP-VAR, because it is computationally efficient as addressed by Fry and Pagan (2011).

4.3 Evidence on Time Variation

4.3.1 Basic Results

We executed 30,000 MCMC replications and discarded the first 5,000 draws to estimate the TVP-VAR model described in the previous section. Table 3 reports the posterior means, the standard errors and 95% credible intervals for selected parameters. The p-values associated with the convergence diagnostic (CD) of Geweke (1992) and the inefficiency factors are also reported. The p-values for the CD statistics are at least 0.05 for each parameter. The efficiency factors are less than 200, which indicates that we drew enough number of uncorrelated samples. Figure 1 presents the estimated stochastic volatility of the structural shocks, ε_t, identified by the recursive ordering. The time variation in the volatility estimates of monetary policy shocks and the residuals of price and output equations are largely consistent with those reported in previous studies (e.g., Mumtaz and Zanetti (2013); Koop et al. (2009); Primiceri (2005); Cogley and Sargent (2005)). The volatility of monetary policy shocks increased substantially around the time when Paul Volcker was appointed as Fed Chairman in 1979 and showed a large decline during the early 1980s. The residual of price equation reached its highest peak during the Great Inflation of mid-1970s. The smoother variation in the volatility of price level compared to that of inflation rate reported in previous studies can be attributed to the difference in variables. The volatility of output fell sharply in the early 1980s, showing a similar pattern to that of unemployment reported in Cogley and Sargent (2005). The observed reduction in volatility of government spending also can be found in Justiniano and Primiceri (2008). We notice that there have been marked increases in the volatility of debt-to-out put ratio at the beginning of 2000s and after the Lehman shock. It is worth noting that the volatility of monetary policy shocks dropped significantly during the period of zero interest-rate policy, especially since after QE2 and QE3 were announced.[18] This is in line with Nakajima (2011), who find effectively low level of stochastic volatility for the monetary policy shocks during the zero interest-rate period in Japan. The results lead us to conjecture that the effects of zero lower bound may be negligible in our TVP-VAR framework with a help of stochastic volatility. Overall, the results show that stochastic volatility model well capture the changes in volatilities and that its inclusion to the TVP-VAR model is important to detect the structural changes in the transmission of government spending shocks.

Figures 2-5 present impulse responses of output and price to government spending and monetary policy shocks for the two alternative identification schemes.

[18] The Federal Reserve's second round of quantitative easing (QE2) and the third one (QE3) were announced in November 2010 and September 2012, respectively.

The impulse response at time t is computed for each MCMC replication based on the estimated time-varying parameters at time t.[19] The shapes of the responses of output and price to government spending shocks are similar across the different identification schemes, although their quantitative differences are evident. Both responses vary over time and their time profiles exhibit similar patterns regardless of the identification schemes. In contrast, the responses of output and price to monetary policy shocks exhibit different shapes across the different identification as documented by Uhlig (2005). Whereas contractionary effects on output and the 'price puzzle' raised by Sims (1992) are observed for recursive identification, it is shown that monetary policy shocks identified via sign restrictions have no clear effect on output and is followed by a slow decline in price. Furthermore, little time variation is found in the responses of output and price, which is in line with the finding of Primiceri (2005).

4.3.2 Time-Varying Government Spending Multipliers

Figure 6 compares point estimates (posterior means) of impulse responses of output and consumption to government spending shocks for the two alternative identification schemes, at the dates, 1970:Q1, 1990:Q1, and 2010:Q1. The responses are scaled so that they show output and consumption increases to a $1

[19] Koop (1996) and Koop et al. (1996) propose a method to calculate impulse response taking into account the history of the observations that affects impulse responses in non-linear models. However, because the method can be computational demanding and a slight difference is expected from the use of the method as addressed by Koop et al. (2009), we follow the simple computational procedure used in Primiceri (2005), Koop et al. (2009), and Nakajima et al. (2011).

increase in government spending. We divide the responses by sample average ratio of respective variables and government spending as in Auerbach and Gorodnichenko (2012).[20] Because of the transformation, the responses are interpreted as output and consumption multipliers. The expansionary output effects become smaller over the period. The shapes and magnitudes of the output responses for recursive identification are similar to those in Blanchard and Perotti (2002b). The changing patterns of the output and consumption multipliers are largely the same across the alternative identification schemes and specifications, although there are some differences in their magnitude. The initial output multipliers to government spending shocks are larger for recursive identification than those for sign restrictions, while subsequent increases in output are larger for the latter. A similar but smaller discrepancy between the multipliers identified by those two approaches can be found in Caldara and Kamps (2008).[21]

Regardless of the identification schemes, the output multipliers are in between -1.0 and 1.5 on impact across the different dates of the sample. After almost one year of decline, the output multipliers increase and reach the highest peak four years after the shock. The peak multipliers range from 1 to 1.9 and from 0.4 to

[20] Ramey and Zubairy (2014) point out a potential problem that arise from the use of sample average ratio in calculating multipliers. Nevertheless, we stick to use the average ratio because we are interested in the causes of the changes in multipliers rather than their sizes. Furthermore, the ratios of output and consumption to government spending do not vary much in our sample period.

[21] Note that Caldara and Kamps (2008) employ the penalty function approach of Mountford and Uhlig (2009), whereas we rely on pure sign restrictions approach exploiting the RWZ algorithm in line with Arias et al. (2014). Arias et al. (2014) address that the penalty function approach undermines the agnosticism of sign restrictions by introducing additional restrictions that create bias in impulse responses and artificially narrow confidence intervals. Kilian and Murphy (2012) and Fry and Pagan (2011), on the other hand, suggest that imposing sign restrictions alone is insufficient and that additional parametric restrictions are necessary.

2.2 for recursive and sign restrictions identification, respectively. The consumption multipliers display similar shapes and time variation to those of output described above. Whereas existing empirical studies that consider linear time series models typically find a crowding-in of consumption, the consumption multipliers calculated from the posterior mean responses suggest that the crowding-in effects become smaller for the both identification scheme. Figure 7 takes up the question whether a crowding-in of consumption in response to a government spending shock is observed in a statistically significant way. The figure displays posterior means of consumption multipliers along with 16th and 84th percentile error bands. The upper row panels indicate that the observed increase in consumption in 1980s becomes smaller, and that the increase is not statistically larger than zero in the 2010s for recursive identification. On the other hand, the lower row panels show that the crowding-in of consumption cannot be observed in a statistically significant way throughout the estimation period for sign restrictions identification. Taken together, we can safely argue that the crowding-in effects of government spending on consumption disappears by the 2010s.

To investigate changes in the transmission of government spending shocks, we compute the cumulative output and consumption multipliers evaluated at horizon 20. The cumulative output and consumption multipliers are defined as the ratio of the sum of output and consumption responses to the sum of government spending path.[22] Figure 8 plots the time profiles of point estimates (posterior means) of

[22] To be precise, the cumulative output and consumption multipliers evaluated at horizon k

the cumulative multipliers for the two alternative identification schemes. The size of the cumulative multipliers differ to some extent according to the identification schemes employed. The cumulative output multipliers for recursive identification are between 0.8 and 1.5, while those for sign restrictions are between -1.7 and 1.5. The figure suggests that the nonlinearities in the responses of output and consumption to government spending shocks are particularly pronounced when sign restrictions identification is employed. Figure 8 also illustrates the similarity between the patterns of time variation in cumulative output and consumption multipliers. They both decline substantially since the late 1970s regardless of the identification schemes. Their co-movement indicates that the time variation in the effects of government spending on output is mostly led by that on consumption.

4.4 Investigating the Changes in the Transmission of Government Spending

In this section, we examine the cause of the decline in government spending multipliers starting in the late 1970s. While we have already seen that the time variation in government spending multipliers does not show cyclical movements, we begin by studying the size of multipliers for different economic scenarios because recent debate on multipliers in the post-war U.S. focuses on their state-dependent nature across the business cycle. Although our TVP-VAR framework

are calculated as: $\frac{\sum_{s=0}^{k} \Delta y_{t+s}}{\sum_{s=0}^{k} \Delta g_{t+s}} \frac{Y}{G}$, $\frac{\sum_{s=0}^{k} \Delta c_{t+s}}{\sum_{s=0}^{k} \Delta g_{t+s}} \frac{C}{G}$, where $y = \ln Y$, $c = \ln C$, and $g = \ln G$. Y, C, and G represent output, consumption, and government spending, respectively.

is not suited to capture the difference in the size of multipliers across the extreme states of business cycles, we attempt to fill the gap by conducting hypothetical exercise with the addition of identification restrictions in the spirit of Canova and Pappa (2011). We then explore the role of monetary policy and public debt, our main suspects for the cause of the observed decline in multipliers.

4.4.1 Calculating Multipliers for Different Economic Scenarios

In contrast with the existing studies, the result in the previous section indicates that the state of the business cycle does not play a major role in determining the size of multipliers. A possible explanation for the different results can be attributed to the difference in methodologies. As we have seen in Table 1, those studies that focus on state-dependent nature of multipliers typically rely on regime switching models that allow discrete change in parameters in a deterministic manner. These methodologies require some measures to differentiate the state of economic slack. The multipliers in each state are calculated primarily reflecting information set within the state, which is differentiated by the measure. Because the information set does not contain that of transitory phase, the estimated multipliers using these methodologies can be viewed as those in extreme states of the business cycle which are independent from the history.

The TVP-VAR framework, on the other hand, allows parameters to vary continuously over time in a stochastic manner and is hence not suited to capture those under extreme states. Nevertheless, it is possible to replicate the multipliers in the extreme states within the TVP-VAR framework, by conducting scenario analysis based on sign restrictions approach.[23] As shown in Canova and Pappa (2011), government spending shocks during certain economic states can be identified by imposing additional sign restrictions. It is important to notice that these multipliers are essentially hypothetical in our TVP-VAR framework, because the shocks under certain states are identified in each period through the same sign restrictions regardless of the actual state of business cycles. The calculated multipliers thus replicate those under the extreme states that are hypothetically assumed to last throughout the estimation period. It is worth noting that the implicit assumption in calculating multipliers here is similar to that in Auerbach and Gorodnichenko (2012), who argue that their regime-based multipliers should be interpreted as bounds from polar settings and more realistic ones should fall between the extremes.

Table 4 presents additional restrictions for different economic scenarios. As in Canova and Pappa (2011), we identify government spending shocks that take place in recession as those accompanied by a simultaneous fall in price.[24] Analogously, those during expansions are assumed to be accompanied by a price rise. Figure 9 presents point estimates of output multipliers in 'recession' and 'expan-

[23] Mountford and Uhlig (2009) first apply sign restrcitions approach to analyze different fiscal policy scenario by calculating linear combination of basic fiscal shocks.

[24] Although Canova and Pappa (2011) assume that a government spending shock has a positive impact on output, we do not impose restriction on output following Mountford and Uhlig (2009).

sion' scenarios at the same selected dates as those in Figure 6. The multipliers are calculated based on the subset of parameters that are chosen from those for the basic scenario by the additional sign restrictions. The multipliers during 'recession' reach values of over 3 after three years at either date. During 'expansion,' on the other hand, multipliers take negative values throughout the estimation period. Although our agnostic sign restrictions yield relatively wide credible intervals, the negative impact on output is statistically significant in the 2000s and 2010s, which can be interpreted as an evidence in support of non-Keynesian effects.[25] Figure 10 depicts the time profiles of point estimates of the cumulative output multipliers at horizon 20 for different economic states. As expected, the cumulative multipliers in the basic scenario fall between those in 'recession' and 'expansion.' Consistent with existing studies, we find larger multipliers in 'recession' and smaller ones in 'expansion.' While the exercise here aims to replicate the multipliers in the extreme states within the TVP-VAR framework, the figure also tells us that cumulative multipliers in 'recession' and 'expansion' both exhibit decline since the late 1970s as those observed in the basic scenario. It follows that the state of the business cycle matters in determining the size of multipliers, however, it does not play a role in the observed decline of multipliers.

[25] Giavazzi and Pagano (1990) find non-Keynesian effects from the Irish debt stabilization experience of 1987-89 and standard contractionary effects from that of 1982-84. The eased credit conditions in the late 1980s are suggested as the cause of the non-Keynesian effects. In this regard, it is worth mentioning that credit conditions tend to be tightened during recession (e.g., Bacchetta and Gerlach (1997)).

4.4.2 Role of Monetary Policy

We next consider contractionary and expansionary monetary policy scenarios. Table 4 reports the additional sign restrictions imposed for these scenarios. As in the case of the state of the business cycle, restriction on output is imposed in neither scenario, because we do not impose restriction on output for basic shocks to government spending and monetary policy.

Figure 11 presents point estimates of output multipliers under different monetary policy scenario at the three dates. As expected, multipliers are larger if it is accompanied by expansionary monetary policy. After a government spending shock, output shows a hump-shaped pattern of increase. On the other hand, output declines immediately after a government spending shock if it is accompanied by contractionary monetary policy. The similarity between the shapes of output responses to government spending shocks in expansionary monetary policy scenario and those in basic scenario suggest that most of the government spending shocks during the estimation period are accompanied by expansionary monetary policy. Note that the decline in output multipliers can still be observed in both scenarios.

Because output responses to government spending shocks accompanied by contractionary and expansionary monetary policy show very similar patterns to those in expansion and recession scenarios, respectively, we further examine the role of monetary policy in determining the size of multipliers across different states of business cycles. Figure 12 presents point estimates of output multipliers during 'recession' accompanied by contractionary monetary policy, and those during 'expansion' accompanied by expansionary monetary policy. Contractionary monetary policy delays the output increase in response to government spending shock during 'recession,' while expansionary monetary policy mitigates the crowding-out effect. However, those monetary policy effects are not strong enough to change the output response drastically. The results here indicate that monetary policy plays a role in determining the shapes of output response, however, it does not play a major role in determining the size of multipliers in different states of business cycles. The result here leads us to conclude that the state of business cycle itself matters for the effectiveness of expansionary government spending. To put it differently, a government spending shock accompanied by expansionary monetary policy does not seem to have a positive impact on output during when the economy is in the midst of a boom.

Figure 13 displays point estimates of cumulative responses of price and interest rate to government spending shocks evaluated at horizon 20 for different monetary policy scenario. The cumulative responses are computed as the cumulative percent change in price level and interest rate divided by the cumulative percent change in the government spending after 20 quarters. In both scenarios, cumulative response of price bottomed out in the late 1970s and has risen sharply since then. In contrast, cumulative response of interest rate shows very different pattern across the state of the economy. While the time profile of interest rate response to government spending shocks and that of price level show similar pattern in contractionary monetary policy scenario, they move in the opposite direction in the expansionary monetary policy scenario. In the former scenario, monetary policy is assumed to be conducted in an uncoordinated manner with the expansionary fiscal policy. The Federal Reserve raises interest rate in response to an increase in government spending followed by heightened inflationary pressure. Therefore, interest rate response to a government spending shock shows largely correlated movement with that of price level until the aftermath of financial crisis of 2007, when interest rates are kept at a low level. The latter scenario, on the other hand, assumes that monetary policy is well-coordinated with the expansionary fiscal policy. While an increase in government spending heightens inflationary pressure, interest rate response moves in the opposite direction from that of price level because monetary policy is conducted in an expansionary manner as well. In either scenario, there seems to be a stable relationship between the interest rate response and price level response to a government spending shock, which suggests that monetary policy response to government spending shocks does not change much throughout the estimation period. Based on this finding together with the result shown in Figure 12, we can conclude that monetary policy does not explain the decline in government spending multipliers.

Why then does government spending become more inflationary, as government debt accumulates? From a viewpoint of the FTPL, Sims (2011) documents that the high inflation of the mid-1970s and 1980s can be attributed to the rapidly increased debt-to-output ratio during the period. According to Cochrane (1999), the analytical content of FTPL is summarized to the following version of intertemporal budget constraint of the government:

$$\frac{\text{nominal debt}}{\text{price level}} = \text{present value of real surpluses.} \tag{4.8}$$

The FTPL states that the price level is determined so that the real value of nominal debt equal to present value of real surpluses, taking an exogenous sequence of surpluses and nominal debt as given. Rearranging the equation (4.8), we get:

$$\text{price level} = \text{nominal debt} \times \frac{1}{\text{present value of real surpluses}}. \tag{4.9}$$

The intertemporal budget constraint of the government suggests that the price level goes up after a government spending shock as long as the shock has a negative impact on present value of real surpluses. The FTPL states that the price level is determined so that the real value of nominal debt equal to present value of real surpluses, taking an exogenous sequence of surpluses and nominal debt as given. Suppose that an increase in government spending has a negative impact on present value of real surpluses. The equation (4.9) then indicates that the price level goes up in response to government spending shocks. Furthermore, the effects of government spending shocks on the price level become larger, as the nominal debt of the economy accumulates. The important presumption is that the sequence of surpluses reacts to neither price nor debt level. We note here that this channel works even if the additional government spending is partially offset by additional taxation. As argued by Sims (2011), "when rational, forward-looking agents believe that newly issued nominal government debt is only partially backed by future taxes, debt issue is inflationary." Figure 14 presents evidence underlining the empirical relevance of the above argument. The figure shows a scatter plot of the point estimates of cumulative responses of price to government spending shocks in the basic scenario against historical data on debt-to-output ratio. There appears to be a strong positive correlation between them, which suggests that the accumulation of government debt makes government spending shocks inflationary.

4.4.3 Time-Variation in Fiscal Policy

We now turn to the role of fiscal policy regimes, which are typically defined depending on their responsiveness to public debt. The U.S. public debt as a share of GDP has consistently increased since the early 1980s, which largely corresponds to the period of decline in government spending multipliers. As argued by Perotti (1999), government spending multipliers become smaller as higher future tax is expected. Therefore, the accumulation of public debt that induces necessity of future tax burden and subsequent corrective action of the government to repay the debt are possible causes of the decline in multipliers.

Nevertheless, we find that government spending becomes more inflationary in accordance with public debt accumulation in the previous section. This may give the impression that public debt is backed only partially by future tax and that a Ricardian fiscal regime is not in place.[26] However, we cannot conclude about the prevalence of either Ricardian or non-Ricardian fiscal regimes from the observed inflationary effects of government spending. Canzoneri et al. (2001) and Canzoneri et al. (2010) demonstrate theoretical plausibility of Ricardian regime by showing that a wide class of fiscal feedback rule from debt level to surplus leads to Ricardian regime. They argue that debt-stabilizing fiscal policy need not be in effect each period to meet the requirements for a Ricardian regime. Furthermore, Davig and Leeper (2007) and Chung et al. (2007) suggest that the FTPL is always operative as long as there is a positive probability of moving to a regime with active fiscal policy in a regime-switching environment. Their argument also applies to our TVP-VAR framework, because it allows continuous and stochastic change in parameters.

The VAR-based methodology of Canzoneri et al. (2001) and Canzoneri et al. (2010) allows us to examine the prevalence of either Ricardian or non-Ricardian fiscal regimes without assuming any particular type of policy rules. They estimate a bivariate VAR in surplus/GDP and liabilities/GDP on the post-war U.S. data, and document that a Ricardian fiscal regime is more plausible. Their methodol-

[26] Woodford (1995) defines a Ricardian regime as the case in which fiscal policy fail to play any role in price-level determination and emphasizes a non-Ricardian regime, suggesting that a Ricardian regime represents a highly special case. Aiyagari and Gertler (1985) consider fiscal regimes in a more flexible way. They define 'polar' Ricardian and non-Ricardian fiscal regimes as the cases in which the fiscal and monetary authorities provide full backing for the debt, respectively. A continuum of fiscal regimes is assumed to lie in between the polar cases.

ogy is attractive because it is VAR-based and hence can easily be extended to our TVP-VAR framework with stochastic volatility. We estimate a bivariate TVP-VAR with two lags in surplus/GDP and liabilities/GDP for the period 1952:Q1-2013:Q4 in the same manner presented in Section 4.2. Same data is used for the debt-to-output ratio described in Section 4.2 and the liabilities/GDP here, but we call it liabilities/GDP following the notation used in Canzoneri et al. (2010). The prior densities are specified as $(\Sigma_\beta)_i^2 \sim IG(40, 10^{-4})$, $(\Sigma_a)_i^2 \sim IG(5, 10^{-3})$, and $(\Sigma_h)_i^2 \sim IG(5, 10^{-3})$, and the initial states of the time-varying parameters are set as $\beta_0 \sim N(0, 10I)$, $a_0 \sim N(0, 10I)$, and $h_0 \sim N(0, 50I)$. We executed 30,000 MCMC replications and discarded the first 5,000 draws. The posterior estimates for stochastic volatilities are presented in Figure 15. As expected, similar result is obtained for the volatility of a liabilities/GDP shock to that in Figure 1. The overall results for the volatility of surplus/GDP shocks well capture the fiscal events showing similar pattern to those of estimated tax shocks reported in Gonzalez-Astudillo (2013). The stochastic volatility of surplus/GDP shocks heightened most around the time of Tax Reduction Act of 1975. It also shows increase in times of tax reform and measures, such as the Reagan Tax Reform of 1981 and 1986, the Bush Tax Cuts of 2001 and 2003, and the American Recovery and Reinvestment Act of 2009. Figure 16 compares point estimates of impulse responses to a one percentage point increase in liabilities/GDP and surplus/GDP at the dates, 1970:Q1, 1990:Q1, and 2010:Q1. The surplus/GDP is ordered first in the top panels and the liabilities/GDP is ordered first in the bottom panel. The former ordering is consistent with a non-Ricardian regime and the latter makes more sense in a Ricardian regime. Regardless of the ordering used, liabilities/GDP declines for several years in response to a surplus/GDP shock across the different dates of the sample. The degree of the decline is smaller for the case in which liabilities/GDP is ordered first. The results are very much similar to those obtained by Canzoneri et al. (2001) and Canzoneri et al. (2010), which suggest that the U.S. government follows a Ricardian fiscal regime throughout the post-war period. As addressed in Canzoneri et al. (2001) and Canzoneri et al. (2010), non-Ricardian explanation is implausible because it requires a negative correlation between present surpluses and future surpluses, which cannot be observed. Furthermore, our application of their VAR-based methodology to the TVP-VAR reveals that the degree of Ricardian behavior of the government has been strengthened.

Figure 17 depicts point estimates of cumulative responses of liabilities to a surplus shock together with historical data on debt-to-output ratio. The degree of Ricardian behavior has been strengthened since the late 1970s, showing some weakening in the early 1990s, the early 2000s, and the late 2000s.[27] A corroborative evidence is provided by Sala (2004), who suggests that the U.S. fiscal policy

[27] While the early 2000s and the late 2000s are the periods during which large-scale stimulus packages are implemented, the early 1990 features steady fiscal consolidation efforts. In response to the accelerated deterioration of the budget due to a recession that began in July 1990, the Budget Enforcement Act that creates caps for discretionary spending and "pay-as-you-go" (PAYGO) rules had been adopted in 1990. However, debt-to-output did not decline until the Omnibus Budget Reconciliation Act of 1993 that brings tax increase came into effect in 1994.

can be characterized as non-Ricardian before 1979, while it is truly Ricardian since the 1990s. It is also worth noting that the periods when weakening of Ricardian behavior is observed largely coincide with the timings often suggested as the periods of FTPL regime (e.g., Davig and Leeper (2011); Gonzalez-Astudillo (2014)). Figure 17 also indicates that the cumulative response of liabilities and the debt-to-output ratio largely move in opposite directions, suggesting that the corrective action of the U.S. government becomes stronger in the presence of higher indebtedness. If the government moves toward more Ricardian fiscal policy in response to the increase in public debt, expectation on future tax burden increases, thereby leading to smaller multipliers. This interpretation shares views on the relationship between debt and multipliers with various strands of literature. The nonlinear relationship between the corrective action of the government and the level of public debt is already pointed out by Bohn (1998) who provides evidence that the marginal response of the U.S. surplus to changes in debt is an increasing function of the debt level. Combining the Ricardian explanation presented above and the findings of Bohn (1998), we conjecture that the accumulation of public debt since the early 1980s plays an important role in changing the fiscal policy stance, and thus serves as the major driving force for the observed decline in government spending multipliers. It should be noted that the changes in fiscal policy stance occurs soon after the passage of the Congressional Budget and Impoundment Act of 1974 that establishes the Congressional Budget Office. Congress has introduced a variety of budget rules since then in attempting to impose a fiscal discipline on the budgetary process. By examining the effects of budget rules, Auerbach (2008) concludes that those rules appear to have had some success at deficit control.

4.5 Conclusion

In this chapter, we have provided new empirical evidence on the evolution of government spending multipliers in the post-war U.S. From a methodological point of view, we present time profile of the changes in multipliers by exploiting a TVP-VAR framework, instead of relying on sub-sample analysis and regime switching models. The identification of government spending shocks are achieved by means of sign restrictions in addition to the traditional recursive method. Irrespective of the use of alternative identification schemes, the results document that government spending multipliers have declined substantially since the late 1970s. Furthermore, time profiles of output and consumption responses suggest that the decline in output multiplier is mostly led by that in consumption multiplier.

Our medium-scale TVP-VAR that includes monetary variables and public debt together with sign restrictions allows us to examine the cause of the decline by conducting scenario analysis. With the addition of restrictions, we can study government spending multipliers under different state of business cycle. Although these multipliers are essentially hypothetical in the TVP-VAR framework, we find larger multipliers in recession and smaller ones in expansion in line with existing literature. The time profiles of output responses in recession and expansion indicate that those can be viewed as extreme bounds, and that the state of business cycle plays little role in the time-variation in government spending multipliers. Calculating the time profiles of price level and interest rate responses to government spending shocks under different monetary policy scenario, on the other hand, we find a stable relationship between them, which indicates that monetary policy response to government spending shocks does not change much throughout the estimation period. It is also shown that the inflationary effects of government spending shocks become larger since the late 1970s in accordance with the accumulation of public debt.

Applying the TVP-VAR technique for the testing of changes in fiscal policy regime, we further find that the degree of Ricardian behavior of the government were strengthened since the late 1970s, which corresponds to the period when government spending multipliers declined. The results lead us to conjecture that the accumulation of government debt during the period may play an important role in changing the fiscal policy stance, and thus serve as the major driving force for the observed decline in government spending multipliers. While empirical evidence on the negative correlation between debt and multipliers has been established for cross-country data, this chapter provides it by analyzing the U.S. time series data.

Much work still need to be done. Although our atheoretical VAR-based approach is a flexible way to model the evolution of time series data, it has limitations in explaining the underlying mechanism. It would be worth exploring to develop a theoretical model that account for the relation between the time-variation in multipliers and fiscal policy behavior provided in this chapter.

4.6 Tables and Figures

Table 1: Empirical studies: The nonlinear effects of government spending shocks in the U.S.

Study	Sample	Method	Results
(1) State-dependent			
Auerbach and Gorodnichenko (2012)	1947:Q1-2008:Q4	Smooth transition VAR (STVAR) (Measure of slack: moving average of GDP growth rate), Blanchard and Perotti (2002b)	Cumulative multipliers (5yrs): 2.24 (recessions), -0.33 (expansions)
Bachmann and Sims (2012)	1960:Q1-2011:Q1	Smooth transition VAR (STVAR) (Measure of slack: moving average of GDP growth rate), Recursive	Cumulative multipliers (5yrs): 2.16 (recessions), 0.15 (expansions)
Batini et al. (2012)	1975:Q1-2010:Q2	Threshold VAR (TVAR) (Measure of slack: GDP growth rate), Recursive	Cumulative multipliers (2yrs): 2.17 (recessions), 0.49 (expansions)
Candelon and Lieb (2013)	1968:Q1-2010:Q4	Short-run threshold VECM (SR-TVECM) (Measure of slack: Chicago Fed National Activity Index), Sign restrcitions	Impact multipliers: around 2.4 at the highest (recessions), between 1 and 0 (expansions)
Caggiano et al. (2015)	1981:Q3-2013:Q1	Smooth transition VAR (STVAR) (Measure of slack: moving average of GDP growth rate), Recursive	Cumulative multipliers (5yrs): 1.09 (deep recessions), -3.28 (strong expansions), 0.83 (mild recessions), -2.37 (weak expansions)
Owyang et al. (2013)	1890:Q1-2010:Q1	Jordà's (2005) local projection method (Measure of slack: unemployment rate), Narrative	Cumulative multipliers (4yrs): 0.78 (high unemployment), 0.88 (low unemployment)
Ramey and Zubairy (2014)	1890:Q1-2013:Q4	Jordà's (2005) local projection method (Measure of slack: unemployment rate), Narrative	Cumulative multipliers (4yrs): 0.76 (high unemployment), 0.96 (low unemployment)
(2) Time-dependent			
Bilbiie et al. (2008)	1957:Q1-1979:Q2 (S1), 1983:Q1-2004:Q4 (S2)	Sub-sample analysis based on VAR, Recursive	Cumulative multipliers (5yrs): 0.42 (S1), 0.35 (S2)
Cimadomo and Benassy-Quere (2012)	1971:Q1-2009:Q4	Rolling window analysis based on Factor-augmented VAR (FAVAR), Blanchard and Perotti (2002b)	Impact multipliers: relatively stable (at around 1.3), Multipliers at two year horizon: declines to negative value in the 1980s and 1990s
Pereira and Lopes (2014)	1965:Q2- 2009:Q2	TVP-VAR, Blanchard and Perotti (2002b)	Multipliers at one year horizon and longer: relatively stable (at around 0.75-0.5) after the late 1970s
Perotti (2004)	1960:Q1-1979:Q4 (S1), 1980:Q1-2001:Q4 (S2)	Sub-sample analysis based on VAR, Blanchard and Perotti (2002b)	Annualized cumulative responses of GDP (3yrs): 2.23 (S1), 1.48 (S2)

Notes: The cumulative multipliers of Bilbiie et al. (2008) presented above are calculated using cumulative responses of government spending and output reported in their study.

Table 2: Contemporaneous identifying restrictions

	Government spending	Monetary policy	Business cycle
Gov. spending	+	?	?
Output	?	?	+
Consumption	?	?	?
Price	?	−	?
Interest rate	?	+	?
Public debt	+	?	−

Notes: This table reports signs imposed on the impulse responses of the variables to an expansionary government spending shock, a contractionary monetary policy shock, and a positive business cycle shock. The question mark indicates that the responses of the variables are unrestricted. A positive sign [negative sign] indicates the response of the variables are restricted to be positive [negative] on impact.

Table 3: Estimation results for selected parameters

	Parameter	Mean	St. dev.	95% interval		CD	Inefficiency
Recursive	$(\Sigma_\beta)_1$	0.0003	0.0001	[0.0003	0.0004]	0.880	29.78
	$(\Sigma_\beta)_{40}$	0.0003	0.0001	[0.0003	0.0004]	0.697	21.46
	$(\Sigma_\beta)_{80}$	0.0003	0.0001	[0.0003	0.0004]	0.461	21.44
	$(\Sigma_\beta)_{120}$	0.0003	0.0001	[0.0003	0.0004]	0.499	27.45
	$(\Sigma_a)_1$	0.0144	0.0032	[0.0109	0.0186]	0.619	41.10
	$(\Sigma_a)_6$	0.0156	0.0043	[0.0113	0.0210]	0.506	69.25
	$(\Sigma_a)_{12}$	0.0139	0.0030	[0.0105	0.0177]	0.506	38.67
	$(\Sigma_h)_1$	0.0520	0.0166	[0.0337	0.0748]	0.051	120.21
	$(\Sigma_h)_3$	0.0254	0.0095	[0.0156	0.0381]	0.163	138.22
	$(\Sigma_h)_6$	0.4274	0.0818	[0.3286	0.5359]	0.877	50.27
Sign restrictions	$(\Sigma_\beta)_1$	0.0003	0.0001	[0.0003	0.0004]	0.371	26.24
	$(\Sigma_\beta)_{40}$	0.0003	0.0001	[0.0003	0.0004]	0.089	33.79
	$(\Sigma_\beta)_{80}$	0.0003	0.0001	[0.0003	0.0004]	0.135	32.46
	$(\Sigma_\beta)_{120}$	0.0003	0.0001	[0.0003	0.0004]	0.254	23.69
	$(\Sigma_a)_1$	0.0148	0.0036	[0.0109	0.0195]	0.609	35.86
	$(\Sigma_a)_6$	0.0157	0.0039	[0.0114	0.0208]	0.209	54.90
	$(\Sigma_a)_{12}$	0.0141	0.0031	[0.0106	0.0181]	0.343	40.56
	$(\Sigma_h)_1$	0.0505	0.0160	[0.0339	0.0697]	0.821	113.93
	$(\Sigma_h)_3$	0.0264	0.0109	[0.0151	0.0407]	0.802	157.36
	$(\Sigma_h)_6$	0.4317	0.0821	[0.3299	0.5392]	0.457	34.30

Notes: The parameters, $(\Sigma_j)_i$, stand for the square roots of the i-th diagonals of covariance matrices, Σ_j, where $j = \beta, a, h$. CD refers to the p-value associated with the convergence diagnostic of Geweke (1992).

Table 4: Restrictions to identify government spending shocks in different scenarios

	Recession	Expansion	Monetary contraction	Monetary expansion
Gov. spending	+	+	+	+
Output	?	?	?	?
Consumption	?	?	?	?
Price	−	+	?	?
Interest rate	?	?	+	−
Public debt	+	+	+	+

Notes: This table reports signs imposed on the impulse responses of the variables to an expansionary government spending shock in different scenarios. The question mark indicates that the responses of the variables are unrestricted. A positive sign [negative sign] indicates the response of the variables are restricted to be positive [negative] on impact.

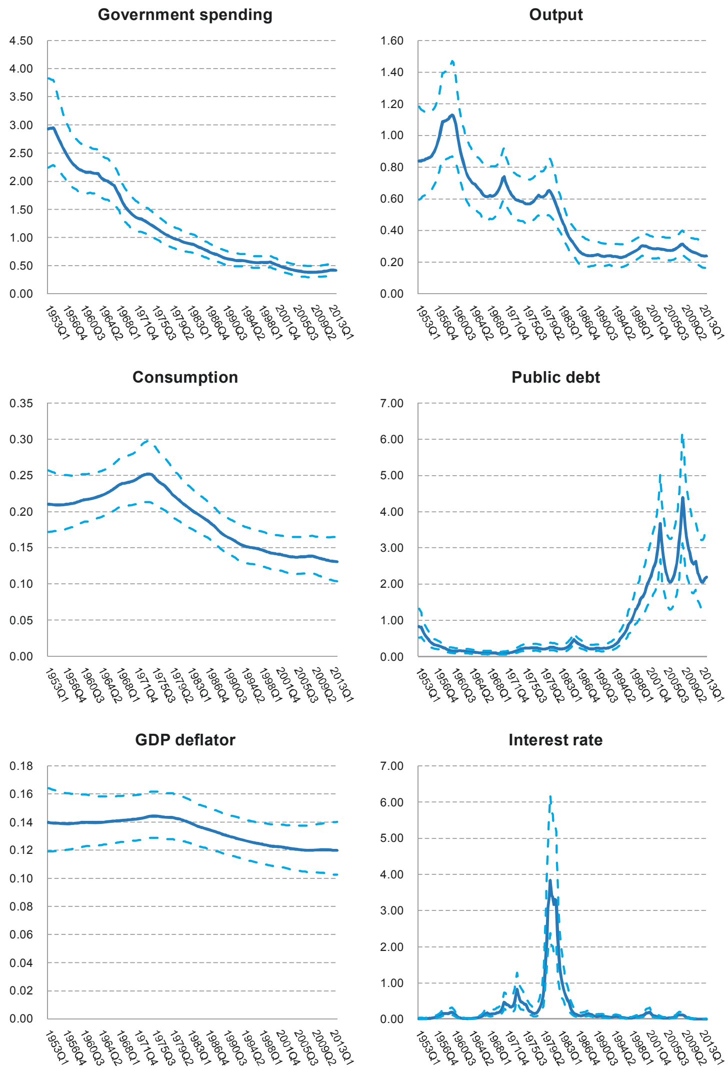
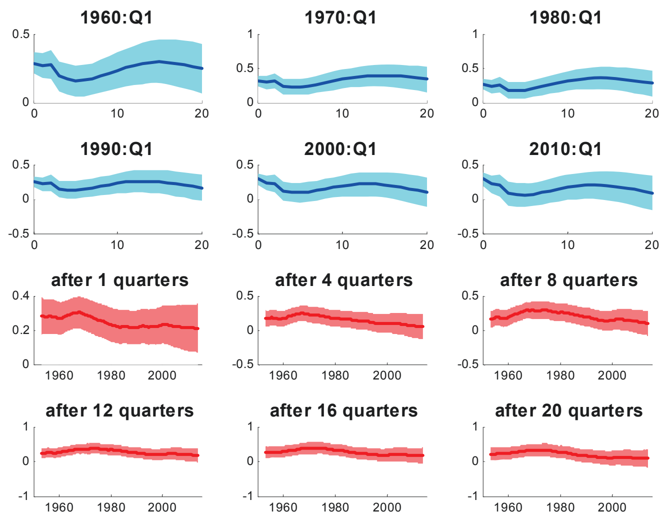
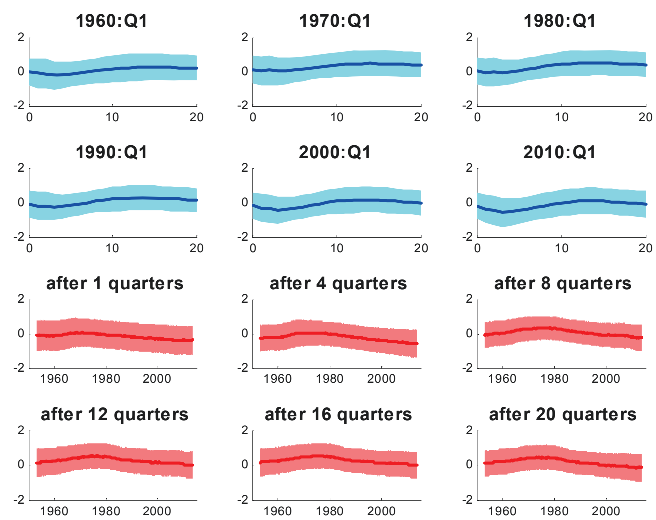


Figure 1: Posterior estimates for stochastic volatility of structural shocks (Recursive)

Notes: Solid lines: posterior mean, dashed lines: 16th and 84th percentiles.



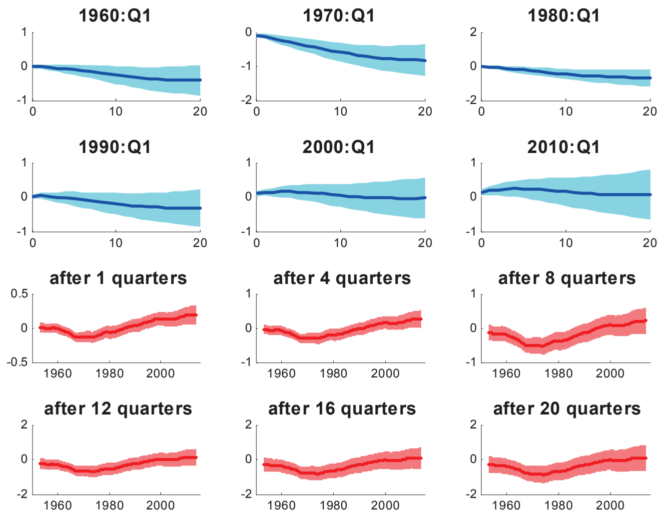
(a) Recursive



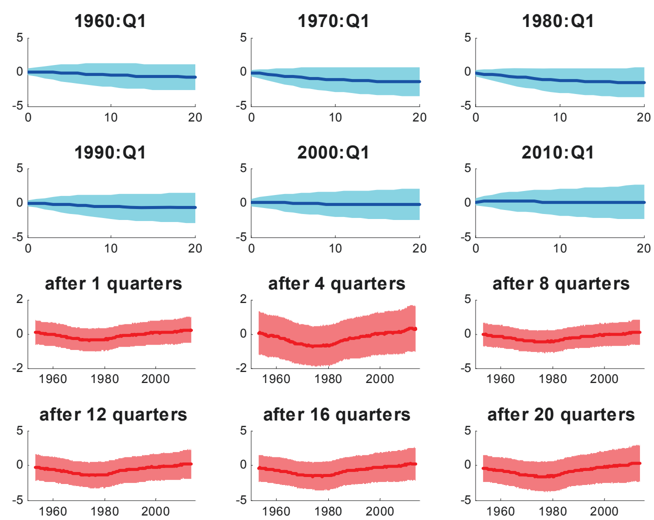
(b) Sign restrictions

Figure 2: Responses of real GDP to an expansionary government spending shock

Notes: The figures show the responses to a one percentage point increase in government spending. The solid lines and the shaded areas represent posterior means and the 16-84 percent credible bands.



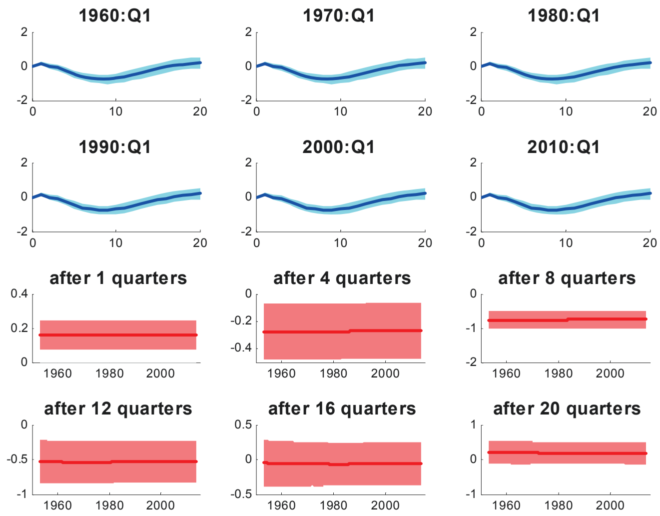
(a) Recursive



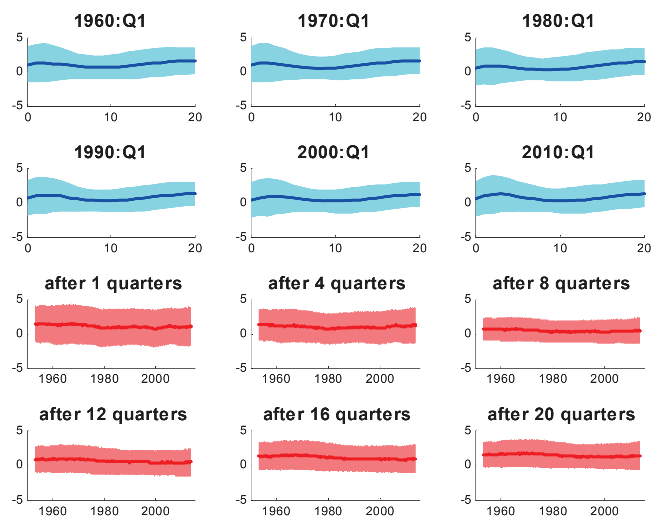
(b) Sign restrictions

Figure 3: Responses of GDP deflator to an expansionary government spending shock

Notes: The figures show the responses to a one percentage point increase in government spending. The solid lines and the shaded areas represent posterior means and the 16-84 percent credible bands.



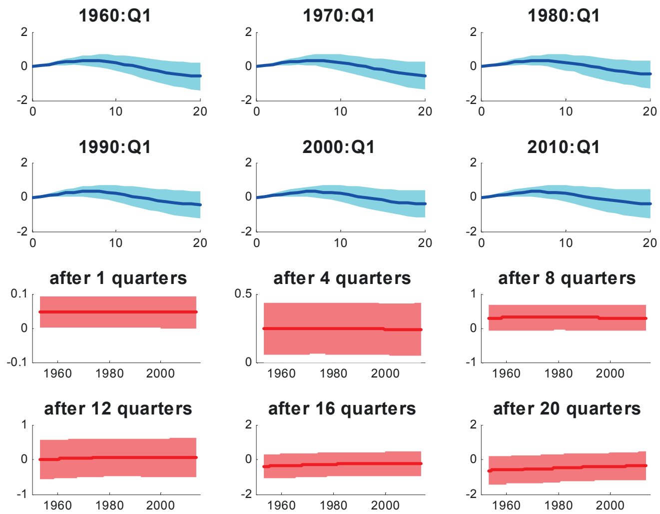
(a) Recursive



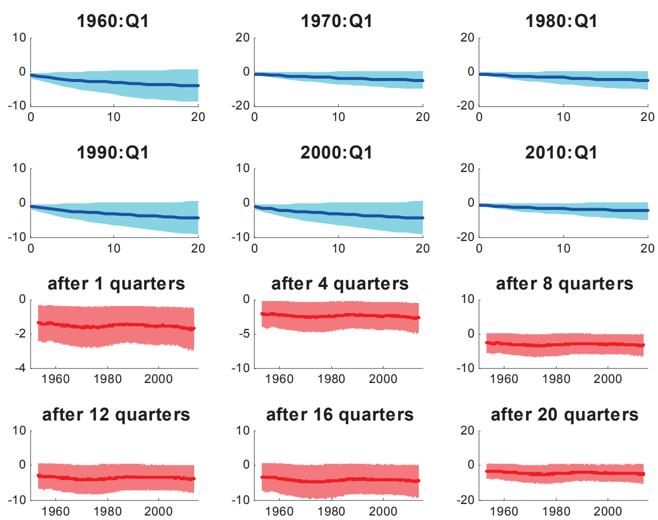
(b) Sign restrictions

Figure 4: Responses of real GDP to a contractionary monetary policy shock

Notes: The figures show the responses to a one percentage point increase in interest rate. The solid lines and the shaded areas represent posterior means and the 16-84 percent credible bands.



(a) Recursive



(b) Sign restrictions

Figure 5: Responses of GDP deflator to a contractionary monetary policy shock

Notes: The figures show the responses to a one percentage point increase in interest rate. The solid lines and the shaded areas represent posterior means and the 16-84 percent credible bands.

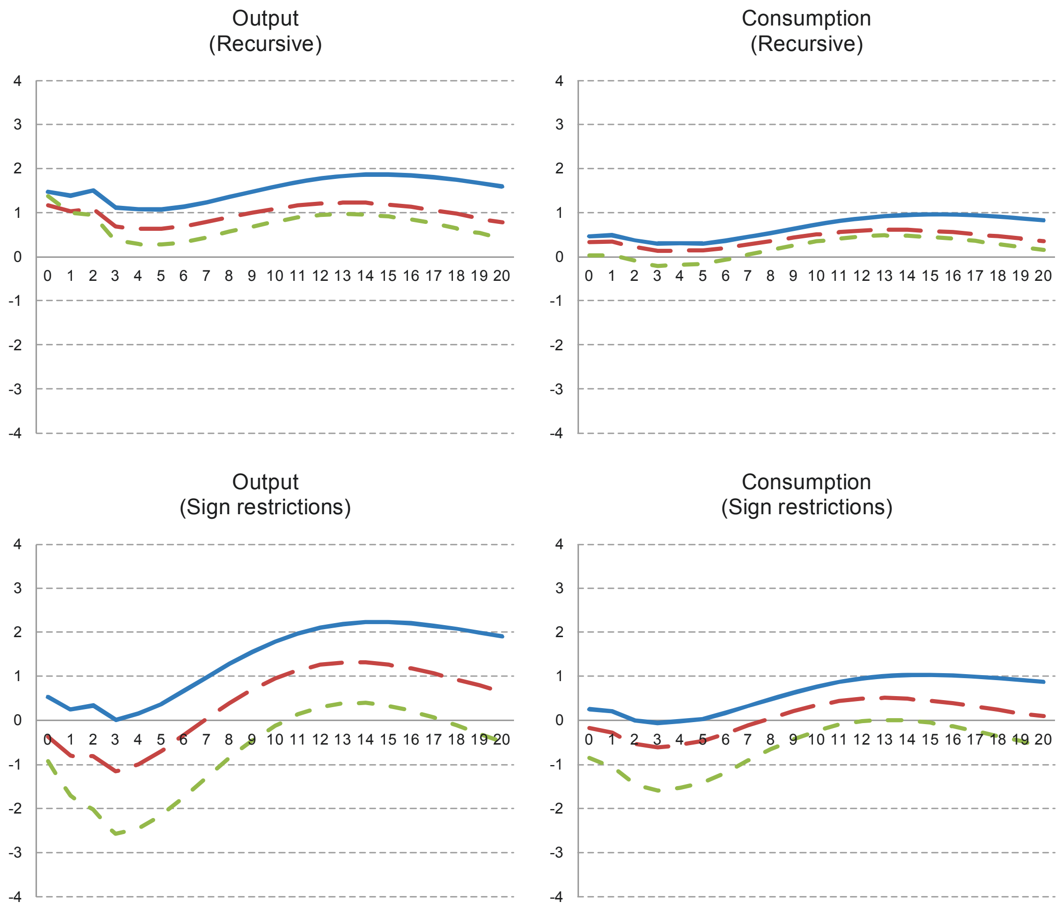


Figure 6: Government spending multipliers

Notes: The figures show posterior means of the responses to a one dollar increase in government spending. Solid lines: 1970:Q1, dashed lines: 1990:Q1, dotted lines: 2010Q1.

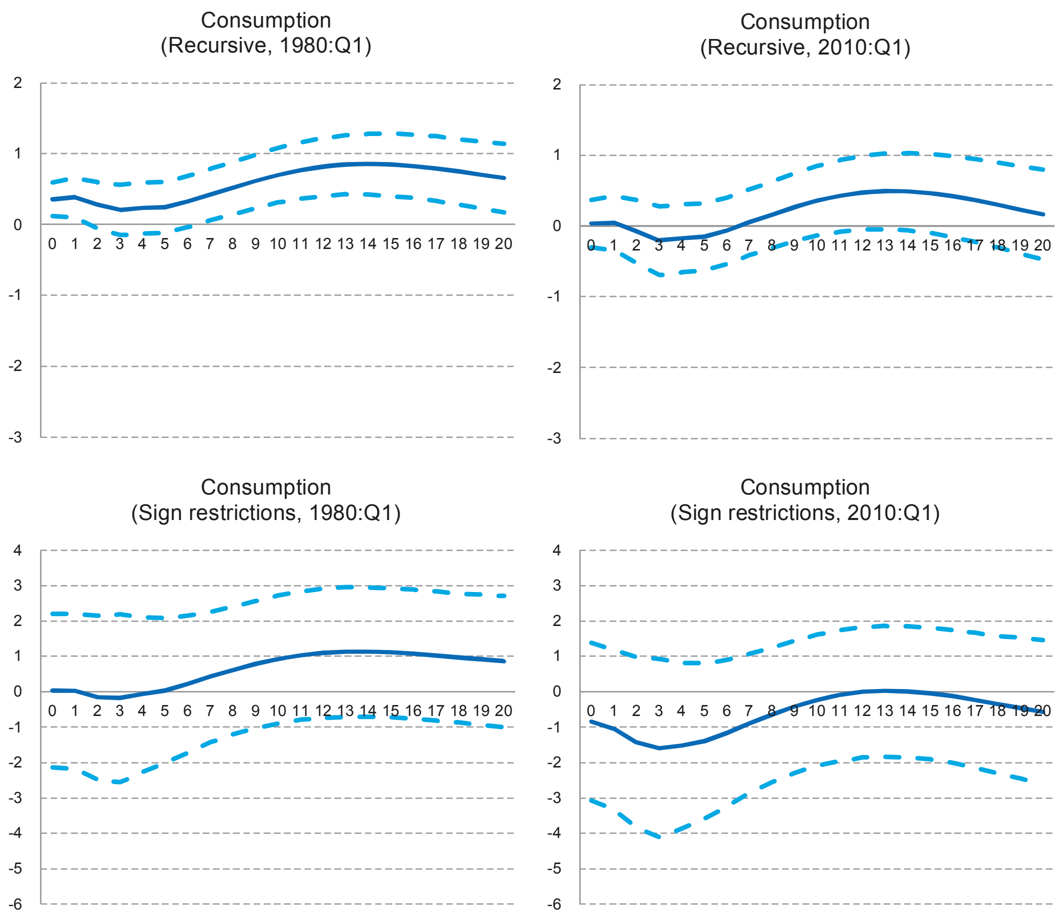


Figure 7: Consumption multipliers

Notes: The figures show the responses to a one dollar increase in government spending. Solid lines: posterior mean, dashed lines: 16th and 84th percentiles.

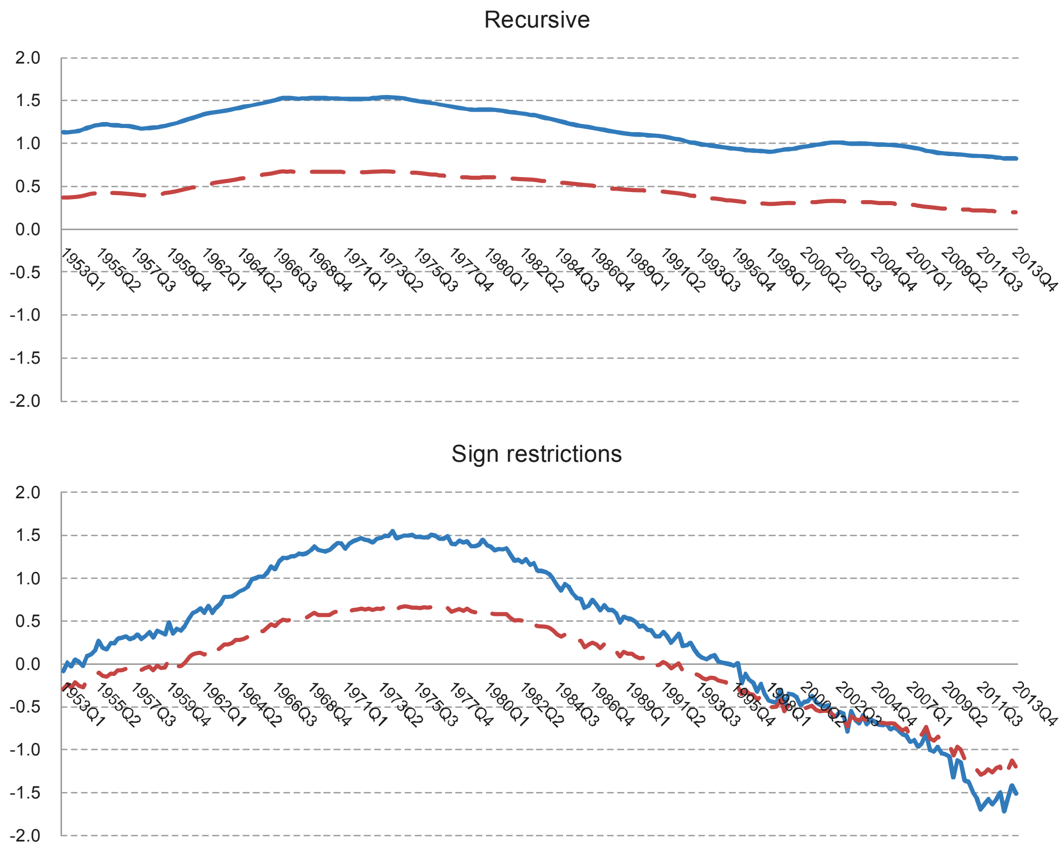


Figure 8: Cumulative government spending multipliers

Notes: The figures show posterior means of the cumulative responses of output (solid lines) and consumption (dashed lines) to a one dollar government spending increase evaluated at horizon 20.

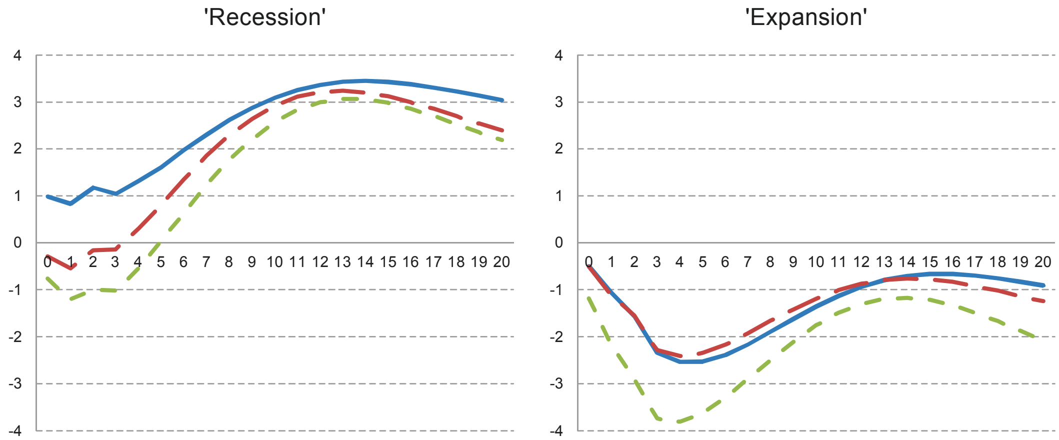


Figure 9: Government spending multipliers in different business cycle scenarios

Notes: The figures show posterior means of the responses of output to a one dollar increase in government spending. Solid lines: 1970:Q1, dashed lines: 1990:Q1, dotted lines: 2010Q1.

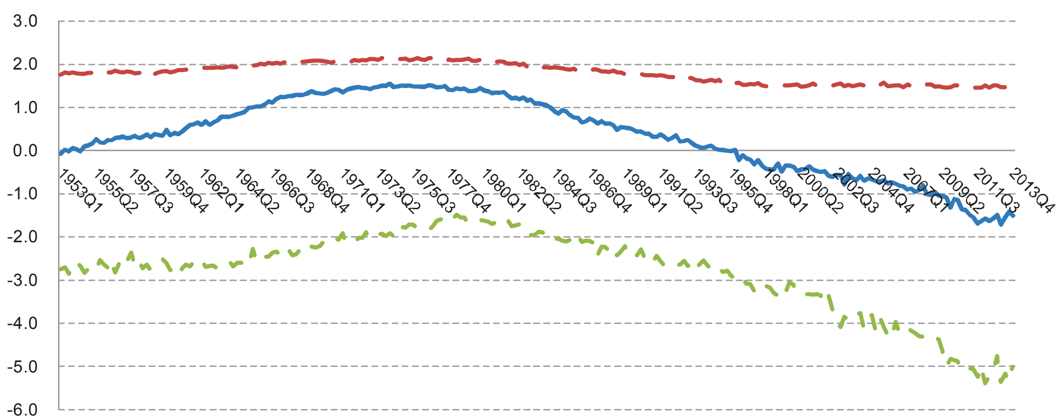


Figure 10: Cumulative government spending multipliers in different business cycle scenarios

Notes: The figure shows posterior means of the cumulative output multipliers evaluated at horizon 20. Solid lines: basic, dashed lines: recession, dotted lines: expansion.

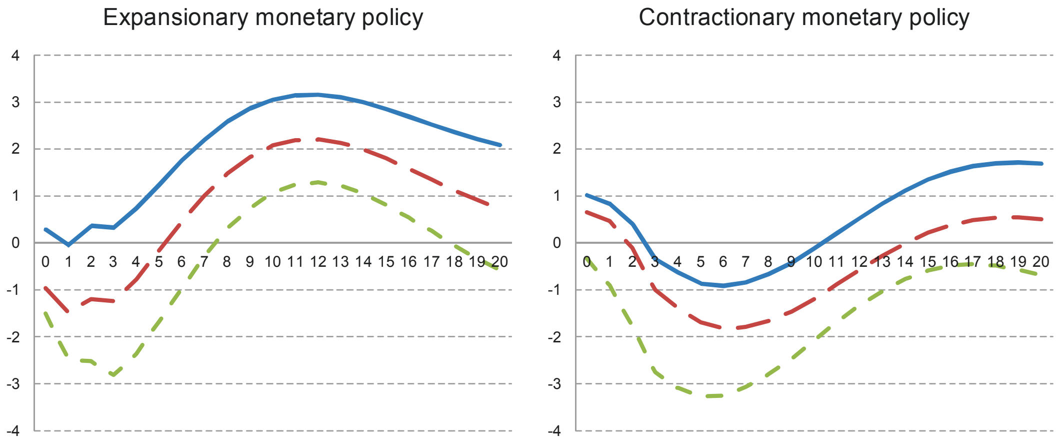


Figure 11: Government spending multipliers in different monetary policy scenarios

Notes: The figures show posterior means of the responses of output to a one dollar increase in government spending. Solid lines: 1970:Q1, dashed lines: 1990:Q1, dotted lines: 2010Q1.

Figure 12: Government spending multipliers in different business cycle and monetary policy scenarios

Notes: The figures show posterior means of the responses of output to a one dollar increase in government spending. Solid lines: 1970:Q1, dashed lines: 1990:Q1, dotted lines: 2010Q1.

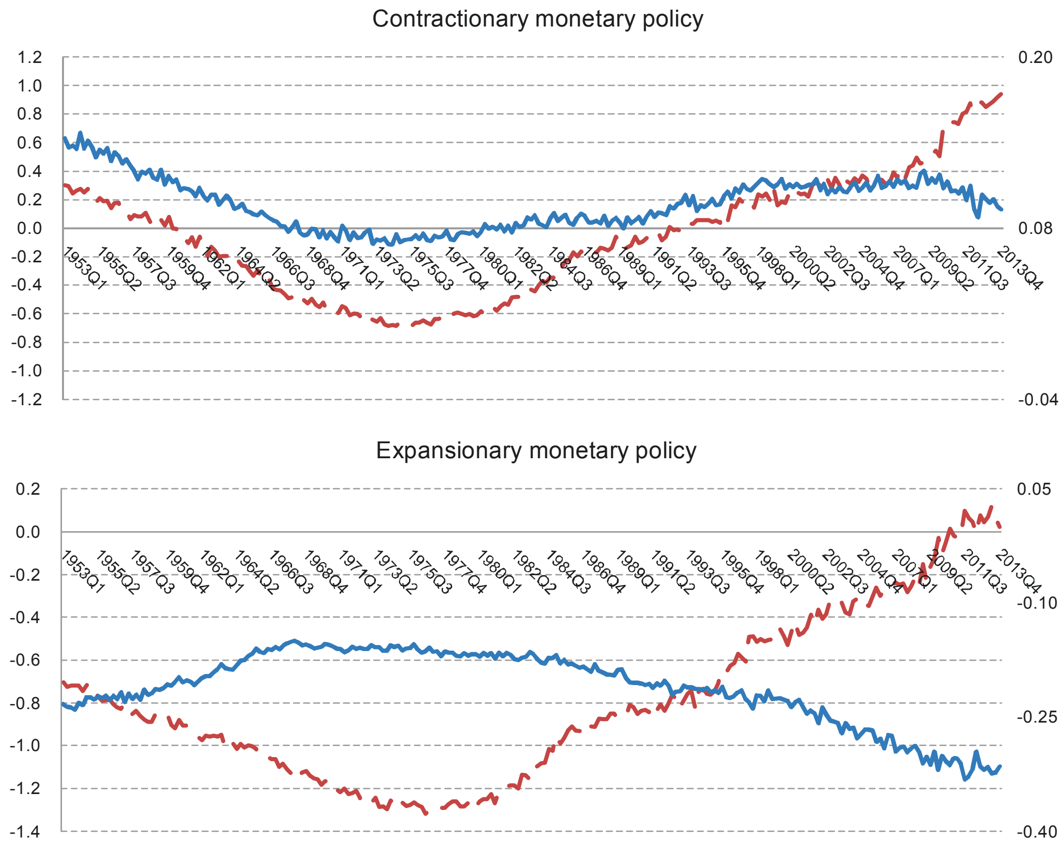


Figure 13: Cumulative responses of price and interest rate in different monetary policy scenarios

Notes: The figures show posterior means of the cumulative percent change in price level (dashed lines, left axis) and interest rate (solid lines, right axis) divided by the cumulative percent change in the government spending after 20 quarters.

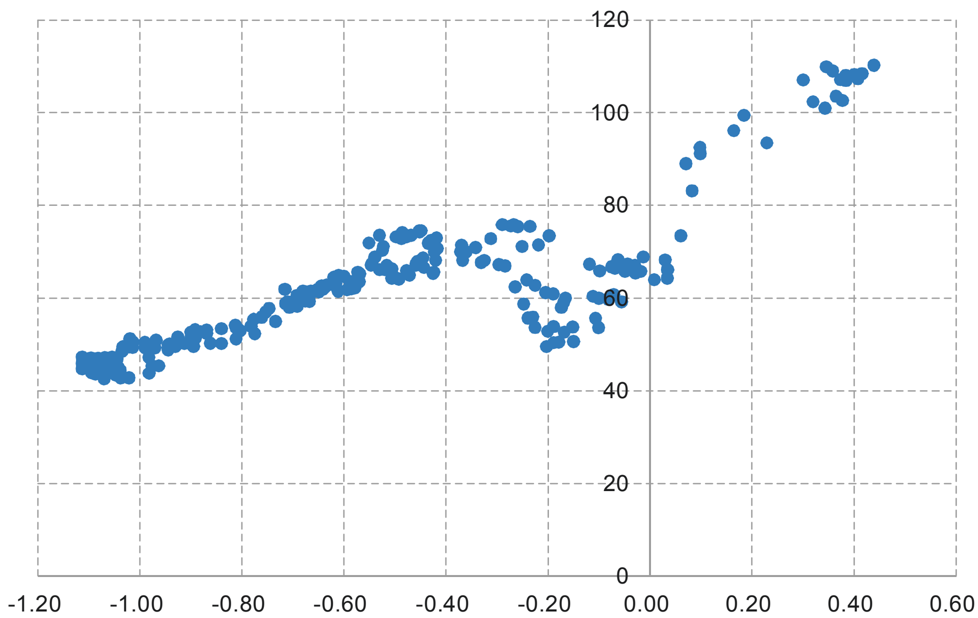


Figure 14: Inflationary effects of government spending and debt-to-GDP ratio

Notes: The figure plots posterior means of the cumulative responses of price level to government spending shocks evaluated at horizon 20 (horizontal axis) in the basic scenario and historical data on debt-to-GDP (vertical axis).

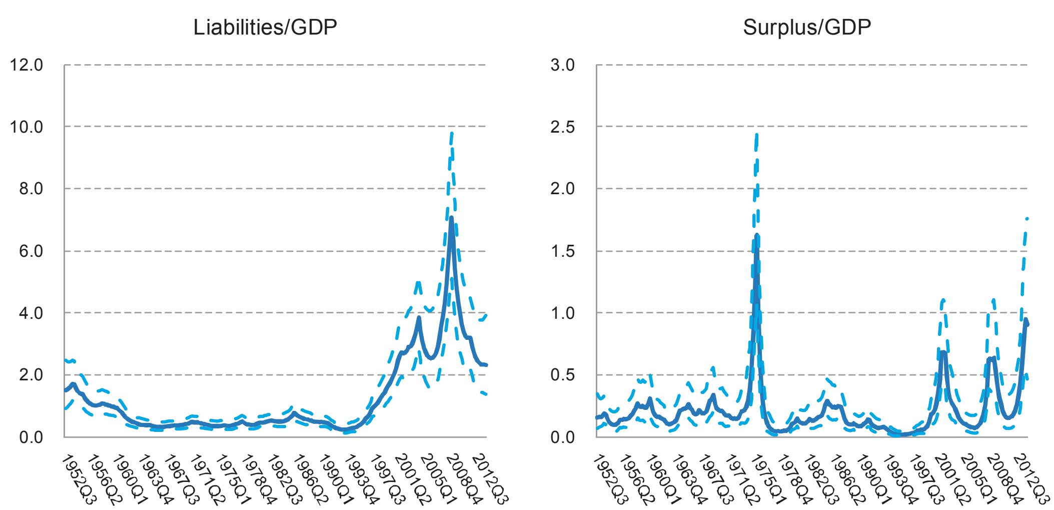


Figure 15: Posterior estimates for stochastic volatility of structural shocks

Notes: Solid lines: posterior mean, dashed lines: 16th and 84th percentiles.

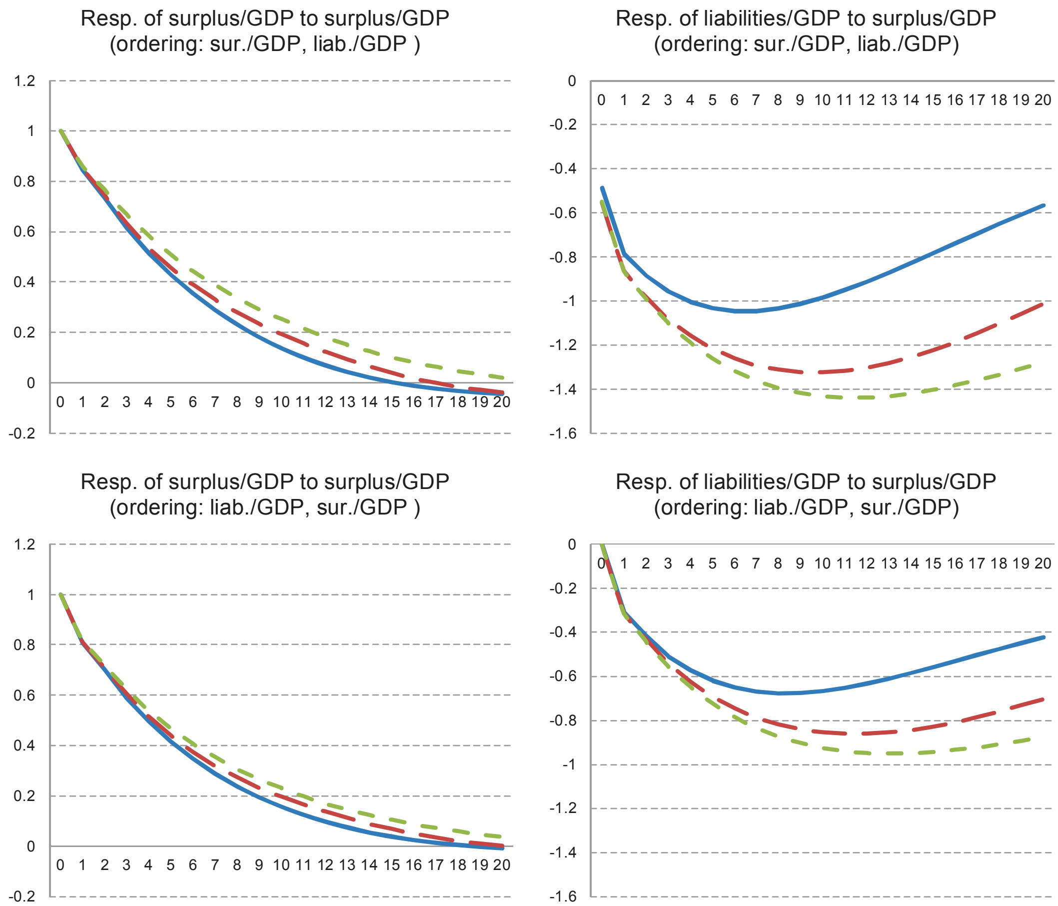


Figure 16: Surplus and debt dynamics

Notes: The figures show posterior means of the responses to a one percentage point increase in surplus/GDP. Solid lines: 1970:Q1, dashed lines: 1990:Q1, dotted lines: 2010Q1.

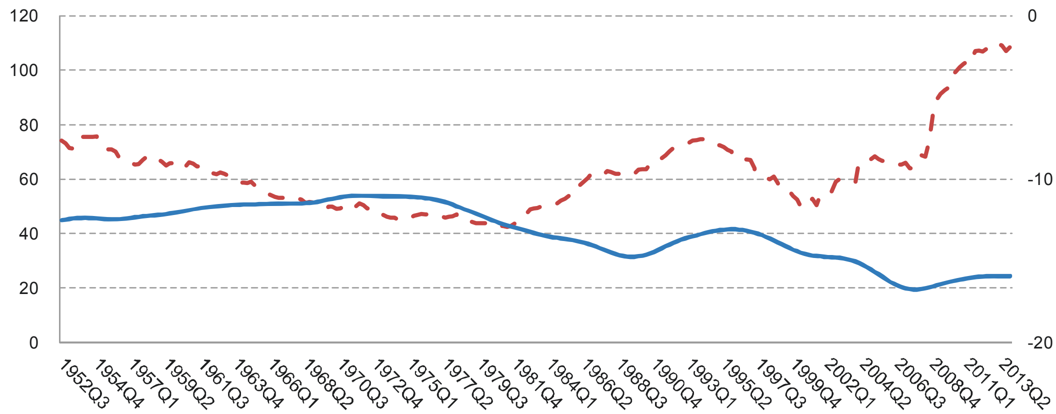


Figure 17: Cumulative response of liabilities/GDP to surplus/GDP

Notes: The figure shows posterior means of the cumulative response of liabilities/GDP to a one percentage point increase in surplus/GDP evaluated at horizon 20 (solid line, right axis) and historical data on debt-to-GDP ratio (dashed line, left axis).

APPENDICES

A. Appendix for Chapter 2: Calculation Details for the Effective Tax Rates

The effective tax rate series are calculated based on the methodology of Mendoza et al. (1994). All data are taken from the *National Accounts of Japan* (93SNA, Reference year: 1995) and are seasonally adjusted by the author. The sources and the formula used are as follows.

Letting τ^h denote households' average tax rate on total income, effective average tax rates for τ^c, τ^l, τ^k are calculated as:

$$\tau^c = \left[\frac{TI}{C - TI}\right] \times 100$$

$$\tau^h = \left[\frac{TDI}{OSPUE + PEI + W}\right]$$

$$\tau^l = \left[\frac{\tau^h W + ESC}{W + TSC}\right] \times 100$$

$$\tau^k = \left[\frac{\tau^l (OSPUE + PEI) + (TD - TDI) + TP}{OS}\right] \times 100$$

where:

- TI : Taxes on products, General government, Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- C : Private final consumption expenditure, Gross domestic product (Expenditure approach at current prices), *Main Time Series.*

- TDI : Current taxes on income, wealth, etc., Households (including private unincorporated enterprises), Secondary distribution of income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- $OSPUE$: Operating surplus, Households (including private unincorporated enterprises), Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- PEI : Property income, Households (including private unincorporated enterprises), Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- W : Wages and salaries, Households (including private unincorporated enterprises), Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- ESC : Employers' social contributions, Households (including private unincorporated enterprises), Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- TSC : Total social contributions, Households (including private unincorporated enterprises), Secondary distribution of income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- TD : Current taxes on income, wealth, etc., General government, Secondary distribution of income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- TP : Other taxes on production, General government, Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

- OS : Operating surplus, Total economy, Allocation of primary income account, *Income and Outlay Accounts classified by Institutional Sectors.*

B. Appendix for Chapter 2: The Log-linearized Model

Ricardian Households

Consumption Euler Equation

$$\hat{C}_t^R = \frac{h}{1+h}\hat{C}_{t-1}^R + \frac{1}{1+h}E_t\hat{C}_{t+1}^R - \frac{1-h}{(1+h)\sigma_c}\left(\hat{R}_t - E_t\hat{\pi}_{t+1}\right) + \frac{1-h}{(1+h)\sigma_c}\left(\hat{\varepsilon}_t^b - E_t\hat{\varepsilon}_{t+1}^b\right) - \frac{1-h}{(1+h)\sigma_c}\left(\hat{\tau}_t^{ctil} - E_t\hat{\tau}_{t+1}^{ctil}\right), \quad \text{(B.10)}$$

where

$$\hat{\tau}_t^{ctil} = \frac{\bar{\tau}^c}{1+\bar{\tau}^c}\hat{\tau}_t^c, \quad \text{(B.11)}$$

$$\hat{\varepsilon}_t^b = \rho_b\hat{\varepsilon}_{t-1}^b + \eta_t^b. \quad \text{(B.12)}$$

Investment Euler Equation

$$\hat{I}_t = \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{I}_{t+1} + \frac{\varsigma}{1+\beta}\hat{Q}_t - \frac{\beta E_t\hat{\varepsilon}_{t+1}^i - \hat{\varepsilon}_t^i}{1+\beta}, \quad \text{(B.13)}$$

where $\varsigma \equiv 1/S^{''}(1)$ and

$$\hat{\varepsilon}_t^i = \rho_i\hat{\varepsilon}_{t-1}^i + \eta_t^i. \quad \text{(B.14)}$$

Q Equation

$$\hat{Q}_t = -\left(\hat{R}_t - \hat{\pi}_{t+1}\right) + \frac{1-\delta}{1-\delta+\left(1-\bar{\tau}^k\right)\bar{r}^k}\hat{Q}_{t+1} + \frac{\left(1-\bar{\tau}^k\right)\bar{r}^k}{1-\delta+\left(1-\bar{\tau}^k\right)\bar{r}^k}\hat{r}_{t+1}^k - \frac{\bar{\tau}^k\bar{r}^k}{1-\delta+\left(1-\bar{\tau}^k\right)\bar{r}^k}\hat{\tau}_{t+1}^k + \hat{\eta}_t^q. \quad \text{(B.15)}$$

Capital Utilization Decision Equation

$$\hat{z}_t = \psi\left[\hat{r}_t^k - \frac{\bar{\tau}^k}{1-\bar{\tau}^k}(1+\hat{r}_t^k)\hat{\tau}_t^k\right], \quad \text{(B.16)}$$

where $\psi \equiv \Psi^{'}(1)/\ \Psi^{''}(1)$.

Capital Law of Motion

$$\hat{K}_t = (1-\delta)\hat{K}_{t-1} + \delta \hat{I}_t. \tag{B.17}$$

Real Wage Law of Motion

$$\begin{aligned} \hat{w}_t = {} & \frac{\beta}{1+\beta} E_t \hat{w}_{t+1} + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta} E\hat{\pi}_{t+1} \\ & - \frac{1+\beta\gamma_w}{1+\beta}\hat{\pi}_t + \frac{\gamma_w}{1+\beta}\hat{\pi}_{t-1} - \frac{1}{1+\beta}\frac{(1-\beta\xi_w)(1-\xi_w)}{\left(1+\frac{(1+\lambda_w)\sigma_l}{\lambda_w}\right)\xi_w} \\ & \times \left[\begin{array}{c} \hat{w}_t - \sigma_l \hat{L}_t - \frac{\sigma_c}{1-h}\left(C_t^R - hC_{t-1}^R\right) \\ -\hat{\varepsilon}_t^l - \eta_t^w - \frac{\bar{\tau}^d}{1-\bar{\tau}^d}\hat{\tau}_t^d - \frac{\bar{\tau}^c}{1+\bar{\tau}^c}\hat{\tau}_t^c \end{array}\right], \end{aligned} \tag{B.18}$$

where

$$\hat{\varepsilon}_t^l = \rho_l \hat{\varepsilon}_{t-1}^l + \eta_t^l. \tag{B.19}$$

Non-Ricardian Households

$$\frac{\bar{C}^{NR}}{\bar{Y}}\left[\hat{C}^{NR}(1+\bar{\tau}^c) + \bar{\tau}^c\hat{\tau}_t^c\right] = \bar{w}\frac{\bar{L}}{\bar{Y}}\left[\left(1-\bar{\tau}^d\right)\left(\hat{w}_t + \hat{L}_t\right) - \bar{\tau}^d\hat{\tau}_t^d\right]. \tag{B.20}$$

Firms

Marginal Cost

$$\widehat{mc}_t = (1-\alpha)\,\hat{w}_t + \alpha \hat{r}_t^k - \hat{\varepsilon}_t^a. \tag{B.21}$$

Labor Demand

$$\hat{L}_t = -\hat{w}_t + \hat{r}_t^k + \hat{z}_t + \hat{K}_{t-1}. \tag{B.22}$$

Profit Payment

$$\frac{\bar{D}}{\bar{P}\bar{Y}}\hat{d}_t = (1-\overline{mc})\hat{Y}_t - \overline{mc}\varphi\widehat{mc}_t. \tag{B.23}$$

Inflation Law of Motion

$$\begin{aligned}\hat{\pi}_t =& \frac{\beta}{1+\beta\gamma_p} E_t\hat{\pi}_{t+1} + \frac{\gamma_p}{1+\beta\gamma_p}\hat{\pi}_{t-1} \\ &+ \frac{1}{1+\beta\gamma_p}\frac{\left(1-\beta\xi_p\right)\left(1-\xi_p\right)}{\xi_p}\left[\alpha\hat{r}_t^k + (1-\alpha)\hat{w}_t - \hat{\varepsilon}_t^a + \eta_t^p\right], \end{aligned} \tag{B.24}$$

where

$$\hat{\varepsilon}_t^a = \rho_a\hat{\varepsilon}_{t-1}^a + \eta_t^a. \tag{B.25}$$

Fiscal and Monetary Authorities

Fiscal Policy Rules

$$\begin{aligned}\frac{\bar{G}}{\bar{Y}}\hat{G}_t + \frac{\bar{B}}{\bar{P}\bar{Y}}\left(\hat{b}_{t-1} - \hat{\pi}_t\right) =& \bar{\tau}^c\frac{\bar{C}}{\bar{Y}}\left(\hat{\tau}_t^c + \hat{C}_t\right) + \bar{\tau}^d\bar{w}\frac{\bar{L}}{\bar{Y}}\left(\hat{\tau}_t^d + \hat{w}_t + \hat{L}_t\right) \\ &+ \bar{\tau}^k\bar{r}^k\frac{\bar{K}}{\bar{Y}}\left(\hat{\tau}_t^k + \hat{r}_t^k + \hat{z}_t + \hat{K}_{t-1}\right) \\ &+ \bar{\tau}^k\frac{\bar{D}}{\bar{P}\bar{Y}}\left(\hat{\tau}_t^k + \hat{d}_t\right) + \beta\frac{\bar{B}}{\bar{P}\bar{Y}}\left(\hat{b}_t - \hat{R}_t\right), \end{aligned} \tag{B.26}$$

where

$$\hat{\tau}_t^c = \rho_{tc}\hat{\tau}_{t-1}^c + (1-\rho_{tc})\,\phi_{tcb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^{tc}, \tag{B.27}$$

$$\hat{\tau}_t^d = \rho_{td}\hat{\tau}_{t-1}^d + (1-\rho_{td})\,\phi_{tdb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^{td}, \tag{B.28}$$

$$\hat{\tau}_t^k = \rho_{tk}\hat{\tau}_{t-1}^k + (1-\rho_{tk})\,\phi_{tkb}(\hat{b}_{t-1} - \hat{Y}_{t-1}) + \eta_t^{tk}, \tag{B.29}$$

$$\hat{G}_t = \rho_g\hat{G}_{t-1} + \left(1-\rho_g\right)\phi_{gy}\hat{Y}_{t-1} + \eta_t^g. \tag{B.30}$$

Monetary Policy Rule

$$\hat{R}_t = \rho_r\hat{R}_{t-1} + (1-\rho_r)\,\phi_{r\pi}\hat{\pi}_{t-1} + (1-\rho_r)\,\phi_{ry}\hat{Y}_t + \eta_t^R. \tag{B.31}$$

Aggregation and Market Clearing

Goods Market Equilibrium Condition

$$\frac{\bar{C}}{\bar{Y}}\hat{C}_t = (1-\omega)\frac{\bar{C}^R}{\bar{Y}}\hat{C}_t^R + \omega\frac{\bar{C}^{NR}}{\bar{Y}}\hat{C}_t^{NR}. \tag{B.32}$$

$$\hat{Y}_t = \frac{\bar{C}}{\bar{Y}}\hat{C}_t + \delta\frac{\bar{K}}{\bar{Y}}\hat{I}_t + \frac{\bar{G}}{\bar{Y}}\hat{G}_t + \left(1-\bar{\tau}_t^k\right)\bar{r}_t^k\frac{\bar{K}}{\bar{Y}}\hat{z}_t. \tag{B.33}$$

Aggregate Production Equation

$$\hat{Y}_t = \varphi\left(\hat{\varepsilon}_t^a + \alpha\hat{z}_t + \alpha\hat{K}_{t-1} + (1-\alpha)\hat{L}_t\right), \tag{B.34}$$

where $\varphi \equiv 1 + \Phi/\bar{Y}$.

C. Appendix for Chapter 3: The Log-linearized Model

Firms

Domestic-good producing firms

$$\begin{aligned}\hat{\pi}_t^d &= \frac{\beta}{1+\kappa_d\beta}E_t\hat{\pi}_{t+1}^d + \frac{\kappa_d}{1+\kappa_d\beta}\hat{\pi}_{t-1}^d \\ &+\frac{1}{1+\kappa_d\beta}\frac{(1-\beta\xi_d)(1-\xi_d)}{\xi_d}\left[\widehat{mc}_t^d+\hat{\lambda}_{d,t}\right], \end{aligned} \tag{C.35}$$

where

$$\hat{\lambda}_t^d = \rho_{\lambda^d}\hat{\lambda}_{t-1}^d + \varepsilon_{\lambda^d,t}, \tag{C.36}$$

$$\widehat{mc}_t^d = (1-\alpha)\,\widehat{\bar{w}}_t + \alpha\widehat{\bar{r}}_t^k - \hat{\epsilon}_t - \alpha_g\hat{k}_{t-1}^g + \alpha_g\hat{\mu}_{z^+,t}, \tag{C.37}$$

$$\hat{\epsilon}_t = \rho_\epsilon\hat{\epsilon}_{t-1} + \varepsilon_{\epsilon,t}, \tag{C.38}$$

$$\widehat{\bar{r}}_t^k = \hat{L}_t - \hat{u}_t - \hat{k}_{t-1} + \widehat{\bar{w}}_t + \hat{\mu}_{z^+,t} + \hat{\mu}_{\Psi,t}. \tag{C.39}$$

$$\hat{d}_t^d = (1-\frac{1}{\lambda_d})y\hat{y}_t - y\widehat{mc}_t. \tag{C.40}$$

Importing firms and import-good wholesalers

$$\begin{aligned}\hat{\pi}_t^{m,c} &= \frac{\beta}{1+\kappa_{m,c}\beta}E_t\hat{\pi}_{t+1}^{m,c} + \frac{\kappa_{m,c}}{1+\kappa_{m,c}\beta}\hat{\pi}_{t-1}^{m,c} \\ &+\frac{1}{1+\kappa_{m,c}\beta}\frac{\left(1-\beta\xi_{m,c}\right)\left(1-\xi_{m,c}\right)}{\xi_{m,c}}\left[\widehat{mc}_t^{m,c}+\hat{\lambda}_t^{m,c}\right], \end{aligned} \tag{C.41}$$

where

$$\hat{\lambda}_t^{m,c} = \rho_{\lambda^{m,c}}\hat{\lambda}_{t-1}^{m,c} + \varepsilon_{\lambda^{m,c},t}, \tag{C.42}$$

$$\widehat{mc}_t^{m,c} = -\hat{\gamma}_t^f - \hat{\gamma}_t^{mc,d}, \tag{C.43}$$

$$\hat{d}_t^{m,c} = \gamma^{mc,d} c^m \left(\hat{\gamma}_t^{mc,d} + \hat{c}_t^m\right) - c^m \left(-\hat{\gamma}_t^f + \hat{c}_t^m\right). \tag{C.44}$$

$$\begin{aligned} \hat{\pi}_t^{m,i} &= \frac{\beta}{1+\kappa_{m,i}\beta} E_t \hat{\pi}_{t+1}^{m,i} + \frac{\kappa_{m,i}}{1+\kappa_{m,i}\beta} \hat{\pi}_{t-1}^{m,i} \\ &\quad + \frac{1}{1+\kappa_{m,i}\beta} \frac{\left(1-\beta\xi_{m,i}\right)\left(1-\xi_{m,i}\right)}{\xi_{m,i}} \left[\widehat{mc}_t^{m,i} + \hat{\lambda}_t^{m,i}\right], \end{aligned} \tag{C.45}$$

where

$$\hat{\lambda}_t^{m,i} = \rho_{\lambda^{m,i}} \hat{\lambda}_{t-1}^{m,i} + \varepsilon_{\lambda^{m,i},t}, \tag{C.46}$$

$$\widehat{mc}_t^{m,i} = -\hat{\gamma}_t^f - \hat{\gamma}_t^{mi,d}, \tag{C.47}$$

$$\hat{d}_t^{m,i} = \gamma^{mi,d} i^m \left(\hat{\gamma}_t^{mi,d} + \hat{i}_t^m\right) - i^m \left(-\hat{\gamma}_t^f + \hat{i}_t^m\right). \tag{C.48}$$

Exporting firms and export-good wholesalers

$$\begin{aligned} \hat{\pi}_t^x &= \frac{\beta}{1+\kappa_x\beta} E_t \hat{\pi}_{t+1}^x + \frac{\kappa_x}{1+\kappa_x\beta} \hat{\pi}_{t-1}^x \\ &\quad + \frac{1}{1+\kappa_x\beta} \frac{\left(1-\beta\xi_x\right)\left(1-\xi_x\right)}{\xi_x} \left[\widehat{mc}_t^x + \hat{\lambda}_{x,t}\right], \end{aligned} \tag{C.49}$$

where

$$\hat{\lambda}_t^x = \rho_{\lambda^x} \hat{\lambda}_{t-1}^x + \varepsilon_{\lambda^x,t}, \tag{C.50}$$

$$\widehat{mc}_t^x = \widehat{mc}_{t-1}^x + \hat{\pi}_t^d - \hat{\pi}_t^x - (\hat{S}_t - \hat{S}_{t-1}). \tag{C.51}$$

$$\hat{d}_t^x = -y^* \widehat{mc}_t^x. \tag{C.52}$$

Domestic and foreign retailers

$$\hat{\pi}_t^c = \left((1-\omega_c)\left(\gamma^{c,d}\right)^{\eta_c-1}\right)\hat{\pi}_t^d + \left(\omega_c\left(\gamma^{mc,c}\right)^{1-\eta_c}\right)\hat{\pi}_t^{m,c}. \tag{C.53}$$

$$\hat{c}_t^m = -\eta_c\hat{\gamma}_t^{mc,d} + \eta_c\hat{\gamma}_t^{c,d} + \hat{c}_t. \tag{C.54}$$

$$\hat{\pi}_t^i = \left((1-\omega_i)\left(p^i\right)^{\eta_i-1}\right)\left(\hat{\pi}_t^d - \hat{\mu}_{\Psi,t}\right) + \left(\omega_i\left(\frac{\gamma^{mi,d}}{p^i}\right)^{1-\eta_i}\right)\left(\hat{\pi}_t^{m,i} - \hat{\mu}_{\Psi,t}\right). \tag{C.55}$$

$$\hat{i}_t^m = -\eta_i\hat{\gamma}_t^{mi,d} + \eta_i\hat{p}_t^i + \hat{\imath}_t + \frac{\bar{r}^k}{\left(\mu_{z^+}\mu_\Psi - (1-\delta)\right)p^i}\hat{u}_t. \tag{C.56}$$

Relative Prices

$$\hat{\gamma}_t^{mc,d} = \hat{\gamma}_{t-1}^{mc,d} + \hat{\pi}_t^{m,c} - \hat{\pi}_t^d. \tag{C.57}$$

$$\hat{\gamma}_t^{mi,d} = \hat{\gamma}_{t-1}^{mi,d} + \hat{\pi}_t^{m,i} - \hat{\pi}_t^d. \tag{C.58}$$

$$\hat{\gamma}_t^{c,d} = \hat{\gamma}_{t-1}^{c,d} + \hat{\pi}_t^c - \hat{\pi}_t^d. \tag{C.59}$$

$$\hat{p}_t^i = \hat{p}_{t-1}^i + \hat{\pi}_t^i - \hat{\pi}_t^d + \hat{\mu}_{\Psi,t}. \tag{C.60}$$

$$\hat{\gamma}_t^{x,*} = \hat{\gamma}_{t-1}^{x,*} + \hat{\pi}_t^x - \hat{\pi}_t^*. \tag{C.61}$$

$$\hat{\gamma}_t^f = \widehat{mc}_t^x + \hat{\gamma}_t^{x,*}. \tag{C.62}$$

Households

Consumption Euler Equation

$$
\begin{aligned}
& (\mu_{z^+} - h\beta)(\mu_{z^+} - h)\left(\hat{\psi}_{z^+,t} + \hat{\gamma}_t^{c,d}\right) \\
= \quad & h\beta\mu_{z^+} E_t \widehat{\tilde{c}}_{t+1} - \left(\mu_{z^+}^2 + h^2\beta\right)\widehat{\tilde{c}}_t + h\mu_{z^+}\widehat{\tilde{c}}_{t-1} \\
& -h\mu_{z^+}\left(\hat{\mu}_{z^+,t} - \beta E_t \hat{\mu}_{z^+,t+1}\right) + (\mu_{z^+} - h)\left(\mu_{z^+}\hat{\zeta}_t^c - h\beta E_t \hat{\zeta}_{t+1}^c\right), \qquad \text{(C.63)}
\end{aligned}
$$

where

$$
\hat{\psi}_{z^+,t} = E_t\left(\hat{\psi}_{z^+,t+1} - \hat{\mu}_{z^+,t+1} - \hat{\pi}_{t+1}^d\right) + \hat{R}_t, \qquad \text{(C.64)}
$$

$$
\hat{\zeta}_t^c = \rho_{\zeta^c}\hat{\zeta}_{t-1}^c + \varepsilon_{\zeta^c,t}, \qquad \text{(C.65)}
$$

$$
\tilde{c}\widehat{\tilde{c}}_t = c\hat{c}_t + \upsilon g^c \hat{g}_t^c. \qquad \text{(C.66)}
$$

Investment Euler Equation

$$
\begin{aligned}
\hat{\imath}_t \quad = \quad & \frac{1}{1+\beta}\hat{\imath}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{\imath}_{t+1} + \frac{\chi}{(1+\beta)(\mu_{z^+}\mu_\Psi)^2}\left(\hat{q}_t + \hat{\zeta}_t^i - \hat{p}_t^i\right) \\
& -\frac{1}{1+\beta}\left(\hat{\mu}_{z^+,t} + \hat{\mu}_{\Psi,t}\right) + \frac{\beta}{1+\beta}E_t\left(\hat{\mu}_{z^+,t+1} + \hat{\mu}_{\Psi,t+1}\right), \qquad \text{(C.67)}
\end{aligned}
$$

where

$$
\hat{\zeta}_t^i = \rho_{\zeta^i}\hat{\zeta}_{t-1}^i + \varepsilon_{\zeta^i,t}. \qquad \text{(C.68)}
$$

Q Equation

$$
\begin{aligned}
\hat{q}_t \quad = \quad & E_t\hat{\psi}_{z^+,t+1} - \hat{\psi}_{z^+,t} - E_t\hat{\mu}_{z^+,t+1} - E_t\hat{\mu}_{\Psi,t+1} \\
& +\frac{\beta(1-\delta)}{\mu_{z^+}\mu_\Psi}E_t\hat{q}_{t+1} + \frac{\mu_{z^+}\mu_\Psi - \beta(1-\delta)}{\mu_{z^+}\mu_\Psi}E_t\widehat{\bar{r}}_{t+1}^k + \varepsilon_t^q. \qquad \text{(C.69)}
\end{aligned}
$$

Capital Utilization Decision Equation

$$\hat{u}_t = \frac{1}{\sigma_a}\left[\hat{\bar{r}}_t^k - \hat{p}_t^i\right]. \tag{C.70}$$

Capital Law of Motion

$$\hat{k}_t = \frac{1-\delta}{\mu_{z^+}\mu_\Psi}\left(\hat{k}_{t-1} - \hat{\mu}_{z^+,t} - \hat{\mu}_{\Psi,t}\right) + \left[1 - \frac{1-\delta}{\mu_{z^+}\mu_\Psi}\right]\left(\hat{\imath}_t + \hat{\zeta}_t^i\right). \tag{C.71}$$

Real Wage Law of Motion

$$\begin{aligned}\hat{\bar{w}}_t \;=\; & \frac{\beta}{1+\beta}E_t\hat{\bar{w}}_{t+1} + \frac{1}{1+\beta}\hat{\bar{w}}_{t-1} + \frac{\beta}{1+\beta}E\hat{\pi}_{t+1}^d \\ & -\frac{1}{1+\beta}\hat{\pi}_t^d - \frac{\beta\kappa_w}{1+\beta}\hat{\pi}_t^c + \frac{\kappa_w}{1+\beta}\hat{\pi}_{t-1}^c \\ & -\frac{1}{1+\beta}\frac{(1-\beta\xi_w)(1-\xi_w)(1-\lambda_w)}{((1-\lambda_w)-\lambda_w\sigma_l)\xi_w} \\ & \times\left[\hat{\bar{w}}_t - \sigma_l\hat{L}_t - \hat{\zeta}_t^l + \hat{\psi}_{z^+,t}\right],\end{aligned} \tag{C.72}$$

where

$$\hat{\zeta}_t^l = \rho_{\zeta^l}\hat{\zeta}_{t-1}^l + \varepsilon_{\zeta^l,t}. \tag{C.73}$$

Risk-adjusted UIP Condition

$$\hat{R}_t = \hat{R}_t^* + (\hat{S}_{t+1} - \hat{S}_t) + \left[-\tilde{\phi}_a\hat{a}_t + \hat{\tilde{\phi}}_t\right]. \tag{C.74}$$

Evolution of Net Foreign Assets

$$\begin{aligned}\hat{a}_t - \frac{1}{\beta}\hat{a}_{t-1} \;=\; & -y^*\widehat{mc}_t^x - \eta_f y^*\hat{\gamma}_t^{x,*} + y^*\hat{y}_t^* + y^*\hat{\tilde{z}}_t^* + (c^m + i^m)\hat{\gamma}_t^f \\ & -c^m\left[-\eta_c(1-\omega_c)\left(\gamma^{c,d}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} + \hat{c}_t\right] \\ & -i^m\left[\begin{array}{c}-\eta_i(1-\omega_i)\left(p^i\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d} \\ +\hat{\imath}_t + \frac{\bar{r}^k}{(\mu_{z^+}\mu_\Psi-(1-\delta))p^i}\hat{u}_t\end{array}\right].\end{aligned} \tag{C.75}$$

$$\widehat{rex}_t = -\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} - \hat{\gamma}_t^{x,*} - \widehat{mc}_t^x. \tag{C.76}$$

Fiscal and Monetary Authorities

Fiscal Policy Rules

$$\hat{g}_t^c = \rho_{gc}\hat{g}_{t-1}^c + \left(1-\rho_{gc}\right)\phi_{gc}\hat{b}_{t-1} + \varepsilon_t^{gc}, \tag{C.77}$$

$$\hat{g}_t^i = \rho_{gi}\hat{g}_{t-1}^i + \left(1-\rho_{gi}\right)\phi_{gi}\hat{b}_{t-1} + \varepsilon_t^{gi}, \tag{C.78}$$

$$\begin{aligned} & g^c\hat{g}_t^c + g^i\hat{g}_t^i + \frac{b}{\beta}\left(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z^+,t}\right) \\ = \; & \tau^c\gamma^{c,d}c\left(\hat{\gamma}_t^{c,d} + \hat{c}_t\right) + \tau^l\bar{w}L\left(\widehat{\bar{w}}_t + \hat{L}_t\right) \\ & + \frac{\tau^k\bar{r}^k}{\mu_{z^+}\mu_\Psi}k\left(\widehat{\bar{r}}_t^k + \hat{k}_{t-1} - \hat{\mu}_{z^+,t} - \hat{\mu}_{\Psi,t}\right) + \tau^k\hat{d}_t + b\hat{b}_t, \end{aligned} \tag{C.79}$$

where

$$\hat{d}_t = \hat{d}_t^d + \hat{d}_t^{m,c} + \hat{d}_t^{m,i} + \hat{d}_t^x. \tag{C.80}$$

$$\hat{k}_t^g = \frac{1-\delta_g}{\mu_{z^+}}\left(\hat{k}_{t-1}^g - \hat{\mu}_{z^+,t}\right) + \left[1 - \frac{1-\delta_g}{\mu_{z^+}}\right]\left(\hat{g}_t^i + \hat{\zeta}_t^{gi}\right), \tag{C.81}$$

where

$$\hat{\zeta}_t^{gi} = \rho_{\zeta^{gi}}\hat{\zeta}_{t-1}^{gi} + \varepsilon_{\zeta^{gi},t}. \tag{C.82}$$

Monetary Policy Rule

$$\hat{R}_t = \rho_r\hat{R}_{t-1} + \left(1-\rho_r\right)\phi_{r\pi}\hat{\pi}_{t-1}^c + \left(1-\rho_r\right)\phi_{ry}\hat{y}_t + \varepsilon_t^R. \tag{C.83}$$

Aggregation and Market Clearing

Aggregate Production Equation

$$\hat{y}_t = \theta\begin{bmatrix} \hat{\epsilon}_t + \alpha\hat{u}_t + \alpha\hat{k}_{t-1} + \left(1-\alpha\right)\hat{L}_t \\ +\alpha_g\hat{k}_{t-1}^g - \left(\alpha+\alpha_g\right)\hat{\mu}_{z^+,t} - \alpha\hat{\mu}_{\Psi,t} \end{bmatrix}, \tag{C.84}$$

where $\theta \equiv 1 + \Theta/y$, and

$$\hat{\mu}_{z^+,t} = \rho_{\mu_{z^+}} \hat{\mu}_{z^+,t-1} + \varepsilon_{\mu_{z^+,t}}, \tag{C.85}$$

$$\hat{\mu}_{\Psi,t} = \rho_{\mu_\Psi} \hat{\mu}_{\Psi,t-1} + \varepsilon_{\mu_{\Psi,t}}. \tag{C.86}$$

Goods Market Equilibrium Condition

$$\begin{aligned} y\hat{y}_t \quad = \quad & (1-\omega_c)\left(\gamma^{c,d}\right)^{\eta_c} c\left(\hat{c}_t + \eta_c \hat{\gamma}_t^{c,d}\right) + (1-\omega_i)\left(p^i\right)^{\eta_i} i\left(\hat{\imath}_t + \eta_i \hat{p}_t^i\right) \\ & + (1-\omega_i)\left(p^i\right)^{\eta_i - 1} \frac{k\bar{r}^k}{\mu_{z^+}\mu_\Psi} \hat{u}_t + g^c \hat{g}_t^c + g_t^i \hat{g}_t^i \\ & + y^*\left(\hat{y}_t^* + \widehat{\tilde{z}}_t^* - \eta_f \hat{\gamma}_t^{x,*}\right), \end{aligned} \tag{C.87}$$

where

$$\widehat{\tilde{z}}_t^* = \rho_{\tilde{z}^*} \widehat{\tilde{z}}_{t-1}^* + \varepsilon_{\tilde{z}^*,t}. \tag{C.88}$$

Measurement Equations

$$\ln \pi_t^{d,data} = 100\hat{\pi}_t^d + \varepsilon_{\pi^d,t}^{me}. \tag{C.89}$$

$$\ln \pi_t^{c,data} = 100\hat{\pi}_t^c + \varepsilon_{\pi^c,t}^{me}. \tag{C.90}$$

$$\ln \pi_t^{i,data} = 100\hat{\pi}_t^i + \varepsilon_{\pi^i,t}^{me}. \tag{C.91}$$

$$\ln \pi_t^{x,data} = 100\hat{\pi}_t^x + \varepsilon_{\pi^x,t}^{me}. \tag{C.92}$$

$$\Delta \ln Y_t^{data} = 100\left(\Delta\hat{y}_t + \hat{\mu}_{z^+,t}\right) + \varepsilon_{y,t}^{me}. \tag{C.93}$$

$$\Delta \ln C_t^{data} = 100 \begin{bmatrix} \hat{\mu}_{z^+,t} + \eta_c \left(\hat{\pi}_t^c - \hat{\pi}_t^d\right) \\ -\frac{c^m}{c^m+c^d}\eta_c \left(\hat{\pi}_t^{mc} - \hat{\pi}_t^d\right) + \Delta\hat{c}_t \end{bmatrix} + \varepsilon_{c,t}^{me}. \tag{C.94}$$

$$\Delta \ln I_t^{data} = 100 \begin{bmatrix} \hat{\mu}_{z^+,t} + \hat{\mu}_{\Psi,t} + \eta_i \left(\hat{\pi}_t^i - \hat{\pi}_t^d + \hat{\mu}_{\Psi,t}\right) + \Delta\hat{\imath}_t \\ -\frac{i^m}{i^m+i^d}\left[\eta_i \left(\hat{\pi}_t^{mi} - \hat{\pi}_t^d\right) + \frac{\bar{r}^k}{\left(\mu_{z^+}\mu_\Psi - (1-\delta)\right)p^i}\Delta\hat{u}_t\right] \end{bmatrix} + \varepsilon_{i,t}^{me}. \tag{C.95}$$

$$\Delta \ln G_t^{C,data} = 100\left(\hat{\mu}_{z^+,t} + \Delta\hat{g}_t^c\right) + \varepsilon_{gc,t}^{me}. \tag{C.96}$$

$$\Delta \ln G_t^{I,data} = 100\left(\hat{\mu}_{z^+,t} + \Delta\hat{g}_t^i\right) + \varepsilon_{gi,t}^{me}. \tag{C.97}$$

$$\Delta \ln M_t^{data} = 100 \begin{bmatrix} \hat{\mu}_{z^+,t} + \frac{c^m}{c^m+i^m}\begin{bmatrix} \eta_c\left(\hat{\pi}_t^c - \hat{\pi}_t^d\right) \\ -\eta_c\left(\hat{\pi}_t^{mc} - \hat{\pi}_t^d\right) + \Delta\hat{c}_t \end{bmatrix} \\ +\frac{i^m}{c^m+i^m}\begin{bmatrix} \eta_i\left(\hat{\pi}_t^i - \hat{\pi}_t^d + \hat{\mu}_{\Psi,t}\right) \\ -\eta_i\left(\hat{\pi}_t^{mi} - \hat{\pi}_t^d\right) + \Delta\hat{\imath}_t \\ +\frac{\bar{r}^k}{\left(\mu_{z^+}\mu_\Psi - (1-\delta)\right)p^i}\Delta\hat{u}_t \end{bmatrix} \end{bmatrix} + \varepsilon_{m,t}^{me}. \tag{C.98}$$

$$\Delta \ln X_t^{data} = 100\left(\hat{\mu}_{z^+,t} - \eta_f\left(\hat{\pi}_t^x - \hat{\pi}_t^*\right) + \Delta\hat{y}_t^* + \Delta\hat{\tilde{z}}_t^*\right) + \varepsilon_{x,t}^{me}. \tag{C.99}$$

$$\Delta \ln L_t^{data} = 100\Delta\hat{L}_t + \varepsilon_{L,t}^{me}. \tag{C.100}$$

$$\Delta \ln w_t^{data} = 100\left(\hat{\mu}_{z^+,t} + \Delta\hat{w}_t\right) + \varepsilon_{w,t}^{me}. \tag{C.101}$$

$$\Delta R_t^{data} = 100\Delta\hat{R}_t. \tag{C.102}$$

$$\Delta \ln rex_t^{data} = 100\Delta\widehat{rex}_t + \varepsilon_{rex,t}^{me}. \tag{C.103}$$

$$\Delta \ln Y_t^{*,data} = 100\left(\Delta\hat{y}_t^* + \Delta\hat{\tilde{z}}_t^* + \hat{\mu}_{z^+,t}\right) + \varepsilon_{y^*,t}^{me}. \tag{C.104}$$

$$\ln \pi_t^{*,data} = 100\hat{\pi}_t^* + \varepsilon_{\pi^*,t}^{me}. \tag{C.105}$$

$$\Delta R_t^{*,data} = 100\Delta \hat{R}_t^*. \tag{C.106}$$

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